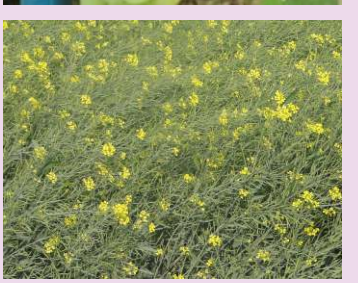
ISSN 0972-6136

Annual Report 2019






ICAR-Indian Agricultural Research Institute
New Delhi-110012

Annual Report 2019

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

Annual Report 2019

Printed: September, 2020

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Acknowledgement
We acknowledge the help received from the Scientific, Technical, Administrative, Financial and Suppporting staff of the ICAR-Indian Agricultural Research Institute in the compilation of this report.

Correct citation: IARI. Annual Report 2019, Indian Agricultural Research Institute, New Delhi – 110 012, India.

ISSN 0972-6136

IARI website: www.iari.res.in

Published by the Director, ICAR-Indian Agricultural Research Institute, New Delhi -110 012, India, and printed at M/s M.S. Printers, C-108/1 Back Side, Naraina Industrial Area, Phase I, New Delhi – 110024 (Phone: 011-45104606)

PREFACE

Our country is determined to achieve the targets of the Sustainable Development Goals by 2030. ICAR-Indian Agricultural Research Institute through its research, education and extension envisages addressing SDG 2 which aims to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. Since more than 50% of our population is directly dependent on agriculture, enhancing agricultural productivity and farmers' income can help spur the economic growth of our Nation. Therefore, IARI is focused on research, education and development the products to enhance agriculture productivity, profitability while maintaining environmental sustainability. Cutting edge genomics tools for precision breeding is being employed which helped in accelerated development varieties and hybrids in the food and horticultural crops with not only higher yield but also nutritionally enriched, resilient to biotic and abiotic stresses as well as with enhanced resource use efficiency.

In 2019, the Institute released 31 varieties/ hybrids of agri-horticultural crops for diversified needs of the Country. Pusa (IARI) wheat varieties occupy about 60% of wheat grown area and contributing to the prosperity of millions farmers. To address emerging issues a total of 4 bread wheat varieties and two durum wheat varieties were released in 2019. This includes bread wheat variety, HD 3249 enriched with 42.5 ppm of Fe and 27 ppm of Zn and durum wheat, HI 8802 with high protein (13.0%) and carotenoid content (5.7 ppm).

To address the Vitamin A deficiency (VAD), a major problem of our population, three pro-vitamin A bio-fortified maize hybrids viz., 'Pusa HQPM-5 Improved', 'Pusa HQPM-7 Improved' and 'Pusa VH-27 Improved' were released. For protein nutrition, the Institute released chickpea variety 'Pusa 10216', the first drought tolerant chickpea variety developed through marker assisted breeding, and Pusa Parvati (BG 3062) suited for machine harvesting.

In vegetable crops, two hybrids and 15 varieties were released this year for commercial cultivation. Two F_1 hybrids one each in bitter gourd (Pusa Hybrid-4) and sponge gourd (Pusa Shrestha) were released. Fifteen varieties were released in different vegetable crops including onion cv. Pusa Sona, garden pea cv. Pusa Prabal, brinjal cvs Pusa Safed Baingan-1, Pusa Hara Baingan-1 and Pusa Oishiki and cucumber cv. Pusa Parthenocarpic Cucumber-6.

Towards achieving *"more crop per drop"* efficient water management and decision support system have been developed. ICAR-IARI developed a wide array of technologies including new farm machinery, resource conservation technologies, beneficial microbes, precision faming and monitoring techniques for reducing the input cost and enhancing farmers' income, while minimizing the GHGs emission.

We played a pivotal role in *Mera Gaon Mera Gaurav* programme which improved outreach of technologies through on field demonstrations and direct interaction between scientists and farmers addressing specific needs from time to time. Pusa *Krishi Vigyan Mela* 2019 with the theme of *"Krishi Vikas: Innovative Technologies"* was

organized from March 5-7, 2019, wherein over one lakh visitors and 170 public and private exhibitors from across the country participated and gained from the *mela.*

ICAR-IARI continued its leadership stride in developing excellent human resource to NARES and CGIAR system. A total of 239 candidates (123 M.Sc., 22 M.Tech. and 94 Ph.D.) including 08 (05 M.Sc./M.Tech. and 03 Ph.D.) international students were awarded degrees by the then Hon'ble Union Minister of Agriculture and Farmers Welfare, Shri Radha Mohan Singh during the 57th Convocation of the Post Graduate School of IARI. ICAR-IARI played a flagship role in developing centres of educational excellence not only within the country by establishing IARI-Assam and IARI-Jharkhand, but also internationally, by assisting 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 higher agricultural education. We also partnered with Western Sydney University (WSU), Australia for a dual and joint Ph.D. programme of our students.

I profusely thank the Director General, ICAR and Secretary, DARE, Dr. Trilochan Mohapatra for his constant guidance and support for enabling the Institute to excel. I acknowledge the funding to the tune of 185 crores from NASF (ICAR), NAHEP (ICAR), DBT, DST and other international agencies for sustaining the excellence in research, education and development programs of the Institute. I congratulate the staff and students for their invaluable contributions and bringing laurels through awards and recognitions to the Institute. Through these achievements, we envisage to improve the livelihood security, profitability of our farmers and make our nation food and nutrition secure while ensuring sustainability.

I express my appreciation to the annual report editorial team for synthesizing the report in time.

September 03, 2020
New Delhi

(Ashok 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.

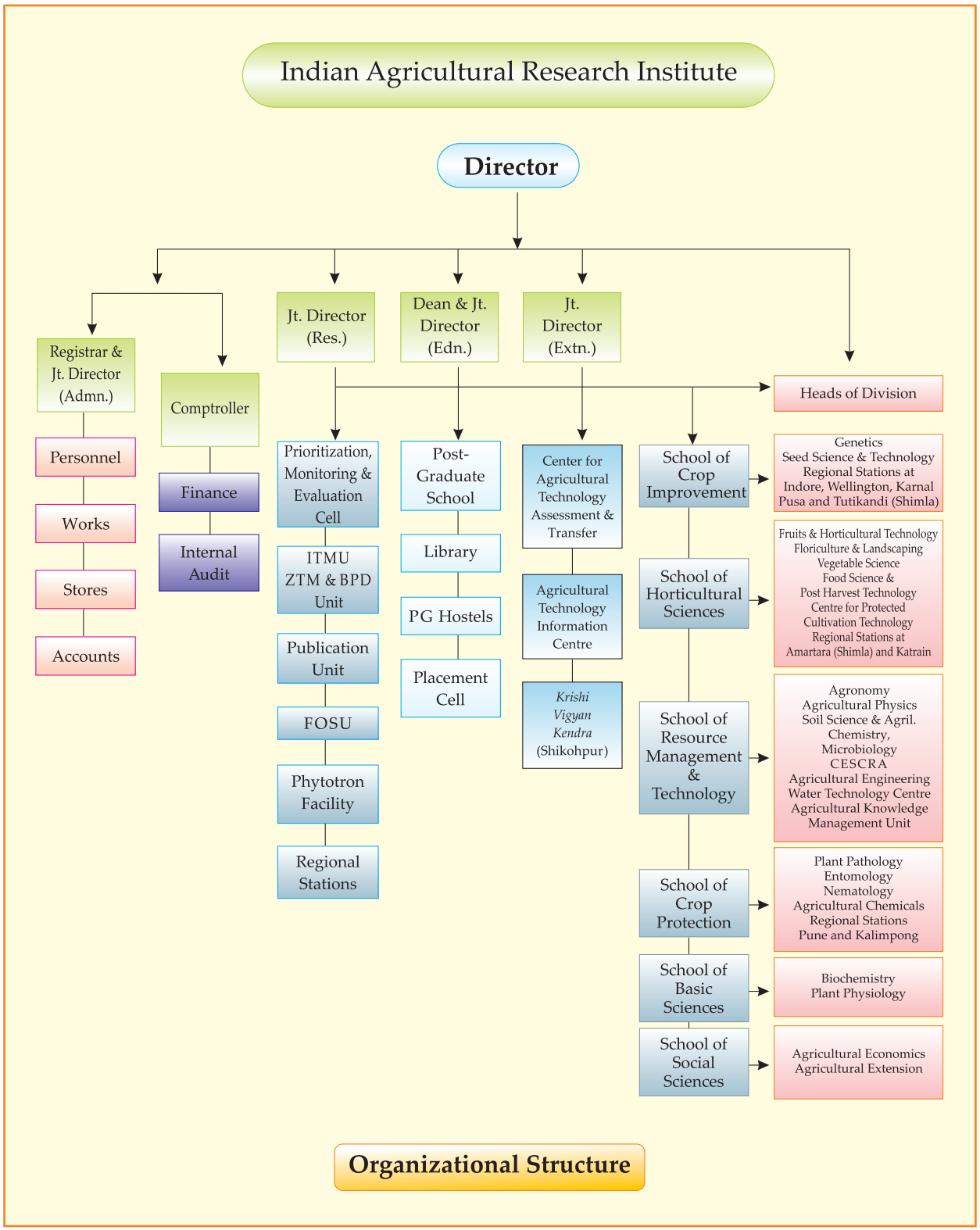
The growth of India's agriculture during the past more than 100 years, is closely linked with the researches done and technologies generated by the Institute. The Green Revolution stemmed from the fields of IARI. Development of high yielding varieties of all major crops which occupy vast areas throughout 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 environmentTo 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 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 daily maximum temperature during the hot period (May 2019-October 2019) ranged from 32.2 °C to 45.5°C and the daily minimum temperature ranges from 20.2°C to 30.9°C. June to September are rainy months during which 559.7 mm of rainfall received. Winter sets in from mid-November and is delightful. The daily maximum temperature during winter (November 2019-March 2020) ranges from 9.0°C to 33.0°C and the mean minimum temperature from 0.6 °C to 18.5°C. During winter 295.7 mm rainfall 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, Gurugram, 3 all India coordinated research projects with headquarters at IARI, and 21 national centres functioning under the all India coordinated research projects. It has sanctioned staff strength of 2364 comprising scientific, technical, administrative and supporting personnel. The revised budget estimates of the Institute constituted a total amount of ₹ 58,295.62 lakh (Unified Budget) for the year 2019-20.



Organizational Structure

EXECUTIVE SUMMARY

The Indian Agricultural Research Institute (IARI) employed cutting-edge science to develop technologies to enhance farmers' income and attain sustainable development goals (SDGs). More than 30 varieties and hybrids with improved nutritional quality, climate resilience and yield were developed in food and horticultural crops. Resource management technologies, and pest and disease management methods, farm machineries, protected cultivation methods and food processing techniques were developed for enhancing the input use efficiency, farmers' income, nutritional security and environmental sustainability. In addition to the regular extension activities on empowering farmers with new agricultural technologies, the Institute has implemented *Mera Gaon Mera Gaurav* programme in large scale. 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 57th Convocation of the Post Graduate School of the IARI was held on February 8, 2019. The salient achievements of IARI in research, extension and education during 2019 are summarized below.

The School of Crop Improvement has developed and released improved crop varieties with higher yield, better nutritional quality and resistance to biotic and abiotic stress tolerance with adaptability to different agro-ecological conditions of the Nation. IARI wheat varieties are cultivated in about 60% of wheat grown area of the Nation and contributing to prosperity of farmers. Bread wheat varieties (HD 3249, HD 3271, HI 1621 and HI 1628) and Durum wheat varieties (HI 8802 and HI 8805) were released at the National level. Wheat variety HD 3249 was released for timely sown, irrigated conditions of NEPZ with an average grain yield of 4.87 t/ha. It has bold, amber coloured, ovate shaped grains and possess 42.5 ppm of Fe and 27 ppm of Zn content. The variety is resistant to multiple biotic stresses. Another wheat variety HD 3271 was released for very late sown conditions of NWPZ and NEPZ with an average grain yield of 3.25 t/ha. It is resistant to yellow and brown rusts and showed moderate resistance against leaf blight, powdery mildew, Karnal bunt and flag smut. Wheat variety HI 1621was released for very late sown, irrigated conditions of both NWPZ and NEPZ with average grain yield of 3.28 t/ha. It has excellent *Chapati* score (7.87), biscuit quality (8.52), bread quality (7.53) and sedimentation value (48.3 ml-NWPZ, 55.2 ml-NEPZ). It is also rich in essential micronutrients like iron and zinc. Wheat variety HI 1628 was released for timely sown, restricted irrigation conditions of NWPZ with an average grain yield of 5.04 t/ha. It has high levels of field resistance to stripe rust and leaf rust compared to checks. HI 8802, a durum wheat variety was released for restricted irrigation, timely sown conditions of Peninsular Zone with an average grain yield of 2.91 t/ha. It contains higher protein (13.0%) and yellow pigment content (5.7 ppm) with overall good acceptability for pasta making. Another durum wheat variety HI 8805 was released for restricted irrigation, timely sown conditions of Peninsular Zone with an average grain yield of 3.04 t/ha. Intensive efforts are being made to develop MAS derived Basmati rice genotypes with inbuilt resistance to bacterial blight, blast, brown plant hopper and salinity tolerance for agronomic performance and response to respective stresses under artificial screening as well as hotspot locations.

In maize, three MAS-derived bio-fortified maize hybrids, *viz*., 'Pusa HQPM-5 Improved', 'Pusa HQPM-7 Improved' and 'Pusa VH-27 Improved' were released. Pusa Vivek Hybrid-27 Improved, a provitamin-A rich (5.49 ppm) maize hybrid, was released for North Eastern Plains Zone. Pusa HQPM-5 Improved was released for cultivation across the country. It possesses 6.77 ppm of provitamin-A, high lysine (4.25%) and tryptophan (0.94%). Pusa HQPM-7 Improved hybrid was released for Peninsular Zone. It possesses 7.10

ppm of provitamin-A and high lysine (4.19%) and tryptophan (0.93%) in protein. A sweet corn hybrid, Pusa Super Sweet Corn-2, was released for Himachal Pradesh, Uttarakhand, Haryana, Uttar Pradesh, Chhattisgarh, Rajasthan, Tamil Nadu and Karnataka. It is a *shrunken2* based single cross sweet corn hybrid. It has high kernel sweetness with a brix of 16.4% at 20-22 days after pollination.

The Institute has released the first MABC derived chickpea variety 'Pusa 10216' through introgression of a QTL hotspot for drought tolerance. It yielded 16 % higher over the recurrent parent. It is released for Central Zone, the largest chickpea growing area in the country. Chickpea variety Pusa Parvati (BG 3062) was released for cultivation in Central India comprising states of Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh and parts of Rajasthan. It is moderately resistant to *Fusarium* wilt, dry root rot and stunt. It is an erect desi chickpea variety suitable for machine harvesting and gives an average grain yield of 2.27 t/ha in 112 days.

Mungbean variety Pusa 0871 was identified for release in Uttar Pradesh for *kharif* season. This variety exhibited yield superiority of 9.11% over the best check. The average yield of this variety is 0.80-1.0 t/ha. It is tolerant to MYMV and matures in 65 days. Lentil variety L 4729 has been released for Central Zone comprising the states of Madhya Pradesh, parts of Uttar Pradesh and Rajasthan and Chhattisgarh for timely sown rainfed condition during *rabi* season. It is a bold seeded variety with average grain yield of 1.7-1.8 t/ha with extra early maturity (103 days). Besides these varieties, a large number of promising genotypes in several crops are under various stages of evaluation in All India Coordinated trials.

The School of Horticulture has developed several varieties/hybrids of vegetable, flower and fruit crops. In vegetable crops, two hybrids and 15 varieties were released this year for commercial cultivation. Two F_1 hybrids one each in bitter gourd cv. Pusa Hybrid-4 (DBGH-12) and sponge gourd cv. Pusa Shrestha (DSGH-9) were released. Fifteen varieties, *viz*. onion cv. Pusa Sona (Sel. 153-1), garden pea cv. Pusa Prabal (GP 473), cowpea cv. Pusa Dharni (CP-55), dolichos bean cv. Pusa Garima (DB-10), brinjal cvs Pusa Safed Baingan-1 (Sel.195), Pusa Hara Baingan-1 (G-190) and Pusa Oishiki (DBL-175), 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), Pusa Long Green(DC-83) and okra cv. Pusa Bhindi-5 (DOV-66) were notified by the Central Sub-Committee on Crop Standard, Notification and Release of Varieties for Horticultural Crops. Pusa Gynoecious Cucumber Hybrid-18 (DGCH-18) and brinjal (DBPR-23) were identified for release in the XXXVII AICRP (VC) Group Meeting and were recommended for cultivation in Zone I and Zone 4, respectively.

Several promising genotypes and hybrids were in different stages of development. In cauliflower, promising genotypes were identified for September, October and November-December maturity. In broccoli, two promising lines Pusa Purple Broccoli-1 and DC-Brocco-13 were submitted for AICRP (VC) multi-location trial. Cabbage hybrid 'KTCBH-822' maturing in 70-75 days after transplanting has been identified for release for Zone I and Zone-VI. Red cabbage genotypes (KTCBR-3 and KTCBR-5) were contributed to AICRP (VC) IET trial. One F_1 hybrid, KTH-301 first CMS based F_1 hybrid in the mid-late group of cauliflower has been identified for commercial cultivation in XXXVII Group Meeting of AICRP (VC) held at TNAU, Coimbatore.

In bottle gourd, DBOGH-6 and DBOGH-12 were found promising with an average yield of 4.9 and 4.8 t/ha, respectively. In sponge gourd, genotype DSG-33 was advanced to AVT-I of AICRP (VC). In ridge gourd, DRG-7 (17.1 t/ha) having attractive green long fruit (35-40 cm) was found very promising compared to Pusa Nutan (16.3 t/ha) was advanced to AVT-II of AICRP (VC) trial. Gynoecious F_1 hybrid DRGH-4 (18.3 t/ha) and DGRGH-8 (18.9 t/ha) were advanced to AVT-II and AVT-I of AICRP (VC) trial, respectively. In brinjal, DBSR 44 (1.65 kg/ plant), DB 9 (2.65 kg/ plant), DBL 21 (3.68 kg/ plant) and DB 144 (2.12 kg/ plant) were identified as heat tolerant, which could give fruits at 40°C during May-June. In tomato, two entries each with ToLCD resistance were entered in AICRP IET and AVT-1 trials. In capsicum, at IARI, New Delhi, KTC-131 was found to have fruit set at high temperature

(40° day and 28°C night) during May under nethouse conditions.

For *kharif* season cultivation, onion genotypes KP-41 (18.22 t/ha) and KP-62 (15.28 t/ha) were developed which can be harvested by 15th November. In garden pea, genotypes (GP 55, GP916, GP473, GP 912-II, VP438-2) had pod setting at high temperature. Exotic lines (M-9 and M-5) were used as donor for developing *Fusarium* wilt resistant line through introgression. In okra, a hybrid DOH-2 was promoted in AVT-II and one variety DOV-9 was entered in IET trial.

In mango, hybrids 8-11 (Amrapali x Lal Sundari) and H-11-2 (Amrapali x Sensation) was developed. From draft Genome of mango, 245 hyper-variable mango SSRs were screened for polymorphism between the parent genotypes, i.e. Amrapali and Sensation. Primers M109 (90.6%), M15 (89.5%) and M17 (84.3%) ascertained hybridity in over 84% of the progenies.

Citrus scion hybrids (Pummelo x sweet orange) were assessed for their growth, yield and fruit quality parameters. Hybrids SCSH-5-10/12, SCSH-9-10/12, SCSH-11-11/12 and SCSH-11-15/12 were found promising. In sweet orange, in 12 clones, fruit weight was ranged from 198.70 g (MS-15) to 303.88 g (MS-3). Three acid lime clones, ALC-4 (45.06), ALC-35 (44.47 g), and ALC-70 (44.20 g) had heavier fruits than Pusa Abhinav (43.69 g). Five pummelo clones (Nos IC-628798 to IC-628802) were registered at ICAR-NBPGR, New Delhi. In grape, Pusa Purple Seedless hybrid ('Pearl of Csaba' x 'Beauty Seedless') developed through *in-ovulo* embryo rescue. Pusa Navrang had highest anthocyanin content (972.7 mg kg^{-1}). In papaya, Hybrid Red Lady (Self) × P-9-5 exhibited positive heterosis for days to flower initiation. For yield, heterosis over the better parent ranged from 12.17% in PS 3 × P-9-5 to -8.49% in Red Lady (Self) × P-9-5 hybrid.

In a rootstock trial in mango, extremely dwarf trees of Pusa Arunima (41.05 and 43.34%) lower than Olour and K-3) were found on K-2 rootstock, for Pusa Surya there was reduction by 37.19 and 18.60%, respectively than Olour. In Kinnow mandarin, fruiting density and yield efficiency were recorded better on *Jatti khatti* rootstock (28.04 m^3; 6.91) followed by sour orange (16.29 m^3; 3.86). In grape fruit, the highest fruit yield in Marsh Seedless (23.13 kg/tree) and Redblush (42.13 kg /tree) was recorded on *Billikichli* and RLC-4 rootstocks, respectively. In sweet orange, dwarfing was induced in cv. Pusa Sharad on Yama Mikan and Pusa Round on C-35 rootstocks.

In flower crops, genetic characterization of 88 rose genotypes was carried out using 102 SSR markers (Genomic and ESTs) of which 63 gave amplification. A floribunda type hybrid of Barbara Bush × Jawala (RH-24-2017), open-pollinated seedling of cv. Pink Parfait (RS-03-2017), hybrid between Dr. Bharat Ram × Rose Sherbet (RH-19-2017) and open-pollinated seedling of cv. Pusa Virangana (RS-01-2016) were found promising for further evaluation. The fragrance profiles for volatiles of Pusa Mahak and Century Two roses was undertaken where about 82 compounds (55% terpenoids) were detected in Pusa Mahak and about 66 compounds (37% phenyl propanoids/ benzenoids) in Century Two.

In chrysanthemum, a yellow coloured mutant from a white coloured spray type cv. Himanshu has been identified, having all traits of parent. It is best suited for pot cultivation. In marigold, year round multiplication of stock plants using IBA+NAA at 250 ppm each for rooting of shoot tip cuttings, under shadenet (75%) with foliar spray + 3rd pinching was found to be most ideal. In lilium, maximum number of flowers per stem (9.0), inflorescence length (35.7 cm) and leaf area (28.7 cm^2) were observed in hybrid "No. 18 x Brunello". Inter-specific pollinations between *longiflorum* Asiatic x Asiatic were less compatible. In iris, cv. 'Tel Star' was earliest to flower (150.4 days) followed by 'Harmes Blue' (154.8 days), plant height was maximum (78.5 cm) in cv. 'Saturns', while flower size (16.7 cm) was noted in cv. 'Miss Shagun.

Amongst turf grass species, St. Augustine and Zoysia performed well 75% shade level. In *Syngonium*, application of water soluble fertilizer @ 2 g/ kg soil + AMF @ 1.5 g/ kg soil recorded the best results with regard to number of leaves, leaf area, leaf relative water content and overall plant presentability. In Easter lily, growing of bulblets in coco peat with NPK (400:250:200 kg/ha) increased the bulblet size.

In Crop Protection programs, studies on diagnostics, diversity analysis, genomics, host-pathogen

interactions, host resistance sources and integrated management of important pests and pathogens of national importance were undertaken. A reliable serological and molecular diagnostics were developed for important viruses infecting chilli, orchids, apples, watermelon, and viroid in apple. Whole genome sequencing and host-pathogen interaction of *Tilletia indica* and *Magnaporthe oryzae* was accomplished. Phytoplasma pathogens belonging to three groups (16SrI-B, II-D & XI-B) on apricot, guava, litchi, mango, pomegarante and grapevine were confirmed from Delhi, Maharashtra and J&K. Another phytoplasma strains causing little leaf disease in peanut from AP and leaf yellows and declining disease of elephant footyam from UP, Uttarkakhand and Tripura were identified.

Genetic diversity studies were performed with *Colletotrichum gloesporoides* species complex, *F. solani* complex, *F. oxysporum* infecting tomato and *Athelia rolfsii* were accomplished which showed wide genetic diversity among the isolates. RS toxin was identified as key component in pathogenicity and virulence of *R. solani* infecting sheath blight of rice. Transcriptome analysis of resistance and susceptible genotypes infected with *Bipolaris sorokiana* on wheat and *Fusarium fujikuroi* in rice led to the identification of differentially regulated genes. Role of three putative silencing suppressor proteins (V2, C2 and C4) of begomovirus was established in viral pathogenicity.

Tebuconazole, captan and potassium phosphite were found effective in management of sheath blight, blast and bakanae disease of rice. Potential bacterial communities were identified in phyllospehre microbiome of rice, which can mitigate several foliar diseases. The bacterial origin volatile compounds were shown to inhibit all developmental stages of Blast pathogen of rice. A liquid bio-formulation of *Bacillus subtillis* was developed to control fungal and bacterial diseases of tomato. 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. Application of neem seed powder extract @ 40g /L and Diafenthuron @ 1g /L has been recommended for eco-friendly management of cabbage pests, especially cabbage aphids during *rabi* season cultivation of cabbage in Himachal Pradesh. Talc based formulation developed for a nematicidal isolate of *Trichoderma asperellum* resulted in significant reduction in reproduction factor of root knot nematode, *Meloidogyne incognita.*

The effect of aphid complex on wheat yield was studied through field experiments on two widely cultivated wheat varieties HD-3059 and HD-3086 utilizing five regression models *viz.,* linear, semi-loge (X), semi-loge (Y), loge-linear and quadratic. Economic injury levels (EIL) were determined to be 6.3 aphids/ tiller at 60 and 14.4 at 70 DAS for HD-3059 and 34.6 at 60 and 29.3 aphids/ tiller at 70 DAS for HD-3086.

Maintenance of National Pusa Collection with 9,66,076 specimens in terms of curation, augmentation, deposition, loan of material *etc*. was continued. Survey, seasonal incidence and predator and prey synchrony of heteropteran predator was conducted during 2017 to 2019 revealed presence of five heteropteran predators *viz*., *Geocoris* sp., *Orius* sp., *Nesidiocoris tenuis*, *Rhynocoris fuscipes* and *Coranus* sp. Significant differences were observed in nitrate reductase activity in aerobic and anaerobic gut bacterial isolates of white grub, *Lepidiota manseuta*. Nine pink bollworm populations collected from different locations were evaluated for 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. Increased activity of alkaline phosphatase and aminopeptidase N in BG II resistant populations indicated association of these two enzymes in imparting resistance in *P. gossypiella* against BG II. Expression of *cyp6cm1* after three hours exposure to neonicotinoid insecticides with discriminating dose was found high in Sri Ganganagar population (*Bemisia tabaci*) compared to that of Bathinda, whereas the expression of *cyp4c64* was higher in Bathinda population.

Transgenic eggplants were developed by overexpression of disulfide-constrained peptide gene (*nAChRbp*). This protein binds to nematode acetylcholine (*ACh*) receptors. Nematodes treated with transgenic root exudates showed reduction in the expression of acetylcholine esterase genes, *Mi-ace-1* and *Mi-ace-2*. Key genes involved in various biological process including effectors, peptidase, CAZymes etc., were predicted for *A. tritici*.

To develop genomic resources for the rice root-knot nematode *Meloidogyne graminicola*, a major biotic stress for the rice crop under upland and rain-fed rice cultivation conditions, the long-read sequencing approach (PacBio Sequel platform) was used. The odorant response (*odr*) genes, expressed in the olfactory epithelium were investigated in the EPN *Heterorhabditis bacteriophora.* Seven *odr* genes could be identified by *in-silico* analysis in *H. bacteriophora* out of which six were successfully amplified and cloned.

Chemo and bioprospecting for agrochemicals through design, discovery and development of novel processes was undertaken. The volatile oil and its major compound, 1,8-cineole were evaluated for its insecticidal activity against *Bemisia tabaci* (whitefly) under lab conditions. *Pelargonium graveolens* aerial parts were found to contain 0.12% volatile oil. The oil was evaluated against *M. graminicola* and *M. incognita* and its activity was found comparable to synthetic nematicides, carbofuran and velum prime. A series of disubstituted and trisubstituted-1H-pyrazoles were synthesized and their derivatives were evaluated for their antifungal activity against *Rhizoctonia solani*. Sixteen nicotic acid hydrazones and amides were synthesized, characterized and evaluated as potential succinate dehydrogenase inhibitors (SDHI). Screening of antagonistic potential of three different strains of *C. globosum* (5157, 2523 and 2034) against four phytopathogens namely, *S. sclerotiorum* 4042, *M. phaseolina, S. rolfsii* and *F. oxysporum* resulted highest fungal growth inhibitory action of *C. globosum* 5157 against *S. sclerotiorum*. Novel prototype for WDG and WDP formulations of EPNs (*S. thermophillum* and *H. indica*) was developed employing green adjuvants. Persistence and degradation of cyantraniliprole, in inceptisol soil has been studied. Microbial biomass carbon, as an index of microbial activity of soil correlated well with the degradation of cyantraniliprole. Sorption behaviour of two antibiotics, namely sulfamethazine and sulfamethoxazole was investigated in sandy loam soil of Delhi. Antibiotics exhibited weak sorption in the sandy loam soil and higher adsorption was exhibited by sulfamethoxazole as compared to sulfamethazine.

About 50,460 fungal specimens at Herbarium Cryptogamae Indiae Orientalis (HCIO) and 4,075 fungal cultures at Indian Type Culture Collection (ITCC) were maintained at the Institute. Sixty isolates of fungus collected from yam, hibiscus, colocasia, brinjal, sunflower, kalmegh, balsam, spring coriander, neem, thumbe and tomato *etc*. in different region of Tripura was identified as *Athelia rolfsii.* Morphology and phylogeny based diversity analysis of agricultural important cryptic species of *Fusarium solani* species complex (FSSC) was undertaken. National Pusa Collection maintained 9,66,076 specimens. A total of 2,266 specimens were identified for various stakeholders. A new species, *Lanelater andamanensis* sp. nov. was described from the Little Andaman Island located in the Andaman group of Islands. From Palla block of Hayana, a nest pest of radish *Phyllotreta striolata* (Fab.) (Coleoptera: Chrysomelidae) was identified. A new species *Hishimonus adi* sp. nov. (Arunachal Pradesh: Pasighat) is described. Similarly, a plant hopper *Cemus sauteri* (Muir) was recorded for the first time from Bilaspur (Himachal Pradesh), and Raichur, Bidar (Karnataka). From rhizosphere of tuberose, a new species of a predatory nematode *Mylonchulus tuberosei* sp. was identified. Another new species of the genus *Oscheius* was described as *O. indicus* n. sp. on the basis of morphological and molecular data.

The research on Crop and Natural Resource Management has made significant advancements in developing efficient resource management technologies for enhancing agricultural productivity and farmers' income. An integrated farming system model has been developed with integration of multiple enterprises (crops, livestock, beekeeping, fisheries, *etc*.) to ensure year-round income and employment of the small holders, having 1.0 ha irrigated land. It can provide net annual income of Rs 3.79 lakh along with 628 man days.

A conservation agriculture (CA) based direct-seeded rice-wheat-mungbean system has been developed as an alternative to conventional transplanted puddled rice - conventional till wheat system, which has 33.5% higher system productivity and saves 25% N in rice and wheat, amounting to 60 kg N/ha/year. Nutrient Expert and GreenSeeker led to higher nitrogen-use efficiency and partial factor productivity in maize and reduced N leaching. A baby corn - chick pea system was found more remunerative, giving higher system productivity and net returns. A

CA-based pearl millet – chick pea system was found to be a promising for sustainable crop intensification with integration of pulses in rainfed ecologies. A nano-fertiliser study revealed that the application of ZnO nano-particle embedded N:P:K (15:15:15) complex fertilizer could lead to a saving of 25% NPK in wheat.

For enhancing water use efficiency in the field, sensing devices for flow measurement and irrigation scheduling were developed. A performance evaluation study in broccoli crop revealed that hydrogel (SPG-1118) performed better by giving 2% and 10% higher yield than P-Gel and control plot, respectively. Four macrophyte combinations, *viz.*, *Typha latifolia* + *Phragmites karka* (TP); *Phragmites karka* + *Arundo donax* (PA); *Arundo donax* + *Typha latifolia* (AT); and Vetiver *zizinoids* +*Typha latifolia* (VT) were assessed for their multi-metal extraction/ reduction potential in metal-spiked waste water of IARI and found that layered planting of *Typha* than mixed planting could be a better option to harness their full multi-metal reduction potential.

Protected cultivation research has come out with promising agro-techniques for production of tomato under low cost protected condition, and coloured capsicum under insect-proof net-house. Off-season production techniques for long melon (*kakari*) and bitter gourd under poly house/ protected structures were also standardized. Pak-choi No. 1 was found promising and suitable for commercial cultivation. Development of indigenous greenhouse aeroponics system for lettuce using mist environment was developed. A sensor controlled fertigation schedule for winter green leafy vegetables, namely, lettuce, pakchoi and Chinese cabbage was also standardized.

An innovative stand-alone, battery less, off-grid, solar-refrigerated evaporatively cooled (SREC) mesh-fabric structure was upscaled and evaluated for storage of perishables. The concept of SREC structure has been built at IARI and demonstrated among users and currently being used by farmers at village Picholiya, Ajmer, Rajasthan. A pressurized aqua-ferti-multi-crop seed drill was developed for sowing of pulses and oilseed crops in dryland areas. The machine can be operated by 55 hp tractor and has a field capacity of 0.23 ha hr^{-1} and 74% field efficiency with a sowing depth of 2.5-3 cm. A self propelled fertilizer band placement applicator-cum-weeder was developed for inter-row weeding and band placement of fertilizers in widely-spaced crops. A tractor-drawn variable rate fertilizer applicator (VRFA) was developed and evaluated. Besides these, a large number of machines/equipment were designed and developed in the institute.

Research on fruits preservation and storage led to the development of osmotic dehydration of apricot fruits. Dipping apricot fruits in 70°Brix sucrose syrup containing 2,000 ppm potassium metabisulphite for 24 h followed by cabinet air-drying (55°C) to desired moisture (20±0.5 %) led to better dried product with good colour and appeal. The post-harvest shelf-life of apple was extended with 0.01% hexanal applied as dip treatment for 3 min. soaking time retained higher firmness, reduced decay and improved the overall quality of the fruit up to 3 month storage under 1-2°C. The nutritional value of the pre-cut cauliflower infusion with calcium after exposing to vacuum for 15 min. showed 13 to 80% increase in calcium content. Florets were shelf stable up to 10 days under 10°C.

Blue Green Algae (BGA)-based composite liquid formulation (LF) was developed and demonstrated in farmers' fields in Palwal, Haryana. Both carrier-based BGA biofertilizer and BGA-based composite liquid formulation increased rice grain yield by 7.9% and 7.1%, respectively. New cyanobacteria C1 (N fixer) and C2 (N-fixing, P-solubilizer) with established bio-inoculants for increasing overall growth and yield and soil enzyme activity were isolated and characterized. Inoculation of *Bacillus megaterium* was found to improve growth and physiology of the turmeric (*Curcuma longa*) under drought stress. For agronomic fortification of wheat grain with iron, a liquid BioIron formulation was developed. It enhanced the Fe content in wheat grain by 83.5%.

Use of *Azolla* biomass as feed supplement and value-added products led to improvement in digestibility of different nutrients by lactating Murrah buffaloes. Utilization of agricultural residues for production of an industrially important biopolymer poly-β-hydroxyalkanoates by microorganisms was also explored. A consortium of two lignocellulolytic fungi, namely *Coprinopsis cinerea* LA2 and *Cyathus stercoreus* ITCC 3745 and limited nitrogen fertilization accelerated *in situ* degradation of paddy straw.

Seasonal climate change projections for Indian region were derived from the bias corrected probabilistic ensemble of 33 global climate models. The analysis projected that rise in minimum temperatures would be more than rise in maximum temperatures with higher variability. The rise in temperatures would be more during *rabi* than *kharif* season, more in northern parts of India than in southern parts. Rainfall may increase during *kharif* and *rabi* seasons with increased variability. Again, the analysis indicated a progressive climate change and variability in *kharif* and *rabi* seasons in India towards the end of the century.

A study on greenhouse gases emission in organic- and inorganically-grown rice - wheat- mungbean systems showed higher cumulative methane (CH_4) and carbon dioxide (CO_2) emissions under organic plots compared to inorganic fertilizer plots. Use of liquid formulation of consortium of methanotrophs MNL7 and MaAL 69 reduced methane emission by 7 to 11% under different rice varieties. The use of Limus (~urease inhibitor) on neem coated urea led to a 12.5% increase in yield and 19.8% reduction in nitrous oxide emission in wheat.

Satellite data analysis revealed that rice residue to the tune of 11.85 million tonnes in Punjab and 1.67 million tonnes in Haryana was burnt on farms. Surplus rice residue and its bio-ethanol potential in India were studied during *kharif, rabi*, and summer seasons in all 662 districts of the country. After different usages by farmers, 19% of the rice residue remains unused and is surplus, which has the potential to produce 12.28 million liters of bio-ethanol.

In Basic and Strategic Research program of the Institute, genomics and next generation phenotyping approaches were used to decipher mechanisms and identify genes/QTLs and donors for yield, resource use efficiency, quality and stress tolerance. Further, remote sensing, GIS, Machine Learning (ML) and Artificial Intelligence (AI) approaches were developed for assessment and management of crops and natural resources.

Genome editing is a precision mutagenesis approach. By using CRISPR-Cas9 genome editing, a loss of function mutant ($dst^{\Delta 184\text{-}305}$) of *DROUGHT AND SALT TOLERANCE* (*DST*) gene was developed in mega rice cv. MTU1010. The $dst^{\Delta 184\text{-}305}$ mutation conferred enhanced leaf water retention under dehydration stress and salt stress tolerance in seedling stage. In Soybean, CRISPR-Cas9 approach is being used to reduce seed phytate content.

Tomato Leaf Curl New Delhi Virus (ToLCNDV) encoded AC4 protein was found to interfere in auxin/IAA synthesis and signaling. AC4 overexpressing in tomato reduced endogenous auxin levels by 60% and caused disease symptoms, while exogenous foliar application of auxin analogue IAA (5 mg/L) alleviated ToLCNDV symptoms. This proved that AC4 mediated interference in auxin synthesis in host is a crucial factor in disease development.

Towards identification of genes for heat tolerance in wheat, wheat *MAPK1* gene was cloned and characterized. Tissue specific RNAseq transcriptome analysis of glumes/awns and developing grains of wheat cvs Raj3765 and BT-Schomburgk grown under control (22±3°C) and heat stress (HS) (38±2°C) conditions led to the identification of stress associated genes and starch biosynthesis pathway-associated transcripts.

The nitrogen use efficiency (NUE) of cereal crops is only 40%, resulting in economic loss and environmental degradation. Bread wheat genotypes (272) were phenotyped for root traits under low and sufficient N levels and superior genotypes were identified. In rice, genotypes with high NUE under sufficient N (APO), high NUE at low N (IR-3-1-1 and NL-42), and N responsive and low NUE (Pusa Basmati 1) were identified. Genome-wide analysis of NIN-LIKE PROTEIN (NLP) family of transcription factors showed that *NLPs* could be a potential target for improving NUE in rice.

Phenomics approaches were used to decipher the component traits of water use in rice. 170 RILs of BVD109 (drought tolerant) x IR 20 (drought susceptible) were phenotyped. It was found that significant amount (15-30%) water is used by rice through nocturnal transpiration, and both drought and nitrogen deficiency found to increase the nocturnal transpiration. QTL with 10-30% PVE were mapped for transpiration and WUE were mapped. By using Genome-Wide Association Studies (GEAS), 10 novel QTLs (*qPRLC9-1, qPRLC1, qPRLS9-1, qPRLS9-2,*

qTRLC6-1, qARSC9, qARSS2-1, qARSS2-2, qARSS1-3, qARDC4-1) for root traits were identified in rice.

Starch quality studies over the decades highlighted the immense health benefits of resistant starch (RS), but the mechanism of RS formation is poorly understood. A detailed biochemical analysis unraveled the role of pullulanase (PUL) enzyme in RS formation and a 'Pullulanase-Amylopectin Trimming Model' was proposed to explain RS formation. Biochemical analysis of variation in the inherent glycemic potential due to complex food matrix in pigmented rice [black (Chakhao) and red (Njavara)] was validated using *in vitro* simulation and cell line screening models. Pro-anthocyanidin in pigmented rice was found have anti-hyperglycaemic activity. To overcome the problem of rancidity and off-odour development during storage of pearl millet flour, a hydrothermal and infrared rays (IR) processing method was developed. The optimized processing method was validated on 12 important zonal varieties of pearl millet growing across India. Global natural vitamin-E (vit-E) market was valued at 820.18 million USD in 2016. The huge demand for natural vit-E is due to lower (<50%) biological activity of synthetic vit-E. A lab scale prototype was developed for efficient and cost effective extraction of natural vit-E from soy products.

Large numbers of molecular markers useful for marker-assisted breeding were developed during this year. *Sugary1* (*su1*) based sweet corn cultivars are popular worldwide. A universal functional marker for *su1* was developed for the first time. In lentil, 9,949 EST-SSR loci were identified from lentil RNASeq data and validated 50 of them using 234 genotypes representing various Lens species and 34 accessions of 12 different legumes. The newly developed markers represent an impressive tool for characterization of germplasm, genetic linkage mapping, phylogenetic studies, as well as to determine disparity in taxonomic status of subspecies of the genus *Lens*. In mustard, STS markers for GER1 and GER5 linked to low glucosinolate were developed and validated. Molecular markers were used for genetic diversity analysis in different vegetable *viz*., onion, carrot and okra germplasm.

Models for simulation of soil processes, yield and yield forecasting were developed. AquaCrop model ver 6.1, which requires relatively less input parameters, was validated for simulation of grain and biomass yield and water productivity of wheat under different tillage, residue and nitrogen management, and can be used satisfactorily for optimizing different management practices for improving yield of wheat. The temporal distribution of both soil water and soil NO_3-N under several conservation agriculture (CA) practices, during the wheat crop growth were characterized by HYDRUS-2D model. The results showed that permanent broad beds (PBB) with residue (PBB+R) is the best for wheat cultivation in maize-wheat cropping system to enhance water and nitrogen availability in the root zone, and reduce their losses beyond the root zone. Saturated hydraulic conductivity (SHC) is an important soil hydraulic parameter determines the rate of water flow systems through the soil. Since the direct measurements of SHC in field condition is very difficult, artificial intelligence (AI) based on artificial neural network (ANN) and support vector machine (SVM) models and multi-linear regression (MLR) model were used to obtain SHC from easily measurable soil parameters like particle size distribution, bulk density (BD) and organic carbon (OC).

Since reliable crop yield forecast system is an imperative for stabilized food security. a novel regional wheat yield forecasting system was developed by assimilating remote sensing derived LAI and weather forecast into crop simulation model, *i.e.* InfoCrop-wheat, using minimum observations as model inputs. The workable system has shown the acceptable accuracy in forecasting phenology, total dry matter and yield of spring wheat at fine scale and minimized the large management input data requirements. It has potential to be adopted for actual applications in many national projects like FASAL and PMFBY of Govt. of India. Multi stage wheat yield estimation using weather-based model was also developed using stepwise multiple linear regression (SMLR), Least absolute shrinkage and selection operator (LASSO) and elastic net (ENET) for district level yield forecast at different crop growth stage of wheat.

The School of Social Sciences and Technology Transfer worked in the major areas such as assessing improved IARI technologies, impact of Cluster Frontline Demonstration, impact of credit in enhancing

household income, performance of different marketing institutions in raising farmer's income, agricultural growth models, ecosystem services and its key determinants, impact and constraints of e-NAM, climate change and innovative extension models, different climate resilient technologies, farmer led innovations (FLIs), agri-nutri linkages and gender empowerment.

Impact assessment of ICAR-IARI wheat varieties from Karnal and Kurukshetra districts of Haryana and Ludhiana and Jalandhar districts of Punjab, Najafgarh and Narela blocks of NCR, Delhi revealed that HD 2967 and HD 3086 are the most adopted wheat varieties in sample areas covering 80-85 per cent of the area under cultivation.

A study on e-NAM found that the number of APMC *mandis* registered were highest in Uttar Pradesh but the highest coverage was in Haryana (94%), followed by Telangana (57.6%). Quality and grading aspects were the major hindrances in participating in e-NAM. Studies on FPOs revealed that FPOs were financially healthy but were unwilling to take risk, which showed conservative management. FPOs have a positive and significant impact on raising farm income to 26 per cent.

Estimated Average Treatment Effect (ATT) of Minimum Support Price (MSP) awareness on the price by sampled farmers revealed that there is no evidence of anchoring effect of MSP on the prices received by the farmers. Impact of export promotion of processed and unprocessed foods sector and its effect on output growth in farm and non-farm sectors indicated that non-farm sector share increased to 91 from 88 per cent. It also highlighted that 10 per cent increase in investment in Food processing industry (FPI) will lead to the highest growth in fish and fish products by 5.39 per cent, followed by 2.64 per cent of growth in meat and poultry.

Under IARI-Post office Linkage Extension Model, the quality seeds of improved IARI varieties were disseminated. The major impacts observed were improved satisfaction on extension service, change in cropping pattern and yield, change in seed management practices, increased social status of post master and increased social security. The adoption index score constructed for different climate resilient technologies was high in convergence led extension model than the innovative farmers led extension model and farmers club led extension model.

A study conducted to understand variety in food consumption among rural households in Uttar Pradesh showed that an increase in income by INR 1000 raises dietary diversity by 0.02 units. An estimation of consumers' willingness to pay (WTP) for biofortified mustard oil found that urban and rural consumers were willing to pay 36 and 26 per cent more than the existing price. A study with a "health belief model" revealed that the urban population had higher level of self-efficacy and confidence to overcome anemia as compared to lower level of self-efficacy amongst rural respondents. Under Agri-Nutri (A2N) Smart Village Model, various capacity building activities and nutri rich seeds of IARI varieties were carried out.

The institute is implementing *Mera Gaon Mera Gaurav*, the flagship programme of GoI, along with IASRI and NBPGR in 120 clusters comprising 600 villages, which are visited by 480 scientists regularly. The objective of the programme is to provide farmers with required information, knowledge and advisories on regular basis by adopting villages. During 2018-19, combining *kharif* and *rabi*, 1274 demonstrations were carried out with NEP and VO partners on various crops in 23 locations. Agricultural Technology Information Center (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, Pusa Agricom, exhibitions, farm literatures and letters.

The Institute's Krishi Vigyan Kendra at Shikohpur, Gurugram, conducted five On Farm Trials (OFTs), organized around 37 training programs with 727 beneficiaries, 355 agricultural extension activities on various areas covering 18,750 beneficiaries and 556 demonstrations covering 295 ha area in various crops for the speedy dissemination of technologies. The IARI regional stations Karnal (Haryana), Pusa (Bihar), Indore (MP), Shimla and Katrain (HP), Wellington and Aduthurai (TN) also significantly contributed to the dissemination of improved IARI varieties and technologies to the farmers through FLDs and other extension interventions like trainings, exhibitions and farmers' friendly literatures.

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*.

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 on the inaugural day. The *mela* was graced with the presence of Shri Radha Mohan Singh, Hon'ble Union Minister of Agriculture and Farmers Welfare, who visited 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. The Institute has awarded so far 4,148 M.Sc., 69 M.Tech. and 4,885 Ph.D. degrees to the students 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. During 2019-20 academic session 10% reservation for the economically weaker section (EWS) was implemented and admitted M.Sc./M.Tech. and Ph.D. students under this category.

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. Partnership Agreement was signed for dual and joint Ph.D. programme of ICAR-IARI students at Western Sydney University (WSU), Australia

Under the ICAR-NAHEP CAAST project on "Genomics assisted crop improvement and management", the Institute has send 10 students for training at international laboratories, and conducted eight trainings for student of NARES. 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 two 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 primary aim of the crop improvement programme of the Institute is to enhance the productivity and nutritional quality of various field crops through judicious use of conventional and modern tools of molecular breeding. A number of 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 3249: Released for timely sown, irrigated conditions of NEPZ with an average grain yield of 4.87 t/ha. It matures in 122-125 days and exhibited resistance against wheat blast, powdery mildew, leaf and stripe rusts, Karnal bunt and flag smut. It also showed moderate resistance to leaf blight in comparison to checks. This variety has the best HMW sub-units' combination for bread making with *Glu-1* score 8/10, high bread loaf volume (533) and *Chapati* score (7.8). It's bold (1000 grain weight 43 g), amber coloured, ovate shaped grains possess 42.5 ppm of Fe and 27 ppm of Zn content.

Field view of HD 3249

HD 3271: Released for very late sown conditions of NWPZ and NEPZ with an average grain yield of 3.25 t/ha. It is resistant to yellow and brown rusts and showed moderate resistance against leaf blight, powdery mildew, Karnal bunt and flag smut. HD 3271 has the best HMW sub-units combination for bread making with *Glu-1* score 8/10 and has the higher value of bread loaf volume, protein content and grain appearance score.

Field view of HD 3271

HI 1621: Released for very late sown, irrigated conditions of both NWPZ and NEPZ with average grain yield of 3.28 t/ha. It has excellent *Chapati* score (7.87), biscuit quality (8.52), bread quality (7.53) and sedimentation value (48.3 ml-NWPZ, 55.2 ml-NEPZ). It has good levels of essential micronutrients like iron (34.1 ppm-NWPZ & 39.0 ppm-NEPZ) and zinc (40.5 ppm-NWPZ & 33.1 ppm-NEPZ) content making it

rich in nutritional quality. It has high levels of field resistance to stripe and leaf rusts.

Field view and grain characteristics of HD 1621

HI 1628: Released for timely sown, restricted irrigation conditions of NWPZ with an average grain yield of 5.04 t/ha. It has good *Chapati* score (7.56), bread quality (7.64), biscuit spread factor (8.27) and high sedimentation value (56.6 ml). It has high levels of field resistance to stripe rust and leaf rust compare to checks.

Grain characteristics of HI 1628

HI 8802: A durum wheat variety released for restricted irrigation, timely sown conditions of Peninsular Zone with an average grain yield of 2.91 t/ha. It is resistant to stem and leaf rusts, Karnal bunt, loose smut, flag smut and foot rot. It has high protein content (13.0%), yellow pigment content (5.7 ppm), hecto liter weight (83.7 kg/hl), sedimentation value (40.4 ml), iron content (39.5 ppm) and zinc content of 35.9 ppm with overall good pasta quality (6.2).

Grain characteristics of HI 8802

HI 8805: A durum wheat variety released for restricted irrigation, timely sown conditions of Peninsular Zone with an average grain yield of 3.04 t/ha. It has high protein content (12.8%), hecto liter weight (83.7 kg/hl), sedimentation value (42 ml), yellow pigment content (4.9 ppm), iron content (40.4 ppm) and zinc content (33.9 ppm) with overall good pasta quality (5.7). It has exhibited high levels of resistance to stem and leaf rusts with good levels of resistance to Karnal bunt, loose smut and foot rot and resistance to flag smut.

1.1.1.2 Genotypes contributed to AICRP trials

During 2019-20, 68 genotypes were contributed for evaluation under AICRP trials under various production conditions of all the wheat growing zones of the country as per details given below:

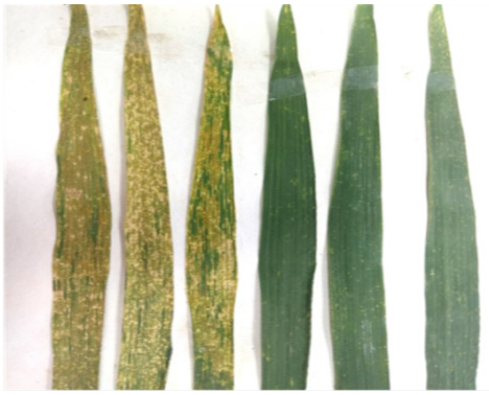
AVT-II (4)	HD 3298, HD 3293, HI 1634, HI 1633
AVT -I (16)	HS 668, HS 679, HS 680, HS 681, HS 675, HD 3334, HD 3332, HD 3331, HI 1636, HI 1637, HD 3377, HI 1641, HI 1642, HI 1646, HI 8823(d), HI 8818(d)
NIVT (43)	HD 3348, HD 3349, HD 3350, HD 3351, HD 3352, HD 3353, HD 3354, HD 3355, HD 3356, HD 3357, HI 1647, HI 1648, HI 1649, HI 1650, HD 3359, HD 3376, HD 3360, HD 3361, HD 3362, HD 3363, HD 3364, HD 3365, HD 3366, HD 3367, HI 1651, HI 1652, HI 8825, HI 8826, HI 8827, HI 8828,HI 8829, HD 3368, HD 3369, HI 1653, HI 1654, HD 3371, HD 3372, HI 1655, HI 8830(d), HI 8831(d), HS 675, HS 676, HS 677, HS 678
Special trial (5)	HD 3373, HD 3374, HD 3375, HD 3379 (CI-HYT IR-ES), HD 3378 (HYPT IR-TS-TAS-NWPZ)

1.1.1.3 Promising genotypes under IARI Common Varietal Trials

Total 160 promising genotypes in terms of grain yield and disease resistance identified in station trials at Delhi, Indore, Pusa, Shimla and Wellington in previous crop season are being evaluated in different multilocation IARI common varietal trials under various production conditions.

1.1.1.4 Marker-assisted transfer of genes for rust resistance

Near-isogenic lines (NILs) of HD 2967+*LrTrk*/*YrTrk*, HD 2733+ *LrTrk*/*YrTrk* and HD 2932+ *LrTrk*/*YrTrk* were developed through MAS. Phenotyping of these lines for leaf rust resistance was done at seedling stage and for stripe rust resistance in field at adult plant stage. In addition, *Yr5* has also been transferred in all the above mentioned varieties using MAS. Crosses were attempted to combine these resistance genes in same genetic background. Some new pyramided lines *viz.*, HD 2967+*Lr19*+*Lr34*+*Yr10*, HD 2733+*Lr19*+*Lr24*+*Yr10* and HD 2733+*Lr34*+*Yr10* were identified and multiplied for further evaluation. New crosses were attempted to combine *Yr5*, *Yr10* and *Yr15* with either *Lr24* or *Lr19*. Apart from seedling



Rust responses in 1. HD2967, 2. HD2733, 3. HD2932, 4. HD2967+*Yr5*, 5. HD 2733+*Yr5* and 6. HD 2932+*Yr5*

resistance genes, adult plant resistance (APR) genes were also combined. Two to three gene combinations of APR genes *viz.*, *Lr34*+*Lr46*+*Lr68* and *Lr34*+*Lr46*+*Lr67* were identified in the background of HD 2733. Besides, *Lr19*/*Sr25* and *Yr15* were transferred in wheat variety HS240 using linked molecular markers.

1.1.1.5 Evaluation of genotypes against stem and leaf rust resistance at Indore

A total of 589 genotypes under IARI Preliminary Disease Screening Nursery (PDSN) were evaluated for field resistance to stem and leaf rusts under artificial inoculations using mixtures of important pathotypes. Of these, 201 entries (34%) showed resistance to both stem and leaf rusts at Indore. Out of 100 bread wheat entries from Indore, the entries viz., HAS 2525, HAS 2528, HAS 2529 and HAS 2558 were found to be resistant to all the three rusts. Total 124 entries were found resistant out of 160 genotypes of CVT evaluated for seedling response to stem rust pathotype 40A.

1.1.1.6 Development of genotypes with better biscuit making quality

Homozygous soft grained BC_2F_3 plants using foreground selection for *PinaD1a* in DBW 14 and *PinaD1a, GluA3c* and *GluD3c* in HI 1563 were selected and multiplied in 2018-19. A set of 15 NILs (BC_2F_4) along with check DBW 14 are being evaluated in station trial during current crop season.

1.1.1.7 Development of wheat genotypes with superior quality traits

Based on four years of testing at various test sites, three genotypes HD 3304, HD 3241, HD 3215 for highest sedimentation value (72-75 ml) and two genotypes QBP 18-8 and QBP 18-10 for high hecto liter weight (80-82.5 kg/hl) and two genotype QBP 18-10 and QBP18-19 for high grain appearance score (7-7.2) have been identified as potential genetic stocks/donors.

1.1.1.8 Development of wheat strain with reduced celiac immunogenicity

Eleven F_5 families and 19 BC_1F_4 families from crosses between nullisomic and ditelosomic lines for chromosome 1A and 6A with durum wheat variety HI 8663 are being evaluated in the field. The 30 F_2 crosses between lines without 1A and 6A and between

ditelosomics for 1A and 6A have been planted in the field and MAS will be exercised to select pyramided plants.

1.1.2 Barley

1.1.2.1 Elite barley lines advanced under All India Coordinated Barley Trials

Five entries *viz*., BHS 478, BHS 479, BHS 480, BHS 481 and BHS 482 were nominated for testing in timely sown rainfed conditions of Northern Hills Zone under AICRP on barley during *Rabi* 2019.

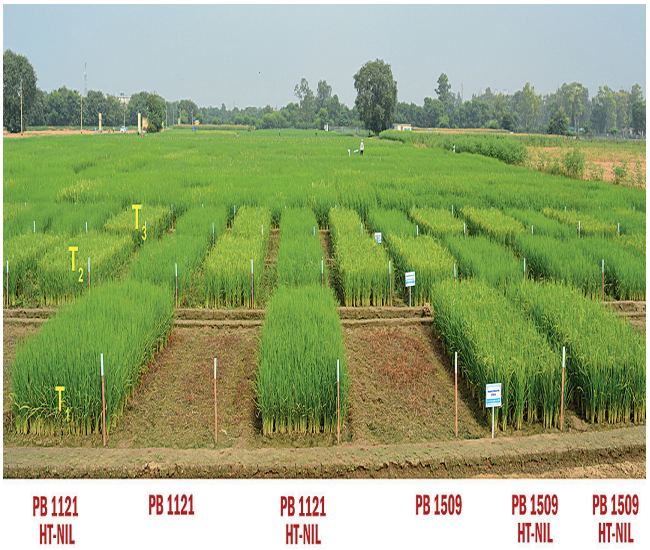
1.1.3 Rice

1.1.3.1 Rice genotypes contributed to AICRP Trials

A total of 37 genotypes were nominated in different stages of testing in the AICRIP trials during *Kharif* 2019 *viz*., Pusa 1692-10-20-1-1-1 in AVT2-BT; Pusa 1847-12-62-19-39-7-15 in AVT2-BT-NILs (BB+Blast); Pusa 1823-12-62 and Pusa 1823-12-82 in AVT2-NILs-Drt, Pusa 1853-12-288 and Pusa 1853-12-192 in AVT2-NILs-(BB+Blast); Pusa 1301-95-12-5-2-4-2, Pusa 1882-12-102-6 and Pusa RH 55 in AVT1-BT; Pusa 1885-13-242-9-3, Pusa 1885-13-125-20-6, Pusa 1886-13-91-26-9, Pusa 1886-13-201-18-13, Pusa 1847-12-62-184-36-9-155 and Pusa 1874-12-62-64-12-6-8 in AVT1-BT-NILs-(BB+Blast); Pusa 1882-12-111-7 and Pusa 1882-12-111-20) in AVT1-BT-NILs-Drt; Pusa 1630-07-12-2-62 and Pusa 1557-06-8-176 in IVT-BT; Pusa 2080-21 and Pusa 2080-1 in IVT-ETP; Pusa 5173-3-5-1-1-1-7 in IVT-IME; Pusa 2070-10-2, Pusa 2070-10-3, Pusa 1824-12-84-17-7-2, Pusa 5000-1-1-1 and Pusa 5000-1-2-1 in IVT-IM; Pusa 5159-1-2-1-1-1-3-3 in IVT-L; Pusa 5268-40, Pusa 1702-10-271 and Pusa 1702-10-289 in IVT-MS and Pusa 1979-14-7-33-99-15, Pusa 1979-14-7-33-99-66, Pusa 1985-15-7-112-25 and Pusa 1984-15-7-58-190 in AVT1-BT-NILs-HT were tested in the AICRIP trials during *kharif* 2019.

1.1.3.2 Evaluation of Imazethapyr tolerant Basmati genotypes under dry direct seeded condition

Four herbicide tolerant Near Isogenic Lines (NILs) namely, Pusa 1979-14-7-33-99-15, Pusa 1979-14-7-33-99-662 in the background of Pusa Basmati 1121, and Pusa 1985-15-7-112-25 and Pusa 1984-15-7-58-190 in Pusa Basmati 1509 background were nominated for AICRIP Trial during *kharif* 2019. These lines were evaluated along with the parents, Pusa Basmati 1121 and Pusa Basmati 1509 for their performance under dry direct seeded condition with four treatments, namely T_1- Weed management with Imazethapyr; T_2 – Conventional weed management with pendimethalin and bispyribac sodium, T_3 – Weed free control (through manual weeding) and T_4 – Unweeded control (without manual weeding or herbicide application for controlling the weeds) to identify the promising herbicide resistant cultivars for enhancing productivity and to assess the weed control efficiency.



Evaluation of Imazethapyr tolerant Basmati genotypes under dry direct seeded condition at IARI. Where, T_1- Imazethapyr Treated Block (@ 0.25% 2-3 Leaf stage of weeds); T_2- Pendimethalin (48 HAS @ 0.7%) +Bispyribac Sodium (20-25 DAS @0.08%); T_3- Weed Free Control (Manual weeding)

1.1.3.3 GGE biplot for zinc analysis: Multi-environment evaluation of rice germplasm for identification of donors for zinc

Enriching the rice endosperm with zinc can help in addressing the ill effects of micronutrient malnutrition among major rice eating population in India. Donor germplasm with stable and higher accumulation of mineral micronutrients in the endosperm across the environments are the pre-requisite towards the development of biofortified varieties. During

Multi-environment evaluation of rice germplasm for identification of donors for zinc

Genotype	New Delhi				Aduthurai			
	FeBR	FeMR	ZnBR	ZnMR	FeBR	FeMR	ZnBR	ZnMR
Karuppunel	16.2	5.4	46.2	40.9	11.9	2.6	47.0	40.8
Budgi	17.8	1.4	35.6	31.6	17.4	2.0	35.4	30.2
Mehvan purple	20.5	1.6	35.6	28.5	20.1	2.4	39.0	29.9
Mehvan green	21.7	4.2	37	33.4	17.1	3.3	33.8	29.6

FeBR, Fe content in brown rice; FeMR, Fe content in milled rice; ZnBR, Zn content in brown rice; ZnMR, Zn content in milled rice

kharif 2019, a set of four accessions as elite donors with polished rice Zn concentration of >28 ppm was identified, out of which Karuppunel was found to be superior across all five diverse environments.

1.1.4 Maize

1.1.4.1 Hybrids released and notified

Pusa Vivek Hybrid-27 Improved: It is a provitamin-A rich maize hybrid released for North Eastern Plains Zone which encompasses Bihar, Jharkhand, West Bengal, Odisha and Eastern Uttar Pradesh. It has been developed through marker-assisted introgression of *crtRB1* gene. It posseses 5.49 ppm of provitamin-A compared to 1-2 ppm in the traditional hybrids. It has average grain yield of 4.85 t/ha and is an early maturing hybrid which matures in 84 days.

Ear and grain characteristics of Pusa Vivek Hybrid-27 Improved

Pusa HQPM-5 Improved: It is a provitamin-A rich QPM hybrid released across the country. It posseses 6.77 ppm of provitamin-A compared to 1-2 ppm in the traditional hybrids. It also possesses high lysine (4.25%) and tryptophan (0.94%) in protein. It has been developed through marker-assisted stacking of *crtRB1*, *lcyE* and *opaque2* genes. It has grain yield of 6.47 t/ha and matures in 88-111 days across zones.

Pusa HQPM-7 Improved: It is a provitamin-A rich QPM hybrid released for Peninsular Zone that encompasses Tamil Nadu, Karnataka, Telangana, Andhra Pradesh and Maharashtra. It posseses 7.10 ppm of provitamin-A compared to 1-2 ppm in the traditional hybrids. It also possesses high lysine (4.19%) and tryptophan (0.93%) in protein. It has been developed through marker-assisted stacking of *crtRB1*, *lcyE* and *opaque2* genes. It provides 7.45 t/ha of average grain yield and matures in 97 days.

Pusa Super Sweet Corn-2: It is a *shrunken2* based single cross sweet corn hybrid released for Himachal Pradesh, Uttarakhand, Haryana, Uttar Pradesh, Chhattisgarh, Rajasthan, Tamil Nadu and Karnataka. It is having high kernel sweetness with a brix of 16.4% at 20-22 days after pollination. It provides 9.5 t/ha of average

Ear and grain characteristics of Pusa Super Sweet Corn-2

dehusked cob yield, and also provides an average of 12.8 t/ha of green cobs. It provides high volume of fodder (18.3 t/ha) as well and matures in 77 days.

1.1.4.2 Entries under AICRP trials

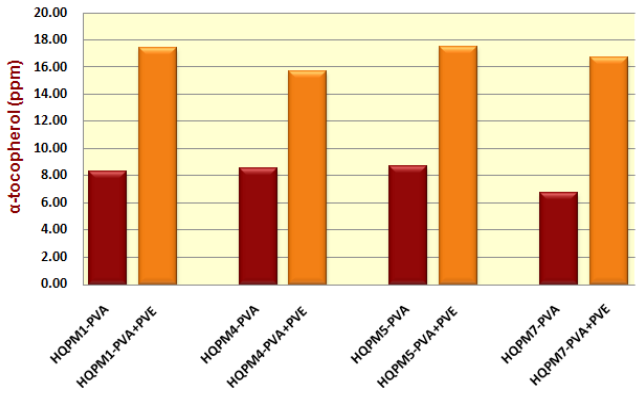
Biofortified hybrids (APH 1, APQH 1 and APQH 8 in AVT-II; APH 2 in AVT-I and APH 3 in NIVT) were evaluated in AICRP trials. Among specialty corn, hybrids of male sterile baby corn (ABHS4 1 and ABHS4 2 in BC-II) were evaluated. Besides, five entries (AH 7985 in BC-I, AH 7204 and AH 7188 in BC-II, and AH 7043 and AH 5021 in BC-III) were also evaluated in baby corn trials. Field corn entries in early maturity group (AH 3254, AH 1608, AH 4045, AH 8622, AH 8323, AH 8178 in NIVT, AH 8106, AH 8127 and AH 8181 AVT-I), medium maturity group (AH 1625, AH 1634, AH 4142, AH 4167, AH 8452 and AH 8245 in NIVT; AH 4271, AH 7067R and AH 181-2 in AVT-I) and late maturity group (AH 5158, AH 1645, AH 4139, AH 4272, AH 8072 and AH 8753 in NIVT) were tested in different zones under AICRP trials. One entry (ADH 1619) in rainfed trial, and two entries (AH 8070 and AH 8071R in NIVT) in forage trial were also evaluated.

1.1.4.3 Development of haploid inducer lines

Conventionally inbreds are developed through repeated inbreeding for 6-7 generations. However, using doubled haploid (DH) technology inbreds can be developed in 2-3 seasons. A set of elite inbreds were crossed with donor(s) for maternal haploid inducer gene. The marker developed and standardized in the lab was used to screen F_2 populations segregating for matrilineal gene (*mtl*) responsible for induction of maternal haploids. Severe segregation distortion for *mtl* gene was observed. Segregants homozygous for mutant version of *mtl* have been selected. These *mtl* positive segregants will be tested for haploid induction capacity.

1.1.4.4 Development of vitamin-E enriched hybrids

QPM and provitamin-A version of four elite hybrids *viz*., HQPM1, HQPM4, HQPM5 and HQPM7 were targeted for marker-assisted introgression of favourable allele of *VTE4* gene. The α-tocopherol in the improved lines (HKI161-PVA-PVE, HKI163-PVA-PVE, HKI193-PVA-PVE and HKI193-2-PVA-PVE) was significantly higher (14.23-16.62 ppm) than the original lines (5.89-9.82 ppm). The improved hybrids possessed 16.83 ppm of α-tocopherol compared to 8.06 ppm in original hybrids.



α-tocopherol level in original and improved hybrids.

1.1.4.5 Identification of novel SNP and InDel in *VTE4* gene

Fifteen diverse inbreds with the favourable allele of *VTE4* possessed wide variation of α-tocopherol (4.76 to 30.07 ppm). Sequence analysis of part of 5′UTR and promoter of *VTE4* revealed 14 SNPs (SNP1 to SNP14) and eight InDels (InDel1 to InDel8). SNP7 at 606 bp (G to A), and InDels viz., InDel1 (27 bp), InDel4 (27 bp) and InDel8 (14 bp) differentiated low and high α-tocopherol accumulating inbreds with favourable haplotype. Hence, the newly identified SNP and InDels in addition to the already reported InDel118 and InDel7 can be useful in selection of favourable genotypes with higher α-tocopherol in maize.

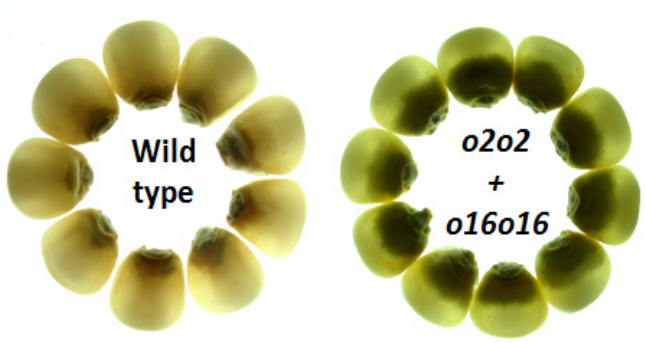
1.1.4.6 Variation for retention of carotenoids during storage

Twenty two biofortified inbreds with *crtRB1* were stored for 6-months. Freeze and vacuum storage were significantly better than traditional storage for retention of both proA and non-proA. Under traditional storage, β-cryptoxanthin (20.7%) had the higher retention than

β-carotene (16.3%), while lutein (53.9%) had better retention over zeaxanthin (42.4%) among *crtRB1*-inbreds. Major fraction of proA was lost during first three months of storage, while non-proA showed slow and progressive degradation under traditional storage. Inbreds with >25% retention of proA have been identified.

1.1.4.7 White maize with *opaque2* and *opaque16*

White maize is a preferred option as human food. Parental lines of white grained hybrids *viz*., HM5 (HKI 1344 × HK 1348-6-2) and HM 12 (HKI 1344 × HKI 1378) were improved by marker-assisted introgression of *opaque2* and *opaque16*. QPM versions of the hybrids were evaluated at Delhi, Karnal and Dharwad during *kharif* 2019. The promising combinations with higher yield and 25-50% opaqueness in the grains were selected. These hybrids had high degree of similarity for plant, grain and ear characteristics with their original versions.



Extent of opaqueness (black region) of kernels in wild type and *o2+o16* inbreds visible on light-box

1.1.4.8 Breeding for high oil maize

High oil (HO) germplasm of exotic origin was used as donor. Crosses were made between HKI161PVA+PVE, HKI163PVA+PVE and HKI193-1PVA+PVE and the HO-donors for introgression of *dgat1* and *fatB* genes. Marker polymorphism was validated for candidate genes between recurrent and donor parents. BC_1F_1 populations were genotyped and heterozygotes were backcrossed to generate BC_2F_1 populations.

1.1.4.9 Development of sticky maize

High amylopectin maize or 'sticky' maize is popular as food 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 introgressed 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. Promising progenies with high amylopectin homozygous were selected, and will be used for reconstituting the hybrids.

1.1.4.10 Development of silkless baby corn

HM4, a popular baby corn hybrid was targeted for introgression of silkless trait. The required mutants carrying genes *viz*., *silkless1* (*sk1*), *tasselseed1* (*ts1*) and *tasselseed2* (*ts2*) were acquired. Each of the mutants was crossed with parental inbreds *viz*., HKI 323 and HKI 1105. F_1s were raised and further backcrossed to their respective parental lines to develop BC_1F_1 populations. BC_1F_1 raised during *kharif* 2019 were genotyped, and selected segregants were selfed to generate BC_2F_2 seeds.

1.1.4.11 Biotic stress tolerance

Development and evaluation of single cross hybrids: AH 7080, AH 7078, AH 8181, AH 8497 and AH 8047 were found to be resistant to TLB, with a disease score of less than 2.0. Further, H 8622, H 7670 and H 7241 in early group, H 7581, H 7956 and H 8134 in medium category and H 8461, H 8464, H 7726 and H 7777 in late category were also resistant to moderately resistant against turcicum leaf blight (TLB) and maydis leaf blight (MLB). These hybrids had >15% standard heterosis over best checks.

1.1.4.12 Enhancement of productivity

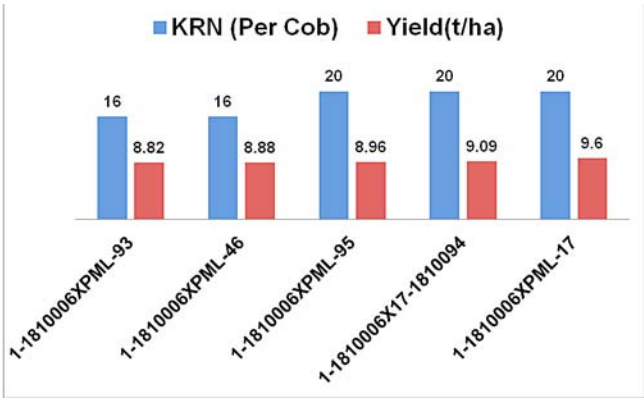
Identification of promising inbred lines: Six inbred lines (AI 04, AI 17, AI 06, AI 13, AI 02 and AI 19) with *per se* yield more than 3.5 t/ha were identified. These are good genetic resources for development of medium to late maturing maize hybrids.

1.1.4.13 Development of new experimental maize hybrids

A set of 13 PML lines belonging to late and medium maturing group were crossed with three broad based testers. Hybrids so obtained were evaluated in Delhi and Bijapur. AH 4271, AH 4158, AH 1619, AH 1625 and AH 1608 were found to be superior to national check, Bio-9544 in medium maturing category. AH 5158, AH 1645, AH 4139, AH4272 and AH 4142 were found to be superior over national check, CMH-02-282 in late maturity.

1.1.4.14 High kernel row number (KRN) as a strategy to enhance productivity

Five inbred lines from low KRN category and six each from medium and high KRN categories were involved in generating crosses following diallel mating design. These 136 combinations were evaluated under Lattice Design at New Delhi during *kharif* 2019. Phenotypic data were recorded for different traits like cob length, cob girth, number of cobs, kernel row number, test weight and total grain yield. The hybrids with high KRN tend to be high yielding.



KRN and yield in some of the promsing hybrids

1.2 MILLETS

1.2.1 Pearl millet

1.2.1.1 Promising hybrids in Intermediate Station Trial (Early/Medium duration hybrids)

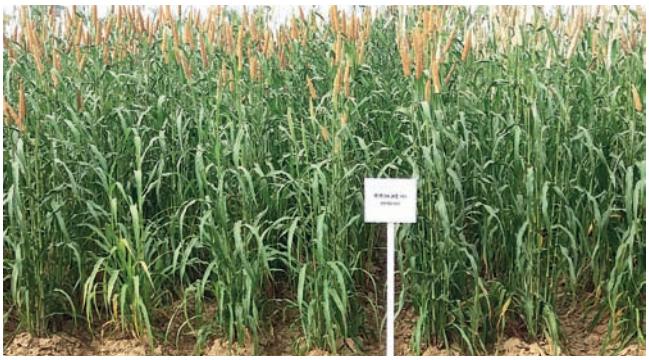
In Intermediate Station Trial, ninety nine hybrids were tested along with three checks at Delhi during *kharif* 2019. Hybrids *viz*. ICMA 11222 x ICFD-16 R-14, ICMA 11222 x ICMR 12555, ICMA 98444 x ICMR 06111, ICMA 14222 x ICMR 12555, ICMA 08666 x PPMI 1244, ICMA 11222 x TPR 14, ICMA 08666 x ICMR 12555 and ICMA 11222 x PPMI 572 were found promising on the basis of yield and related traits.

1.2.1.2 Hybrids with high iron and zinc

Thirty nine biofortified hybrids including one check were tested in Initial Station Trial. These hybrids were developed using iron and zinc enriched parental lines. Seven hybrid combinations *viz*, ICMA 08666 x HFeIT-17/2 (Fe: 106.4 ppm, Zn: 68.3 ppm), ICMA 08666 x ICFD-14 R-61 (Fe: 91.1 ppm, Zn: 61.3 ppm), ICMA 08666 x ICFD-14 R-74 (Fe: 110.7 ppm, Zn: 61.0 ppm), ICMA 11222 x HFeIT-17/2 (Fe: 119.9 ppm, Zn: 61.0 ppm), ICMA 11222 x HFeIT-17/34 (Fe: 120.6 ppm, Zn: 7.3 ppm), ICMA 11222 x ICFD-14 R-74 (Fe: 103.8 ppm, Zn: 57.5 ppm), and ICMA 11222 x PPMI 953 (Fe: 151.4 ppm, Zn: 82.6 ppm) were found promising. The range of iron and zinc in the selected biofortified hybrids was observed to be 91.1-151.4 ppm and 57.5 - 82.6 ppm, respectively.

1.2.1.3 Identification of stable restorer line with high iron and zinc

Ten genotypes along with checks were evaluated in RBD at six locations under rainfed conditions. Significant differences were observed in genotype, environment and genotype × environment interaction mean squares for grain Fe and Zn contents, indicating differential nutrient accumulation by the genotypes. The first two principal components obtained in AMMI analysis were significant and cumulatively explained

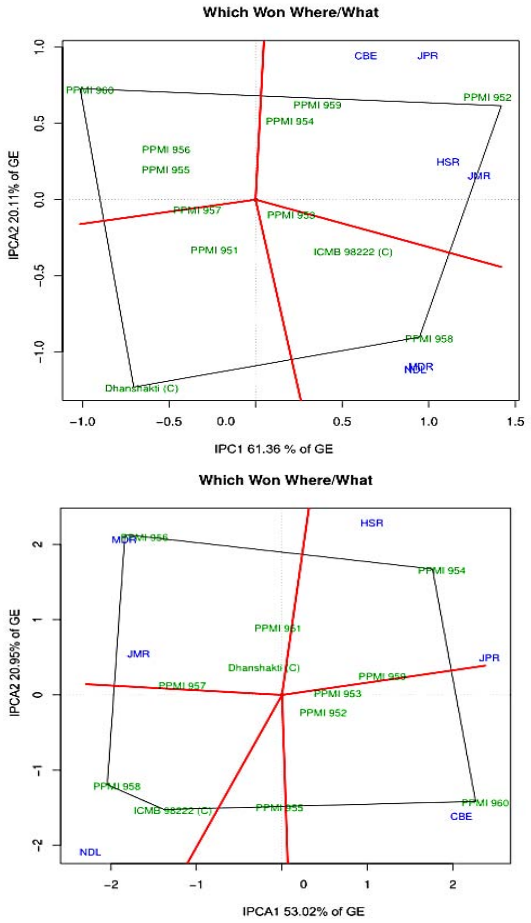


Field view of genotype PPI MI 953

the total variation 81.47% for Fe and 73.97% for Zn. A positive and moderately high correlation (r=0.6) between Fe and Zn contents suggests good prospects of simultaneous improvement for both micronutrients. Among the ten genotypes, PPMI 953 was found to be more stable with high mean for Fe (90 ppm) and Zn (59 ppm). On crossing with designated A lines of pearl millet, the line PPMI 953 was found to be restorer for A_1 system with complete fertility restoration of F_1 panicle. Hence, PPMI 953 may be used as source for further genetic improvement with respect to grain micronutrient content or can be directly used as male parent in development of high iron pearl millet hybrids.

1.2.1.4 GGE biplot analysis among genotypes with high iron and zinc

The genotypes PPMI 952, PPMI 958, Dhanshakti and PPMI 960 appeared on the corners of "which won where" polygon revealing that they were the best genotypes in specific environments. In case of grain iron content, genotype PPMI 958 appeared on the corner of the polygon where NDL and MDR environments fell. This suggests that PPMI 958 was the best cultivar for NDL and MDR. Likewise, the PPMI 952 genotype remained on the vertex of the polygon where the HSR, JMR, JPR and CBE environments fell; indicating PPMI 952 was the best cultivar for these environments. The genotypes PPMI 960, PPMI 955, PPMI 956, Dhanshakti and PPMI 951 located on the vertices did not fall in any environment, suggesting that these genotypes were not the best in any of the environments. The genotypes, *viz*. PPMI 953 and PPMI 957 remained in the centre of origin showed stable performance across the environments. Similarly, for grain Zn, PPMI 952, Dhanshakti and PPMI 953 remained in the centre of origin showed stable performance across the environments. Also, genotypes suited for specific locations were given by AMMI 2 biplot as PPMI 954 for HSR, PPMI 959 for JPR, PPMI 960 for CBE, PPMI 958, ICMB 98222 and PPMI 955 for NDL. The genotypes, PPMI 956, PPMI 951 and PPMI 957 were found to be the best genotype for location MDR and JMR. Hence, evaluation of test environment could help in identifying environments that could be utilized for selecting superior genotypes for mega environment.



AMMI 2 biplot for 10 high Fe and Zn genotypes

1.2.1.5 Inheritance of fertility restoration for A_5 cytoplasm

An investigation was carried out to understand the genetics associated with fertility restoration of the A_5 system of CMS in pearl millet using pollen fertility and seed set percent as criteria for determining the fertile and sterile plants. Three diverse cytoplasmic nuclear male sterile A-lines belonging to the A_5 cytoplasm ($ICMA_5$02555, $ICMA_5$07999 and $ICMA_5$12222) were crossed with two restorer lines (A_5RT-17/8 and A_5RT-17/26) to produce six F_1s and their respective F_2s and backcrosses. These were evaluated for male sterility (S) and fertility (F) at IARI, New Delhi during *kharif* 2019, and segregation ratio was established in all the generations using χ^2 test. The segregation pattern of male-sterile (S) and male-fertile (F) plants observed in F_2 and BC_1 indicated dominant single gene control

of male fertility restoration with $ICMA_5$02555 and $ICMA_5$07999. However, segregation pattern with male sterile line $ICMA_5$12222 had a good fit to 15F:1S ratio indicating two gene control with duplicate interaction. Association between pollen fertility and seed set percent was significant and positive.

1.3 GRAIN LEGUMES

1.3.1 Chickpea

1.3.1.1 Varieties released

Pusa Parvati (BG 3062): It has been released for cultivation in Central India comprising states of Madhya Pradesh, Maharashtra, Gujarat, Chhattisgarh and parts of Rajasthan. Its average grain yield is 2.27 t/ha and it matures in 112 days. It has attractive grain colour and 100-seed weight of 23 g. It has high degree of resistance to *fusarium* wilt and is moderately resistant to dry root rot and stunt. It is an erect desi chickpea variety suitable for machine harvesting.

Field view of BG 3062

Pusa Chickpea 10216 (BGM 10216): Pusa chickpea 10216 is the first introgression line developed through marker-assisted breeding. It has been released for cultivation in Central India comprising states of MP, Maharashtra, Gujarat, Chhattisgarh and parts of Rajasthan. It is a drought tolerant variety developed through introgression of drought tolerant/avoidance root traits from ICC 4958 into Pusa 372, a widely adapted desi chickpea variety. Its average yield is 1.45 t/ha and matures in 110 days. Its 100-seed weight is 22 g. It is moderately resistant to *fusarium* wilt.

Grain characteristics of BGM 10216

1.3.1.2 Promising entries contributed to AICRP and State Varietal Trials

Two drought tolerant introgression lines (BG 4005 and BGM 10218) were promoted to AVT-2 for final year of testing. Two entries, BG 4001 (*desi*) and BG 4008 (*kabuli*) were promoted to AVT-1 in South Zone. Eight desi entries (BG 4010, BG 4011, BG 4012, BG 4013, BG 4014, BG 4015, BG 4016 and BG 4017) and two large seeded kabuli types (BG 4018 and BG 4019) were entered in five different IVTs during 2019-20. From Dharwad centre, six promising entries (BGD 1501, BGD 1536, BGD 1510, BGD 1524, BGD 1534 and BGD 3059) were contributed for evaluation in multilocation trials during *rabi* 2019-20. Four genotypes *viz*. one *kabuli* (BG 3057) and three desi (BG 3088, BG 4002 and BG 004) were nominated for testing in UP State Varietal Trials during 2019-20. The large seeded kabuli entry BG 3057 has been promoted to second year of testing in UP state.

1.3.1.3 Breeding material generated

Crosses were attempted at IARI, New Delhi involving wilt resistant/erect breeding lines/cultivars. Ten backcrosses were also made to generate BC_3F_1 for introgression of wilt resistance genes and pyramiding into Pusa 362, Vijay, Pusa 1103, Pusa 547, Pusa 3043, GNG 1958, GNG 2171 and PBG 7. Fourteen mega varieties have been targeted towards introgression of wilt, drought and aschochyta blight using MABC approach and are in various stages of BC_3 advance generations.

1.3.1.4 Breeding for disease resistance and plant type amenable to mechanical harvesting

In preliminary yield trial-MH, 590 *desi* and *kabuli* wilt resistant single plant progenies were evaluated for yield in augmented design along with checks (HC5 and Pusa 3022). Five station trials and one advance trial (AT-MH) was conducted with 126 tall and erect breeding lines. The screening of F_4 and F_5 families derived from hybridization of high yielding chickpea varieties with rust tolerant lines under artificial epiphytotic condition was carried out at RRC Dharwad. The progenies with low rust score and high grain yield were selected in each family. Very few segregants with low rust score and high grain yield were selected in two crosses (ICC 1745 with JG 11 and BGD 111-1). The F_2 population of a cross ICC 14395 x Pusa 212 advanced to F_3 by SSD method with the objective of developing mapping population for DRR. F_6 and F_7 progenies were screened for root disease complex. Progenies tolerant to *Fusarium* wilt and dry root rot disease complex and high grain yield were selected.

1.3.1.5 Development of BGM tolerant lines

Using *C. pinnatifidum* as source of resistance to Botrytus Grey Mold (BGM), breeding lines were developed *viz*., GLW 91, 69 and 36, which had high level of tolerance to BGM. Available screening data of two years (field screening at Pantnagar and cut twig screening at PAU, Ludhiana) was used for association mapping. Strong correlation between both the screening methods was indicated by paired-t test. BSA approach was used to screen DNA bulks of the five most resistant and five most susceptible lines using 300 simple sequence repeat (SSR) markers. Eighty eight markers were found x^2 to be polymorphic. The *Chi*-square statistic values showed strong correlation of TA144, GA102, TA194, TA140 and TR2 with the resistant bulks signifying their usability as a putative marker linked to BGM resistance and develop BGM tolerant genotypes in chickpea

1.3.1.6 Genetics of stem bending (lodging)

Genetics of stem bending (lodging) was studied in an inter-varietal cross involving BG 362 (lodging susceptible) and FLIP 07-183C (lodging resistant). All the F_1 plants of the cross were lodging resistant indicating that gene (s) governing lodging resistance in FLIP 07-183C was dominant over that of lodging susceptibility. The F_2 plants of the cross segregated into 350 lodging resistant: 33 lodging susceptible plants. These numbers are in good fit with the ratio of 15 resistant: 1 susceptible ($\chi 2$ value 3.66, $p = 0.05 - 0.10$) suggesting that two dominant non-allelic genes with duplicate gene action controlled lodging resistance in FLIP 07-183C. The two non-allelic duplicate dominant genes for lodging resistance are designated as *Sb1/sb1* and *Sb2/sb2*. The presence of both the alleles in homozygous (*Sb1Sb1Sb2Sb2)* or heterozygous (*Sb1-Sb2-)* or either of the two dominant alleles, *Sb1* and *Sb2*, in homozygous (*Sb1Sb1sb2sb2* or *sb1sb1Sb2Sb2)* or heterozygous (*Sb1sb1sb2sb2* or *sb1sb1Sb2sb2)* condition governed lodging resistance. The presence of recessive alleles at both the loci in homozygous (*sb1sb1sb2sb2)* condition resulted in lodging susceptibility. The segregation pattern observed in F_2 was confirmed by studying the breeding behavior of 315 F_3 families of the cross. The segregation pattern observed in F_3 for lodging resistance and susceptibility confirmed the segregation observed in F_2. This is the first report on the inheritance of lodging resistance in chickpea.

1.3.1.7 Genetics of internodal length

F_2 population (241 plants) derived from the cross HC 5 (long internodes) and E 100YM (spontaneous brachytic growth mutant with short internodes) was phenotyped for internode length (long *vs* short) during *rabi* 2018-19. F_1 from the cross had normal plant type with long internodes (similar to HC 5), indicating dominance of normal plant type over brachytic plant type. The F_2 population of the cross gave a good fit to the 3:1 (normal : brachytic) ratio suggesting that a single recessive gene with pleiotropic effect controls brachytic growth in E100YM.

1.3.2 Pigeonpea

1.3.2.1 Development of short duration lines with improved plant type

Two hundred and fifty advanced generations determinate semi-dwarf breeding lines with medium height (around 1 m) and semi-erect compact plant type were evaluated in station trial and 25 early maturing bold seeded (9 -11 g/100 seeds) lines were selected.

Short duration determinate semi-dwarf breeding lines with medium height (around 1 m) and semi-erect compact plant type

Besides, 75 determinate semi-dwarf (medium plant height around 1 m) semi-erect compact lines derived from the cross Pusa Dwarf x ICP 8863 were evaluated and 10 early maturing lines (125-135 days) were selected.

1.3.3 Mung bean and lentil

1.3.3.1 Varieties released

Pusa 1641: It is a high yielding mung bean variety with an average yield of 1305 kg/ha. It showed 11.3 to 13.8% higher yields over four checks. It also showed resistance to MYMV in northern India in AICRP trials. Pusa 1641 has average protein content of 25.4%. It flowers at 36 days after sowing and matures in 62 to 64 days. 100 seed weight of the variety is 4.1 to 4.2 g. It has been identified for release in Delhi and NCR.

Field view of Pusa 0871

L 4729: Lentil variety L 4729 has been released for Central Zone comprising the states of Madhya Pradesh, parts of Uttar Pradesh and Rajasthan and Chhattisgarh for timely sown rainfed condition during *rabi* season. It is a bold seeded variety with average grain yield of 1.7-1.8 t/ha with extra early maturity (103 days). L 4729 is moderately resistant to wilt in Central Zone. It has average protein content of 24.9%.

Field view of L4729

1.3.3.2 Promising entries contributed to AICRP trials

Eight entries of mung bean *viz*., Pusa M 1971, Pusa M 19111, Pusa M 1972, Pusa M 1931, Pusa M 1932, Pusa M 1941, Pusa M 1942 and Pusa M 1831; and six entries of lentil viz., PLSS 1901, PLSS 1902, PLLS 1901, PLLS 1902, PLEE 1901 and PLEE 1902 were contributed for evaluation in different stages of AICRP trails.

1.3.3.3 Hybridization and breeding material handled

Mungbean: Forty eight crosses were made. Forty seven F_1s were raised. Two thousand six hundred and forty four single plant progenies in different generations were evaluated. Three station trials were conducted to identify high yielding entries for coordinated trials for spring summer and *kharif* season.

Lentil: Sixty five crosses were made. One hundred and six F_1s were raised in lentil. Three thousand and one hundred forty seven single plant selections from different generations were evaluated. Three station trials were conducted to identify high yielding entries for coordinated trials.

1.3.3.4 Genetic variation for root architectural traits in response to phosphorus deficiency in mungbean at the seedling stage

One hundred and fifty three mungbean genotypes were studied to compare root architectural traits under normal and low phosphorus conditions. Significant variations, medium to high heritability, near normal distribution and significant correlations were observed for studied root traits. Total root length (TRL) was positively correlated with total surface area (TSA), total root volume (TRV), total root tips (TRT) and root forks. The first two principal components explained the 79.19 and 78.84% of the total variation under normal and low phosphorus conditions. TRL, TSA and TRV were major contributors of variation and can be utilized for screening of phosphorus uptake efficiency at seedling stage. Released Indian mungbean varieties were found to be superior for root traits than other genotypic groups. Based on comprehensive phosphorus efficiency measurement, IPM-288, TM 96-25, TM 96-2, M 1477, PUSA 1342 were found to be top five highly efficient genotypes, whereas, M 1131, PS-16, Pusa Vishal, M 831 and IC 325828 were highly inefficient genotypes.

1.3.3.5 Genetics and molecular mapping for salinity stress tolerance at seedling stage in lentil

To understand the genetics and molecular mapping for salinity stress tolerance in lentil at the seedling stage, mapping populations were developed by crossing salt sensitive (L-4147 and L-4076) and salt-tolerant (PDL-1 and PSL-9) genotypes. The parents, F_1, F_2, F_3 and backcross populations were assayed in salt solution at 120 mM NaCl for assessing salinity stress tolerance based on seedling survival and a Fluorescein diacetate (FDA) signal. The F_1s were found tolerant to salinity stress indicating their dominance over the sensitive ones. The F_2 segregation fitted well with the expected monogenic frequency ratio of salt-tolerant : salt-sensitive plants, which indicates that salinity stress tolerance is governed by a single dominant gene. This was also confirmed in F_3 and backcross segregation data. Allelism test supported the hypothesis that the same gene was conferring stress tolerance in tolerant genotypes (PDL-1 and PSL-9). This matched with a major QTL of seedling survival under salinity stress. Four hundred and ninety-five SSR markers were analysed for polymorphism and 11 of them were found polymorphic between the parents. Among eleven polymorphic markers, seven were associated with seedling survival under salinity stress. The QTL of this trait was mapped within a map distance of 133.2 cM in F_2 mapping population (L-4147 x PDL-1) and it was found located on linkage group 1 (LG_1) and explained 65.6%. of phenotypic variance. This report on QTL mapping should be useful for dissection of candidate genes and development of molecular markers for improvement of salinity stress tolerance in lentil.

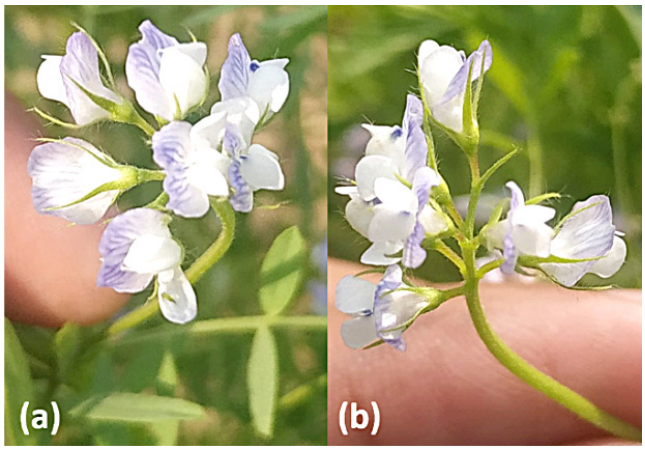
1.3.3.6 Genetic dissection of grain iron and zinc concentration in lentil

Iron (Fe) and zinc (Zn) deficiencies are wide spread in South Asia and Africa. Biofortification of food crops is a viable means of addressing micronutrient deficiencies. Lentil is an important pulse crop that provides affordable source of proteins, minerals, fibre and carbohydrates for micronutrient deficient countries. An association mapping (AM) panel of 96 diverse lentil genotypes from India and Mediterranean region was evaluated for three seasons and genotyped using 80 polymorphic simple-sequence repeat (SSR) markers for identification of the markers associated with grain Fe and Zn concentrations. A Bayesian model based clustering identified five subpopulations, adequately explaining the genetic structure of the AM panel. The linkage disequilibrium (LD) analysis using mixed linear model (MLM) identified two SSR markers, GLLC 106 and GLLC 108, associated with grain Fe concentration explaining 17% and 6% phenotypic variation, respectively and three SSR markers (PBALC 364, PBALC 92 and GLLC592) associated with grain Zn concentration, explaining 6, 8 and 13% phenotypic variation, respectively. The identified SSRs exhibited consistent performance across three seasons and have potential for utilization in lentil molecular breeding programme.

1.3.3.7 Five flowers per peduncle-A novel trait identified in cultivated lentil

Two multi-flowering (MF) genotypes from the ICARDA nursery *viz.*, PMF-1 and PMF-2 were identified in the cultivated lentil, expressing five-flowers per

peduncle (FPP) on some nodes at multiple flowering nodes of each plant. Furthermore, the genotype PMF-1 also uniquely expressed multi-flowering expression to the tune of 6 and 7-FPP in some plants. Five-FPP was recorded under open field conditions at IARI, New Delhi (2017-18 and 2018-19) and Sehore (Madhya Pradesh; 2018-19) and also in the partially-controlled glasshouse conditions of National Phytotron Facility, New Delhi. In addition, two genotypes (PMF-3 and PMF-4) forming four FPP and a genotype, ILL7663 forming two FPP at multiple flowering nodes were also used for the detailed analysis of various flowering traits. Significantly longer peduncle length (PL) was recorded in the genotype PMF-1 and PMF-2 over other genotypes. We speculate, MF in lentil is the result of the interaction between certain genetic loci with the environmental conditions during the bud formation stage. Further, these identified novel resources will be used for the genetic studies aimed to identify the locus regulating MF in lentil.



The lentil genotype PMF-1 expressing the formation of 7-flowers per peduncle (a) Top view; (b) Side view

1.3.3.8 Microgreens

The microgreens of 20 genotypes each of lentil and mungbean were grown at Delhi and Leh for the estimation of various antioxidant and micronutrient contents. The mungbean genotype, PS16 showed highest non-enzymatic antioxidant activities, when grown at Leh and Delhi conditions. Whereas, lentil genotypes, K75 and PL2 showed highest activity in Leh and Delhi, respectively. The enzymatic antioxidant activity for mungbean genotype MH421 showed highest CAT while MH96-1 showed highest POD activity. In lentil, PL2 showed highest CAT activity, while L830 and K75 showed higher soluble protein contents. Among micronutrients, Fe and Zn content in mungbean (Delhi) was found ranging between 223.31 to 294.77 and 97.87 to 130.74 ppm, respectively; whereas, for Leh this was found ranging between 215.28 to 496.96 and 106.77 to 158.01 ppm, respectively. Overall, the microgreens when grown at Leh showed more antioxidants and micronutrients when compared to those grown at Delhi.

1.4 OILSEED CROPS

1.4.1 Mustard

1.4.1.1 Entries contributed to coordinated trials

During 2019, a total of 17 entries were contributed to AICRP-Rapeseed Mustard trials at National level including four entries promoted to various Advance Varietal Trials *viz*., LES 54 (AVT-II Quality), LES 59, PDZ 11 and PDZ 12 (AVT I Quality). New entries contributed for their evaluation in Initial Varietal/ Hybrid Trials were IVT-Early (NPJ-229, NPJ-230); IVT Timely Sown (NPJ 231, NPJ 232); IVT-Rainfed (NPJ-233, NPJ-234), IVT Late Sown (NPJ 235, NPJ 236) and IVT-Quality (LES 60, LES 61 and PDZ 13). In addition, two entries (NPJ 237 and NPJ 238) were contributed for their testing in National Disease Nursery.

1.4.1.2 Promising lines/ hybrids being evaluated in station trials

A total of 88 promising genotypes were evaluated in different station trials. Twenty-one hybrids were also evaluated under multilocation *trail*.

1.4.1.3 Breeding material generated

To address the various objectives of the project, a total of 1642 plants to progenies of different generations selected during 2018-19 have been raised for quality and different sowing conditions *viz*., early, timely, late and rainfed.

1.4.1.4 Development and utilization of male sterility and fertility restorers for hybrid breeding

Nucleus seed of two fixed CMS lines and their maintainer was produced. Twenty-one, 18 and 17 nuclear background are being maintained under conversion in *mori, eru, bar,* respectively. Eighty six fertility restorers are being maintained and utilized in hybrid development.

1.4.1.5 Hybridization and pre-breeding

For improving the yield (seed and oil), yield component traits and disease resistance in timely sown breeding material, 130 crosses were attempted. To infuse genetic variability and improve agronomic traits other *brassica* species are being utilized. One hundred and 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.

***Brassica carinata* derived *B. juncea* Introgression Lines (ILs) being evaluated under rainout shelter**

1.4.1.6 Cytoplasm diversification and CMS line development

To transfer nuclear genome from 8 genetic backgrounds to *Ogu* cytoplasm BC1 or F1 crosses were attempted. Twentyfive nuclear backgrounds in different sterility inducing cytoplasms *viz., Moricandia arvensis (mori), Diplotaxiserucoides (eru)* and *Diplotaxisberthautii (ber)* were maintained by attempting 75 paired crosses with the 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

1.4.1.7 Phenotyping of 0/00 fixed and advanced lines through biochemical assay

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, 3917 single plants/bulks were analysed of which 3302 were having <2% erucic acid. Single plants/bulks, 3052 in number, from double low quality material including breeding material, advance breeding lines, released varieties were also analyzed for total glucosinolates content of which 787 single plants/bulks were possessing <30 ppm glucosinolates.

1.4.1.8 Phenotyping for identification of high and low tocopherol genotypes

α-tocopherol, a lipid soluble compound is considered to play an important role as an antioxidant, protecting the integrity of the cellular membranes under normal and stress conditions. Edible oils that are the major source of vitamin E are poor in α-tocopherol content. The objective of this work is to increase the α-tocopherol content of *Brassica juncea*. Most of the commonly grown varieties of *Brassica juncea* have very low levels of α-tocopherol in comparison to γ-tocopherol. The values of the different tocopherol forms in commonly grown varieties of *B. juncea* are presented below.

Tocopherol profiling of selected Indian mustard varieties

Sl. No.	Genotype	Tocopherols (ppm)			
		Delta	Gamma	Alpha	Total
1	PM30	7.87	114	45.91	167.8
2	PM 29	6.76	107.94	61.54	176.3
3	PDZ-9	5.36	112.39	58.81	176.6
4	RLC3	0.85	64.78	42.96	108.6
5	RH749	0.06	84.82	41.13	126.0
6	NPJ-203	0.04	87.44	29.39	116.9

The total tocopherol content in the seeds varied from 108.6 to 176.6 ppm, with γ-tocopherol present in highest proportion, while, the α-tocopherol made only a small percentage. Based on the pre-liminary phenotypic data, specific crosses between 'Low' x 'High' parents have been attempted. *In silico* analysis helped in developing gene based primers for re-sequencing of genes to study the variation in the coding region.

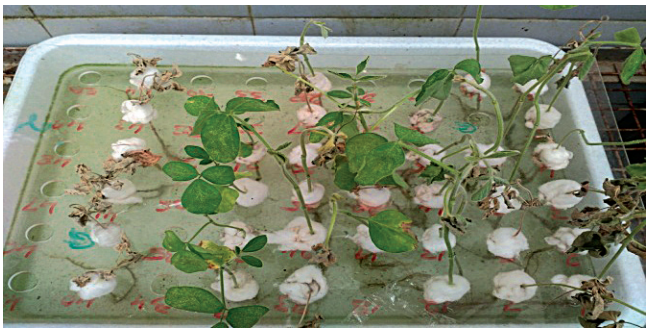
1.4.2 Soybean

1.4.2.1 Entries contributed to Coordinated trial

DS 1318, DS 1320, DS 1326, DS 1312 and DS 1324 in NIVT, and DS 3110 in AVT I were contributed for evaluation in AICRP trials.

1.4.2.2 Identification of drought tolerant genotypes

A set of 328 germplasm lines were screened for terminal drought stress induced through spraying of 0.2% potassium iodide (KI) at R5 stage (seed filling stage) to mimic terminal drought. The genotypes *viz*., EC 105780, TGX 1835-3E, SL 61, NSO 78, PK 1243, PS 1370, JS 2000-20, PK 1180, HIMSO 1587 and PK 1243 were identified as tolerant lines to terminal drought stress based on the per cent reduction in seed yield and 100-seed weight of treated plot over the control. The tolerant lines were again tested under similar conditions in the subsequent year and they were found to be tolerant to drought. Second screening method employed was *in-vitro* screening techniques based on seedling survivability under hydroponics conditions. This technique involves drought treatment to V3 stage seedlings (third unrolled leaf stage) and genotypes were classified into different groups based on seedling survivability. Hydroponics based seedling survivability method for drought tolerance in soybean was standardized and same method was used to screen 70 diverse germplasm lines. The genotypes HIMSO 1587, SL 46 and TGX1835-3E recorded more than 98% seedling survivability under hydroponics screening conditions and were identified as highly tolerant to drought. Results obtained from soil culture methods (seedling recovery and seedling non-recovery) under controlled conditions were in conformity with hydroponics.



Evaluation of soybean genotypes under hydroponics

1.4.2.3 Development of off-flavour and KTI-free soybean genotype

Lipoxygenase produced primarily by *Lox2* gene develops off flavor in soybean seeds. Through marker-assisted backcross breeding approach, null allele, *i.e*. *lox2* is being transferred from donor genotype (PI 596540) to Kunitz trypsin inhibitor (KTI)-free soybean lines. The plants in BC_2F_2 generation were subjected to gene-based marker assisted selection to identify plants homozygous for *kti* and *lox*. Identified plants will be subjected to field evalution.

1.4.2.4 Testing seed viability through accelerated ageing

Seeds of good and poor storing soybean genotypes along with their $F_{2:3}$ seeds were subjected to accelerated ageing test. Germination and vigour indices were considered to classify the seeds as good and poor in storability. The conditions of accelerated ageing were optimized at 41±1^{0}C in 100% relative humidity for 72 h. Genotypes with high viability had good germination (%), more normal seedling and high vigour index I and II.

Genotypes with poor vigour index after accelerated ageing test

1.4.2.5 Inheritance of drought tolerance in soybean at seedling stage

Crosses were made between two tolerant (PK 1180 and SL 46) and two susceptible (UPSL 298 and PK 1169) germplasm lines. F_1 plants were selfed to raise F_2 progeny. F_2 plants at V3 stage were screened for seedling survivability. Segregation analysis of F_2 population derived from a cross PK 1180 x UPSL 298 has shown a goodness of fit to 3 tolerant: 1 susceptible with probability of 0.992 at $\chi 2$ (3:1) value of 0.015 under hydroponics. The results were confirmed in another F_2 population derived from a cross PK 1169 x SL 46.

1.4.2.6 Mapping of drought tolerance in soybean at seedling stage

The results obtained from single marker analysis have shown that the marker *Satt277* is linked to drought tolerance at seedling stage.The marker has shown a goodness of fit to 3:1 ratio in the F_2 population by $\chi 2$ tests. Linkage analysis indicated that marker *Satt277* linked to drought tolerance was located on chromosome 6. The genetic distance between the marker (*Satt277*) and tolerance gene is 3.2 cM.

1.5 SEED SCIENCE AND TECHNOLOGY

1.5.1 Studies on seed quality traits

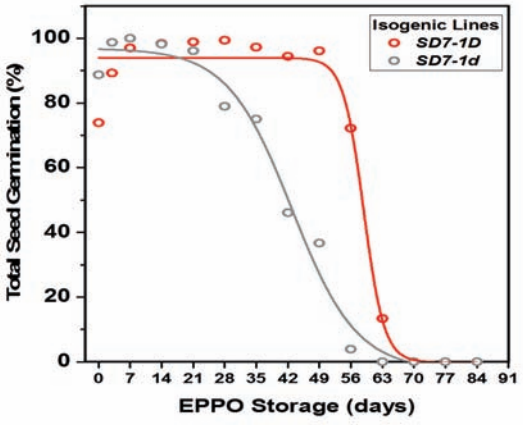
1.5.1.1 Seed vigour evaluation in rice hybrids and its parental lines

Three released rice hybrids and their parental lines were assessed for physical, physiological, biochemical and molecular traits related to seed vigour. Significant differences were found among the three rice hybrids and their parental lines for 100-seed weight, weight of kernel, husk, endosperm and embryo and a positive association with germination (%), seed vigour index-I and seed vigour index-II. Electrical conductivity (EC) was negatively correlated with germination (%), seed vigour index-I and seed vigour index-II among all the genotypes and lower EC and water soluble sugar values recorded in all three hybrids as compared to its respective parental lines. Higher activity of ROS scavenging enzymes such as CAT, POD and SOD in hybrids was measured as compared to their parental lines. There was a significant positive correlation between standard seed vigour parameters and seedling emergence and vigour parameters estimated at 10th and 20th day under field pot conditions. The study showed heterosis for some seed physical, physiological and biochemical traits in rice hybrids and validated seed vigour QTLs presence in the rice hybrids.

1.5.1.2 GWAS identified *Rc* gene having major role in rice seed longevity under dry storage conditions

Seed deterioration during storage results in reduced seedling vigour and poor emergence. The rate of ageing depends on storage conditions (RH, temperature and oxygen) and genetic factors. In rice, seeds stored under dry conditions may take months to show symptoms of ageing, so quick moist ageing (CD/AA) tests are used to estimate longevity

parameters. However, the results of these tests often show poor correlation with long-term storage under dry conditions. This is mainly due to differences in the physiology of seeds at a different water activity (*aw*) under these two ageing conditions. Here, we investigated genetic variation in the seed subjected to dry elevated partial pressure of oxygen (EPPO) ageing (21 days at 35°C) for 300 *Indica* rice accessions. A wide range of genotypic variation was observed for germination parameters after ageing. A 1M-SNP dataset was screened for marker-trait associations using a linear mixed model accounting for population structure. Association analysis yielded eleven unique loci across the genome for all measured longevity parameters by applying a significance threshold of P<0.00001. The significant SNP on the most reliable locus (L7) was located within the *Rc* gene, a *b*HLH transcription factor (TF), regulating pro-anthocyanidin (PAs) synthesis in seeds. Further, storage experiments using isogenic lines (*SD7-1D* and *SD7-1d*) with the same genetic background confirmed the functional role of *Rc* gene conferring tolerance to dry EPPO ageing. Functional *Rc* gene results in accumulation of PAs in the pericarp of rice seeds, an important sub-class of flavonoids, have strong antioxidant activity, which may explain why genotypes with an allelic variation for this gene show variation in seed tolerance to dry EPPO ageing. In summary, our experiments with dry EPPO ageing and subsequent GWA analysis identified seed longevity loci which differ from loci previously identified in rice under moist deterioration conditions.



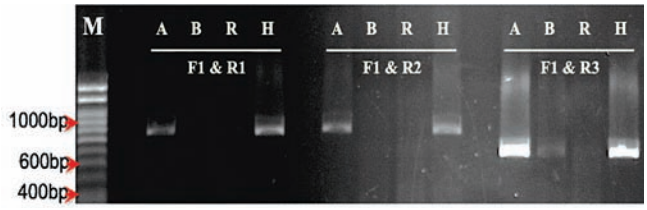
Comparison of survival curves obtained with seeds of isogenic lines (SD7-1D and SD7-1d) stored under dry-EPPO ageing conditions

1.5.1.3 Early seed vigour in rice

Microarray data obtained from dry mature rice seeds of three rice genotypes with the contrasting phenotype for speed of germination was subjected to MapMan analysis to better deduce the reasons for differential response of the rice genotypes for the speed of germination *per se*. It was found that early germinating genotype is well equipped with the transcripts of regulatory pathways like transcription factors, protein modification, protein degradation, hormonal balance, cell redox potential, calcium regulation, Map kinases, receptor kinases and G proteins.

1.5.1.4 Genetic purity evaluation in CMS line of pearl millet

SCAR markers (SCAR1, SCAR2 and SCAR3) were developed for evaluating the genetic purity of A-line against the B-line admixtures in pearl millet genotypes with A_1 cytoplasm .



A-line specific SCAR markers developed for ensuring the purity of A-line against the B-line admixtures in pearl millet genotypes with A1 cytoplasm

1.5.1.5 Seed dormancy in mungbean

Studies were taken up to understand the resistance to pre-harvest sprouting in mungbean cultivars. Initially 106 mungbean genotypes were characterized for pod and seed characters and then screened using standardized pod germination and standard seed germination methods. 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 hardseededness except the roundness of seeds. Significant negative correlation was observed between hardseededness and seed size characters as well as 100-seed weight (-0.37). Considering both pod and seed characters, six promising cultivars with

contrasting resistance to pre-harvest sprouting (seed dormancy) were identified and were further studied for their seed water absorption. 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.

1.5.1.6 Biochemical assessment in relation to hard seed in mungbean

One dormant (D) (TM 96-25) and one non dormant (ND) (Pusa 1331) genotypes were selected for biochemical studies of dormancy development in four different stages of seed development. The seed viability at stage 3, *i.e.* approx. 26 days after anthesis (DAA) is similar in both D and ND genotypes but later the germination percentage was reduced in D type due to hardseededness. The proanthocynadin content and seed coat permeability were studied using different staining methods. No role of proanthocynadins in mungbean dormancy was found. There is an increase in the lignin content and peroxidase activity in the stage 4 of D type compared to ND, indicating the role of lignin in the mungbean dormancy.

1.5.1.7 Seed dormancy behavior in Indian mustard and storability potential of conventional and quality mustard genotypes

Seed dormancy behaviour was evaluated in conventional and quality Indian mustard and some of the quality genotypes showed dormancy. Among various dormancy breaking protocols prechilling was found to be more effective. The antioxidant enzymes involved in ascorbate-glutathione cycle *viz*., ascorbate peroxidase (APX), dehydroascorbate reductase (DHAR), monodehydroascorbate reductase (MDHAR), and glutathione reductase (GR) were studied in conventional and quality Indian mustard. Significant differences were found in different types of mustard with respect to these enzymes. Conventional and quality Indian mustard varieties were assessed for superoxide and hydrogen peroxide content in the seeds. It was found that double zero genotypes had significant high content of superoxide radical compared to single zero and conventional genotypes. The superoxide radical was found to be negatively correlated with seed vigour indices.

1.5.1.8 Morphological, physiological and molecular traits associated with seed vigour and longevity in soybean

Eighty eight soybean genotypes were characterized on the basis of 36 descriptors comprising various plant, leaf, flower and seed traits. Variability was observed for growth habit, 50% days to flowering, growth type, plant height and shattering behavior. Promising genotypes were selected on the basis of good plant vigour and disease resistance. Distinct classes could be made on the basis of plant and seed vigour; high vigour and low vigour groups were represented by EC 39098, IC 90755, PLSO 6A; and CAT 582, CAT 356, IC 317660, respectively. Range of germination was 83-95% for high vigour genotypes and 75-85% for low vigour genotypes.

1.5.2 Studies on seed priming

1.5.2.1 Priming technologies for enhancing planting value in specialty maize under sub-optimal temperature conditions

Sub optimum temperatures had severe effect on seed germination and field performance of specialty maize. QPM and sweet corn genotypes were most sensitive to sub-optimum conditions. Among treatments seed hydropriming (17h/25^{O}C) followed by dry dressing with Thiram, halopriming with KNO_3 @ 0.3%, $ZnSO_4$ @ 0.3% + $MnSO_4$ @ 0.5%, bio-priming with *T. harzianum* and drought alleviating bacteria along with Bio phos were significantly better in improving seed germination, vigour and field stand under sub-optimum conditions in specialty maize.

1.5.2.2 Effect of priming treatments on pigeonpea under temperature stress conditions

Eight priming treatments standardized for sub-optimal conditions were given to seeds of two varieties of pigeonpea, *i.e.* Pusa 991 and Pusa 992 and sown in three different sowing dates. Significant differences for various seed quality, field emergence and yield

attributing traits among the varieties and sowing time were observed. Priming treatments had significant effect on first count (%), germination (%), vigour index II, mean emergence time, plant height (cm) and seed yield/plant (g) of pigeonpea varieties under different sowings dates/temperature conditions. Seed yield in both the varieties significantly decreased with delay of sowings, however, the exposure of seeds for 24 h at 40°C resulted in highest seed yield/plant under temperature stress conditions, which was at par with seed exposure for 6 h at 40°C treatment. Exposure of seeds for 24 h at 40°C enhanced seed yield/plant up to 2.8% in cv. Pusa 991 and 2.2% in Pusa 992 in comparison to control under different temperature conditions. Under laboratory conditions, haloprimed seeds when tested under salt stress conditions (6EC) resulted in significantly higher vigour index II over control.

1.5.2.3 Effect of priming treatments on soybean under temperature stress conditions

Five priming treatments: T1- Control (untreated), T2- Hydropriming (4 h at 25°C), T3- Exposure for 1 h at 40°C, T4- Osmopriming (6h at 25°C in 60% PEG 6000) and T5- Halopriming with Salt (4h in 4 EC solution) standardized for sub-optimal conditions were given to seeds of two soybean varieties *i.e.*; Pusa 9752 and JS 335 and sown in three different sowing dates. No plants were established, except few in T3, because of continuous rains during first two sowings. Data from the third sowing revealed significant differences between the varieties for plant height, numbers of pods/plant, and seed yield/plant. The planting value of soybean seeds was found significantly affected by the priming treatments when sown at 36^0C. Significant decrease in mean emergence time and improvement over control in field emergence (%), plant stand establishment (%) and plant height (cm) was observed in seeds exposed to 40°C for 1 h.

1.5.3 Technologies for mitigating biotic and abiotic stresses

1.5.3.1 Mitigating effect of elevated temperatures on seed set, yield and quality in wheat

Five mitigation treatments, *viz.* glycine betaine (600 ppm), salicylic acid (200 ppm), ascorbic acid (10 ppm), KCl (1%) and citric acid (1.5 %) were evaluated on two wheat varieties, *viz*. HD3117 (late sown) and HD 3171 (timely sown). Phenology of wheat crop was significantly affected by higher temperature. The overall trend across various sprays revealed that plant height and number of tillers showed a declining trend as the sowing was delayed from November to January, irrespective of the chemical sprayed. Two characters *viz*., 1000-seed weight and germination percentage were affected significantly due to heat stress. Glycine betaine (600 ppm) followed by salicylic acid (200 ppm) were most effective in mitigating adverse effects of heat stress.

1.5.3.2 Seed transmission of a distinct soybean yellow mottle mosaic virus strain in natural (*Vigna radiata*) and experimental (*Phaseolus vulgaris*) hosts

As the modes of transmission of soybean yellow mottle mosaic virus (SYMMV) has not been described, we assessed the possibility of SYMMV to be transmitted through seed collected from field infected mungbean plants and mechanically sap inoculated French bean plants using serological and molecular techniques followed by progeny assays. Direct antigen coated enzyme linked immunosorbent assay (DAC-ELISA) and reverse transcription polymerase chain reaction (RT-PCR) results are inconsistent with field infected mungbean seed tissues to confirm seed transmissibility, irrespective of seed number used. Seed from mechanical sap inoculated French bean showed higher absorbance values in DAC-ELISA and amplification corresponding to replicase, movement and coat protein regions of SYMMV genome. The relative accumulation of SYMMV assessed through quantitative RT-PCR (qRT-PCR) was higher in pod walls, immature seed and stamens and stigma of mechanical sap inoculated French bean plants. Progeny assays with infected seed revealed the seed transmissibility of SYMMV at the rate of 63.33% in mungbean and 73.33% in French bean. Mechanical sap inoculation of mungbean progeny seedlings on French bean cv. Pusa Parvati produced characteristic symptoms of SYMMV. The results obtained from this study demonstrate that SYMMV is seed borne in nature and can be transmitted to next generation seedlings.

1.6 SEED PRODUCTION

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

Seed production of different crop varieties of IARI

Seed Production (t)				
Crop group	**Nucleus Seed**	**Breeder Seed**	**IARI Seed**	**Total Seed**
Seed Production Unit IARI, New Delhi				
Cereals	3.35	149.76	283.97	437.08
Pulses	0.6116	5.321	16.4804	22.413
Oilseeds	0.141	3.241	9.052	12.434
Others				
Sub total	**4.1026**	**158.322**	**309.5024**	**471.927**
Regional Station, Karnal				
Cereals	3.8	229.7	335.14	568.64
Pulses		1.14	0.24	1.38
Oilseeds	0.01	1.71	0.44	2.16
Others	0.03	0.55	1.35	1.93
Sub total	**3.84**	**233.1**	**337.17**	**574.11**
Regional Station, Indore				
Cereals		202.9		202.9
Sub total		**202.9**		**202.9**
Regional Station, Pusa, Bihar				
Cereals		117.931	115.172	233.103
Pulses		0.075	7.65	7.725
Oilseeds			0.559	0.559
Others (Tobacco)			0.58	0.58
Sub total		**118.006**	**123.961**	**241.967**
Total	**7.943**	**712.330**	**770.633**	**Grand Total = 1490.904**

2. HORTICULTURAL SCIENCES

There has been record increase in area and production under horticultural crops since 2013-2014. This trend indicates healthy sign in country's march ahead towards nutritional security, besides its role in food 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 by Central Sub-Committee on Crop Standard, Notification and Release of Varieties for Horticultural Crops: Two F_1 hybrids one each in bitter gourd cv. Pusa Hybrid-4 (DBGH-12), sponge gourd cv. Pusa Shrestha (DSGH-9) and fifteen varieties, *viz*. onion cv. Pusa Sona (Sel. 153-1), garden pea cv. Pusa Prabal (GP473), cowpea cv. Pusa Dharni (CP-55), dolichos bean cv. Pusa Garima (DB-10), brinjal cvs Pusa Safed Baingan-1 (Sel. 195), Pusa Hara Baingan-1 (G-190) and Pusa Oishiki (DBL-175), 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), Pusa Long Green (DC-83) and okra cv. Pusa Bhindi-5 (DOV-66) were notified.

Varieties identified by AICRP (VC). Pusa Gynoecious Cucumber Hybrid-18 (DGCH-18): Identified for release in the XXXVII AICRP (VC) Group Meeting and is recommended for cultivation in Zone I. It is the first tropical gynoecious based hybrid of cucumber with distinct earliness and desirable horticultural traits for spring summer and *kharif* season cultivation. Fruits

Fruits of DGCH-18

are attractive green with mild whitish-green stripes, 18-20 cm long having soft skin, crispy and tender flesh with average fruit weight 200-210 g. It is ready for first harvest in 40-45 days after sowing during spring-summer and *kharif* season. Average yield is 245.26 q/ha, which is 31% higher than National check (PCUCH-3).

Brinjal (DBPR-23): This variety was identified for release in the XXXVII AICRP (VC) Group Meeting for cultivation in Zone IV (Punjab, UP, Bihar, Jharkhand). It is an early variety suitable for growing in *Kharif* season. Fruits are round (15 cm length, 7.5 cm diameter), shiny purple with non-spiny green calyx and borne solitary. The average fruit weight is 250 g. The average yield is 410 q/ha with a potential yield of 580 q/ha.

Fruits of brinjal DBPR-23

2.1.1 Cole Crops

2.1.1.1 Cauliflower

Development of new promising materials: A total of 408 CMS based F_1 hybrids of early group cauliflower were evaluated during September-November maturity period. The promising hybrids were DCEH-2123, DCEH-20921, DCEH-312303 and DCEH-81508 for September month (>15.0 t/ha), DCEH-2171, DCEH-15267, DCEH 21571 and DCEH 15267 for October (20 t/ha) and DCEH 26715 and DCEH 22371 for November (25 t/ha) maturity. In mid-early group, 22 CMS based F_1 hybrids were evaluated and promising hybrids (>34 t/ha) were DCMEH-9313, DCMEH 9325, DCMEH 1093 and DCMEH-976 for November-December harvesting. Two F_1hybrids, namely (DCH 312397 and DCH 1527) of early group and DCMH 1544 and DCMH 8405 of mid-group were contributed in AICRP(VC).

Screening of ***germplasm for disease resistance:*** Screened 356 lines of cauliflower for Alternaria leaf spot (*Alternaria brassicicola*) and identified 18 as resistant, 106 moderate resistant, 139 moderate susceptible, 88 susceptible and 5 were highly susceptible. The resistant lines were Lawyana, vv17, AL-15, DC KP-18, SM, EC 16258 and DC-53. For downy mildew, 28 lines were found to be resistant, 76 moderate resistant, 62 moderate susceptible, 82 susceptible and 102 were highly susceptible. The resistant lines for downy mildew were BR-2, HR-12-4, SM, DC-KP-18, AL-15, DC-260-328, DC 395aa, DC-333, PCF-165, DC-405, DC SK-15, DC-1005, DC-476, PH-2-2, VV, KT-22, PC-1 and KT-22.

Genetics of mustard type green leaf colour in cauliflower: A natural mutant 'GPMT-101' in cauliflower has mustard type attractive green leaves for use as potential morphological marker. Its genetic investigation was attempted using F_2 population from crosses between wild type (*i.e.* normal cauliflower) genotypes (DC 23000, DC 85, DC-109, and Pusa Meghna) and mutant 'GPMT-101', which revealed that the green mustard type leaf in 'GPMT-101' is governed by a single recessive gene.

Genetics of downy mildew resistance: Downy mildew is major disease in mid-group and resistance to it was investigated in F_2 population from Pusa Sharad × BR-2 and Pusa Himjyoti × BR-161, which segregated into 170 (resistant): 46 (susceptible) and 156 (resistant): 52 (susceptible) and 172 (resistant): 65 (susceptible), respectively confirming the resistance is governed by a single dominant gene. Further, the 190 RILs from PHJ/PS x BR-2/BR-161/BR-207 segregated in 114 (resistant): 76 (susceptible) indicating selection bias towards resistance during RILs development.

Determination of glucosinolates in cauliflower: Glucosinolates were analysed in genotypes of white cauliflower (15), purple cauliflower (1) and broccoli (2) using HPLC. Three to six prominent, peaks were seen, which were for glucoerucin, sinigrin and progoitrin. Progoitrin, was detected in 10 white cauliflower genotypes ranging from 0.36 to 15.28 µmol/100 g, while sinigrin was in the range of 1.17 to 278.22 µmol/100 g. Maximum glucoerucin was in GPMT-1 (724.8 µmol/100 g). Popular varieties Pusa Sharad, Pusa Shukti and Pusa Paushja contained glucoerucin as 642.87, 162.73 and 157.97 µmol/100 g FW, respectively. Purple cauliflower and broccoli had higher content of progoitrin and sinigrin than their non-coloured counterparts, however, glucoerucin was less. GSLs showed significant heterosis over the parents in two F_1 crosses, *i.e.* BR-207 × Pusa Himjyoti and Pusa Paushja × Pusa Shukti.

Phenotypic screening of cauliflower advanced lines for resistance to Downy mildew: A total of 29 advanced breeding cauliflower lines were screened for resistance to downy mildew. Among these lines, DMR-2-0-7 (3-5-1-1 x DC-466 F_7), DMR-11-0-5 (309 x BR-2 x 309 BC_2F_6) and (CCM x DC-522, F_6) were found highly resistant.

2.1.1.2 Heading broccoli

Twenty lines of tropical broccoli were evaluated for earliness (November maturity), marketable head yield and horticultural traits and identified DC-Brocco-22 (14 t/ha) and DC-Brocco-15-4 (12 t/ha) and DC-Brocco-17-5 (11.5 t/ha). Furthermore, two promising lines Pusa Purple Broccoli-1 and DC-Brocco-13 were submitted for AICRP(VC) multi-location trial.

2.1.1.3 Cabbage

Two 'No-chill type' cabbage genotypes PA-1 and PA-2 were evaluated for earliness and head yield during October-November months. Of them, PA-2 was promising for head yield (22 t/ha) alongwith desirable head traits for November maturity, which was also advanced to AVT-I in AICRP(VC).

2.1.2 Cucurbitacious Crops

2.1.2.1 Cucumber

Identification of promising genotypes: Out of 32 selections evaluated, DC-39 and DC-43 showed consistently good performance with respect to fruit size, quality traits and yield (17.9 and 16.8 t/ha) showing an increase of 26.9 and 19.1%, respectively over national check Pant Khira-1 (14.1 t/ha). Gynoecious hybrids DGCH-31 and DGCH-40 yielded 24.3 and 25.9 t/ha, respectively as compared to national check Pant Sankar Khira (19.8 t/ha). A new gynoecious hybrid DGCH-64 was entered IET of ACRP (VC). Among the 12 gynoecious parthenocarpic pickling cucumber (gherkin) line sevaluated, DG-8 (Pusa Pickling Cucumber-8) was found most promising with an average fruit yield 84.9 t/ha (849 kg/ 100 m^2) during winter season (November-March) under low cost polyhouse, which is 19.2% superior over Annaxo. A natural variant, DC-48 with stay-green trait, extended shelf-life and other desirable horticultural traits was maintained and used in the breeding programme.

During *kharif* season 2019, 127 lines were screened for downy mildew resistance under natural and challenged inoculation conditions. Genotypes DC-77 (17.8 t/ha) and DC-70 (16.5 t/ha) showed highly resistant disease reaction against downy mildew besides having high yield, earliness and other desirable horticultural traits as compared to local resistant check Barsati (13.9 t/ha), Pharai Barsati (13.4 t/ha) and Panipat Local (14.7 t/ha). Out of 20 F_1 hybrids evaluated DCH-16 (19.5 t/ha) and DCH-19 (1.8.9 t/ha) were found most promising with high yield and tolerant to downy mildew disease.

Identification of Cucumis sativus var. hardwickii with ToLCNDV resistance: Among *C. sativus var. hardwickii* genotypes, three genotypes (H-6, H-9 and H-16) were found to be highly resistant to this viral disease with score of less than 2.5 in scale of 0-10. The genotype, H-16 was used to develop F_1 with three cultivated genotypes (Pusa Uday, Pusa Barkha and DC-43).

Identification of cucumber genotypes with resistance to downey mildew: One hundred and fifty four genotypes were evaluated for resistance to downey mildew caused by *Pseudoperenospora cubensis* both under natural field conditions and through artificial inoculation. The time of maximum disease appearance was September-November. Two genotypes, DC-70 and DC-77 showed good resistance under both conditions.

2.1.2.2. Bitter gourd

***Indentification of promising hybrids*:** Twenty eight hybrids were evaluated for yield and related traits and the three best performing F_1 hybrids for yield were S-2 × PA (DBGH-246; 30.33 t/ha), PDMGy-201 × PV (DBGH-163; 30.07 t/ha) and S-2 × PDM (28.19 t/ha).

***Promising selections*:** Six promising genotypes, namely, DBGS 06-21, DBGS 60-52, DBGS 52-46, DBGS 54-58, DBGS 03-23 and DBGS-57-55 were evaluated under station trial. Among them, DBGS 06-21 gave the highest yield (24.53 t/ha) followed by DBGS 60-52 (21.24 t/ha) under open field conditions. The fruits of

DBGS 06-21 are dark green, 15-20 cm long, 4.5-5.5 cm diameter with pointed tubercles, discontinuous ridges, and individual fruit weight 85-90 g. Two promising selections (DBGS 32-1 and DBGS 57) were found promising under polyhouse conditions and recorded fruit yield of 4.10 and 3.85 q/100 Sq.m with individual mean fruit weight of 95 and 120 g, respectively.

***Inheritance of fruit length*:** Inheritance of fruit length was investigated in the cross DBGS-2 × DBGS-34. The parents DBGS-2 and DBGS-54 had 26.64 & 12.60 cm long fruits, respectively; the parent DBGS-34 recorded fruit length of 5.75 cm, and hence, these crosses were found most suitable for genetic study of this trait. The mean fruit length in F_2 (10.87 cm) was in between the short fruit parent and mid parent, and the distribution skewed toward the short fruit parent (DBGS-34) illustrating that short fruit length is partially dominant over long fruit types.

Variation of fruit length in F_1 population of DBGS-2 x DBGS-54

2.1.2.3 Muskmelon

***Identification of promising genotypes*:** The most promising genotype DM-154 was identified for open-field cultivation during station trial (28 genotypes). In summer 2019 it yielded of 23.2 t/ha having green flesh and 11.9^{0}Brix TSS followed by DM-156 (22.7 t/ha, TSS 11.8^{0}Brix) and DM 193 (22.4 t/ha, TSS 11.6^{0}Brix) out of the 24 genotypes.

***Promising selection for protected cultivation*:** The new selection of specialty melon (C. *melo* var. *inodorous*) DHM-39 has been developed, which was evaluated for 3 years in polyhouse/net house during summer (Feb-May) and off-season (Sep-Nov.) First fruit gets ready for harvest in about 85 days after sowing. Its fruit is oblong with average weight of about 1.5 kg. The rind colour of fruit is golden-yellow with no sutures. Its shelf-life is very high and fruits can be stored at room temperature for 15-20 days they are fruit is non-slipping at maturity. Fruit flesh is thick, light orange, juicy and very crispy with no typical musky flavour and high sweetness with 13.8^{0}Brix TSS. Its average yield is 5.5 tonnes / 1000 m^2 under protected cultivation. Other promising lines are DHM-162 (5.3 t/1000 m^2 with green flesh & TSS 13.6^{0}Brix) & DHM-159 (4.8 t/1000 m^2) under protected cultivation.

Fruits of specialty melon genotype DHM-39

***Promising hybrids of muskmelon*:** Two new hybrids from *C. melo* var. *cantoupensis* group DMH-18 (26.2 t/ha, TSS 11.9^{0}Brix) and DMH-23 (23.0 t/ha, TSS 11.4^{0}Brix) were found most promising in station trial (36 hybrids). Two hybrids (DMH-5 and DMH-11) were promoted to AVT-II Hybrid Trial of AICRP (VC). Specialty melon hybrid DMH- 112 was found to be most promising with yield of 5.8 tonne/1000 m^2 followed by DMH-119 (5.6 tonne/1000 m^2) under nethouse during off-season cultivation from September to November.

***Inheritance of flesh colour and climacteric fruit ripening*:** The population developed from Pusa Madhuras (*C. melo* var. *cantaloupensis*) and DHM-159 (*C. melo* var. *inodorous*) was used to study inheritance pattern of flesh colour and climacteric behavior of fruits. It was found that two genes are responsible for

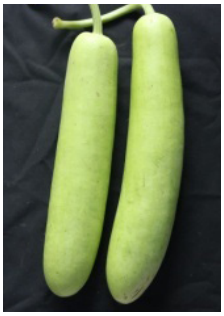
flesh colour and 12:3:1 ratio was observed, while non-climacteric ripening of fruit was found to be controlled by single dominant gene.

***Identification of source of resistance for* ToLCNDV *resistance*:** Eighty six genotypes from different horticultural groups of muskmelon were screened against *ToLCNDV* in field as well as net house during August to November. Two new sources of resistance (DSM-132 & DSM-19) were identified from *Cucumis melo* var. *momordica* germplasm. The most susceptible genotypes were DOM-118 (*C. melo* var. *conomon*) and Pusa Sarda (*C. melo* var. *inodorous*).

2.1.2.4 Bottlegourd

***Genotype identification for hybrid seed production*:** In order to develop morphological marker for hybrid testing to study the inheritance of segmented leaf shape in bottle gourd, genotype with normal leaf parents (Pusa Naveen) was crossed with genotype with segmented leaf parents (IC-5880840)(117). In F_2, leaf character segregated in a ratio of 3 segmented: 1 normal leaf plants (χ^2: 0.11; p value 0.64). When F_1 was back crossed with Pusa Naveen, the progenies were segregated in 1:1 pattern (χ^2: 0.45; p value 0.51), while in cross between F_1 and IC-588084, all progenies were having segmented leaf type. The result has indicted the dominant behavior of gene for segmented leaf. The character expressed even at first true leaf stage and hence can be used for identification of hybrid seed even at first true leaf stage.

***Evaluation of hybrid and varieties*:** During *kharif* 2019, 31 F_1 hybrids were evaluated out of which DBOGH-6 and DBOGH-12 were found promising with an average yield of 4.9 and 4.8 t/ha, respectively. Out of 27 single plant selections, DBOGV-225 and DBOGV-170 were found promising with an average yield of 3.8 and 3.5 t/ha, respectively as compared to Pusa Naveen (3.2 t/ha).



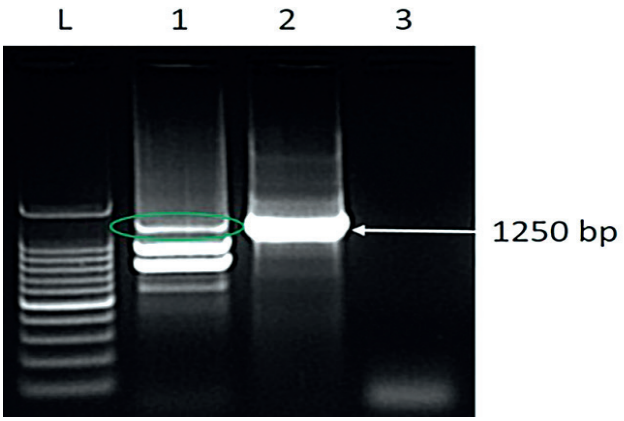
DBOGH-6

DBOGH-12

***Detection of phytoplasma in fasciated stem of bottle gourd*:** Existence of phytoplasma infection was suspected in fasciated stem of bottle gourd and was characterized using nested PCR with universal P1 and P7 primers gave the expected product of ~1800 bp, followed by nested PCR with R16F2n and R16R2 primers which gave an expected product of ~1250 bp.

Faciated stem in IC-588084

Normat Stem



Nested PCR of phytoplasma DNA amplification from bottle gourd with primer pair R16R2n/R16F2n
Lane M: Marker 100 bp DNA ladder, lane 1: fasciated stem tissue, lane 2: Positive control,lane 3: Negative control

2.1.2.5 Pumpkin

Promising genotypes: Fifty genotypes were evaluated for yield and yield related traits, out of which six, namely, DPU-14, DPU-26, DPU-41, DPU-54, DPU-58 and DPU-165 were found promising. The plants of DPU-

14 are medium viny with flattish-round fruits, medium ribs, orange flesh, average fruit weight 2.6 kg and with flesh thickness 2.7 cm. The fruits of DPU-41 and DPU-165 are flattish-round having average fruit weight of 2.0 and 1.5 kg and flesh thickness of 2.5 and 2.1 cm, respectively. Genotype DPU-26 had cylindrical fruits having average weight of 3.5 kg and flesh thickness of 3.5 cm. The genotypes DPU-41, DPU-43 and Narendra Upkar showed the field tolerance against begomovirus (*ToLCNDV*) and potyvirus (*PRSV*).

Pumpkin hybrid DPU-41 x Narendra Amrit

In order to improve carotenoids content and flesh quality, selections were made in F_2 segregating populations of pumpkin x butternut squash and butternut squash x pumpkin hybrids. Twenty five segregating generations (5 F_4, 6 F_5, 9 F_6, 5 F_7) were further advanced and promising individual plants were selected in each generation.

Promising hybrids: Thirty F_1 hybrids were developed and evaluated for yield and related traits in the spring-summer season. The best performing F_1 hybrids were DPU-41 x Narendra Amrit (av. fruit weight 3.78 kg, flesh thickness 3.4 cm), DPU-145 x Narendra Agrim (av. fruit weight 2.35 kg, flesh thickness 3.4 cm), DPU-145 x DPU-63 (average fruit weight 2.38 kg, flesh thickness 3.12 cm) and DPU 41 x DPU 45 (av. fruit weight 2.3 kg, flesh thickness 2.8 cm).

2.1.2.6 Luffa (Sponge gourd)

Development of promising selections and F_1 hybrids: Genotype DSG-33 was advanced to AVT-I of AICRP (VC). Out of 42 F_1 hybrids evaluated, DSGH-38 (17.1 t/ha) and DSGH-95 (16.8 t/ha) were found promising as compared to national check Kalyanpur Hari Chikni (12.3 t/ha). Another genotype DSGH-38 was entered in IET, while DSGH-95 was advanced to AVT-I of AICRP (VC) trial.

2.1.2.7 Ridge gourd

Out of 19 selections, DRG-7 having attractive green long fruit (35-40 cm) was found to be very promising showing an yield of 17.1 t/ha as compared to Pusa Nutan 16.3 t/ha was advanced to AVT-II of AICRP (VC) trial. Gynoecious F_1 hybrid DRGH-4 (18.3 t/ha) and DGRGH-8 (18.9 t/ha) were found promising and were advanced to AVT-II and AVT-I of AICRP (VC) trial, respectively. A new gynoecious based hybrid DRGGH-12 was entered in IET of AICRP (VC) trial. Twenty eight satputia (*Luffa hermaphrodita* (L.) Bhandari) lines were evaluated for yield and other traits. The line D-Sat-4 (Pusa Tripti) was found most promising having green superficial ribs, ready for first harvesting in 48-50 days and showed average fruit yield 15.5 t/ha, which was 35% superior over Kashi Khushi during spring summer season.

Fruits of Pusa Tripti

2.1.3 Solanaceous Crops

2.1.3.1 Brinjal

Promising varieties: Long fruited line DBPL-186-3-13-3 (dark pink, 40.89 t/ha) and round fruited line DBR-

99-3-12-3-4 (black purple, 49.87 t/ha) were found very promising for fruit yield over check.

Fruits of brinjal DBR-99-3-12-3-4

Promising hybrids. Out of 49 hybrid combinations, hybrids DBHR 0190 (shiny purple round with green calyx round, 70.47 t/ha), DBHL-129502 (purple long, 60.84 t/ha) were found to be superior over the check variety Navina (52.14 t/ha) and Pusa Hybrid-6 (38.74 t/ha).

2.1.3.2 Biotic Stress Tolerance

***Genetic analysis of Fusarium wilt resistance*:** The F_2 and backcross population from the cross of susceptible variety (Pusa Uttam) with resistant line (DBR-160-2-3-1-3) were phenotyped in sick plot for *Fusarium* wilt using root dip inoculation method. Out of the 210 F_2 plants, 164 plants were resistant and 46 plants were susceptible, which clearly segregated in 3: 1 (R:S) Mendelian ratio with χ^2 value of 1.073 (P = 0.03). This result suggests that wilt resistance is governed by single dominant gene.

***Screening for virus/ phytoplasma resistance*:** A total of 83 lines were screened for virus resistance. The infected and symptomless plants were examined under electron microscope. The results revealed the presence of PVY, PVX, Carla virus and phytoplasma in most of the lines. The line DB-65 was found to be resistant to all the virus and phytoplasma.

***Identification of novel heat tolerant lines*:** A total of 62 lines were evaluated for growth and yield traits at two growing season during summer season (March-July) and *kharif* season (July-November). Based on the finding, novel heat tolerant lines DBSR 44 (1.65 kg/ plant), DB 9 (2.65 kg/ plant), DBL 21 (3.68 kg/ plant) and DB 144 (2.12 kg/ plant), were identified which can give fruit at temperature higher that 40°C during May-June.

2.1.3.3 Tomato

Two promising entries for ToLCD resistance were nominated to AICRP (VC) ToLCV resistance (IET) trials. Two entries promising for ToLCD resistance were promoted to AICRP (VC) ToLCV resistance AVT-1 trials. The highest yielding hybrid was H-337 (60.3 t/ha; DSI score-0.1). Among these six F_1 combinations were found promising for resistance to ToLCD (DSI: 0.1) and high yield (> 60 t/ha). In multi-location trials at ICAR-IIVR, Varanasi and ICAR-IARI, New Delhi, 15 ToLCD resistant hybrids were evaluated. Using MAS approach marker- assisted backcross breeding (MABB), more than 55 advanced backcross lines (BC_1F_6) carrying ToLCD resistance have been developed. The *Ty-3* gene based lines were performing better for ToLCD resistance. Among these, six lines were promising for yield per plant (>7.0 kg). Under genetic enhancement of IARI released tomato varieties, segregating F_2 population of [PED x (15SB x LA1777)] x DT2020 (carrying *Ty-3* gene) were screened for ToLCD resistance under field conditions. Fifty germplasm accessions including wild relatives were augmented.

***Promising selection for protected cultivation*:** Ten hybrids along with a commercial hybrid GS-600 were evaluated under protected conditions. Hybrid DTPH-60 recorded total yield of 15.6 q/100 m^2 area, TSS 5.0°Brix and lycopene 5.8 mg/100 g FW with average fruit weight of 108 g. Hybrid DTPH-60 was also evaluated at farmer's field/ stations of various institutes and the performance was found very good. Eight cherry tomato selections were also evaluated and Sel.-1 recorded the average fruit yield of 10.0 q/100 m^2 area with of TSS 10.1°Brix.

2.1.3.4 Chilli

***Evaluation for heat tolerance*:** Station trial of chilli lines was carried out during summer season for high temperature tolerance. Genotypes DLS-161-1 and DLS-

10-2 performed well with a total yield of 9.0 and 10.5 t/ha, respectively. Genotype DLS-161-1 had cluster pendant fruits, light green colour at immature stage with a fruit length of 7-8 cm and fruit width of 0.8-1 cm. While, genotype DLS-10-2 had single erect fruit with medium green colour fruits, fruit length of 5-6 cm and fruit width of 0.7 to 1.0 cm fruit.

***Evaluation of promising breeding lines*:** Promising breeding lines for fruit yield and overall agronomic performance developed in previous years were evaluated in *kharif*, 2019. These included sixteen lines where DChV-5, DChV-13 and DChV-27 have been found promising giving total yield of 13, 11.5 and 9.8 t/ha in comparison to check varieties Kashi Anmol and LCA-334 with yields of 9.0 and 7.8 t/ha, respectively.

At Regional Station, Pune, 25 chilli lines procured from ICAR-NBPGR, New Delhi were planted under field conditions in *kharif* season for screening against viruses. Among these, IC EC777203 was found to be promising was most tolerant along with good yield. It had minimum number of thrips count/plant, medium plant height (40 cm), 20-25 fruits/plant, 12-15 cm fruit length, individual fruit weight (10-12 g) and per plant yield ranging from 100-110 g. The total soluble solids were estimated at 2.73^{0}Brix, while the vitamin C content was 18 mg/100 g at mature green stage.

Fruits of IC EC777203

2.1.3.5 Capsicum

Total 15 promising advance lines developed at Regional Station, Katrain were evaluated at IARI, New Delhi under nethouse conditions during November 2018-19. Out of these lines, KTC-131 was found to have fruit set at high temperature (40° day and 28°C night) during May. Lines KTC-130 and KTC-145-1 produced fruits of orange colour having good horticultural traits. The maximum fruit size (8.33 cm length and 5.5 cm width) was obtained in KTC-152 followed by Yolo Wonder (7.0 × 5.5 cm) and Hybrid 6-3 (6.16 × 6.23 cm). Maximum average fruit weight was produced in Hybrid- 6-3 (105 g) followed by KTC-145 (92.66 g) and KTC-130 (90.66 g). Among them KTC-145 (1,100 g/plant), KTC-142 (850 g/plant) and KTC-130 (800 g/plant) were found promising.

2.1.4 Root Crops

2.1.4.1 Carrot

Promising genotypes: Forty genotypes/ breeding lines during August end sowing were evaluated for quantitative and quality traits. Based on the quality for root shape, surface, external & internal colour and external appearance, the genotypes DCat-4, DCat-8, DCat-13 and DCat-122 were found promising. Fifty genotypes/ breeding lines were assessed for quantitative and quality traits. Based on the quality of root shape, surface, external & internal core colour and external appearance, the promising genotypes identified were DCat-122, DCat-98, DCat-13, DCat-36, DCat-7 and DCat-53 with average root weight of 148.3, 140.0, 140.0, 138.3, 136.7 and 135.0 g and root yield of 32.33, 30.80, 30.80, 30.43, 30.10 and 29.70 t/ha, respectively. Genotype DCat-76 recorded the highest harvest index (84.51%).

Promising hybrids: In normal season, 60 CMS based F_1 hybrids of tropical-subtropical carrot were assessed for quantitative and quality traits. Based on the quality for 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 and DCatH 734 with average root weight of 160.0, 158.3, 153.3, 151.7, 151.7 and 151.7 g, respectively. These hybrids recorded root yield of 35.20, 34.83, 33.73, 33.37, 33.37 and 33.37 t/ha, with heterosis of 33.33, 31.93, 27.77, 26.40, 26.40 and 26.40%

over standard check (Pusa Vasuda), respectively. Twenty four hybrids had self-core colour. The mean harvest index of the hybrids for ranged from 67.97 (DCatH 792) to 86.18% (DCatH 5396). The highest harvest index (86.18%) was observed in the hybrid DCatH 5396 followed by DCatH 9192 (85.76%) and DCatH 9100 (85.44%).

For biochemical traits, the best hybrids for TSS, fructose, juice recovery and total sugars were DCatH 792 (9.30°Brix), DCatH 792 (9.7% mass), DCatH 9854 (62.70%) and DCatH 9192 (16.90%), respectively. Similarly, for the quality traits namely, total carotenoids, lycopene, β-carotene, lutein and total antioxidant activity, the best performing hybrids were DCatH 5396 (75.57 µg/100 g FW), DCatH 9834 (43.76 µg/100 g FW), DCatH 5322 (18.65 µg/100 g FW), DCatH 5326 (1.47 µg/100 g FW) and DCatH 7126 (1.91 mg GAE/100 g FW), respectively. In temperate carrot, 13 F_1 hybrids from Katrain Station were evaluated at Delhi centre and promising hybrids identified were Kt-7 x NK, Kt-10 x KS-59 and Kt-28 x NK.

Roots of DCatH 5392 carrot

2.1.4.2 Onion

***Breeding for kharif onion*:** Development of bulbs is a major problem in *kharif* season due to high temperature and incessant rains. A total of 60 half-sib families were evaluated for bulb production during *kharif* season, where only 60, 48 half-sib families survived, these of 48 half-sib families, ten half-sib families produced more than 10% bulbs. The well-formed bulbs were harvested in December and planted again under open field conditions to complete another cycle of recurrent selection.

***Evaluation and development of selections*:** Forty two genotypes were evaluated for their marketable yield during *kharif* season. Genotypes, KP-41 consistently performed better for two successive years. The bulb of KP-41 (18.22 t/ha) and KP-62 (15.28 t/ha) were ready for harvesting by 15th November, while the other genotypes were by end of December. Some of the selections for *kharif* cultivation season are being carried out for the last 3 years and a white breeding line KH015 has been identified which formed very good bulbs. The bulbs are around 5-6 cm in diameter and the leaves are light green in colour.

***Breeding for bolting tolerance*:** Resistance to bolting was tested at two different transplanting dates. Based on the pooled results, five accessions were observed to be bolting tolerant out of 55 accessions. These accessions will be further screened for bolting resistance.

***Breeding for higher yield in garlic during rabi season*:** In garlic, 28 accessions were evaluated for yield and other horticultural traits. Genotype PG S207 recorded significantly higher yield (16.7 t/ha) followed by PGS 206 (15.9 t/ha), PG S204 (15.5 t/ha) and G 41 (14.3 t/ha). Lowest yield was recorded in G 50 (6.3 t/ha).

***Breeding for Stemphylium blight resistance*:** A total of 109 onion and allied species were screened for Stemphylium blight resistance. Based on the percent disease index (PDI), two *Allium* species, *viz*., leek (*A. ampeloprasum* L.) and chive (*A. schoenoprasum*) were found to be immune to Stemphylium blight. Four onion accessions were rated as moderately resistant, 60 were categorized under moderately susceptible, 35 accessions as susceptible and 8 accessions were categorized as highly susceptible.

2.1.5. Leguminous Crops

2.1.5.1 Garden pea

New genetic material with high yield and disease resistance. Evaluated 30 new bulks derived from F_6

generations breeding materials against 2 checks (Pusa Shree & Arkel). Among these, 16 lines were grouped as early maturity and 14 were medium maturity. The promising genotypes having attractive long green curved pods in early group (GP 1501 GP 1502, GP 1503, GP 1504, GP 1702, GP 1703, GP 1705, GP 1706 and in medium maturity (GP 1701, GP 1704, GP 1705-1, GP 1705-4, GP 1707, GP 1708, GP 1710, VP 445-9). The genotypes, GP 1101, GP 1102, and GP 1505 are under testing in AICRP (VC) trials.

Development of lines for wilt resistance: Thirty two germplasm and 94 crosses (39 F_2, 37 F_3, and 18 F_4) were evaluated in wilt sick plot for screening and selection. The genotypes GP 6, GP 17, GP 48, GP 55, GP 473, EC-414, EC 927769, and the 8 crosses VRP-6 x GP6, GP 438 x GP 473, 2011/PEV-3-1 x GP 48, GP 901 x Golden pod, GP 6 x G P55/ GP 55-2, GP 17 x 2011/PEV-2, GP 55 x 2011/PEV-2 and 2017/ PEV-5 x GP-17 were found resistant and were retained for further advancement.

Development of powdery mildew resistance lines: The genotypes found highly resistant to powdery mildew were GP 6, GP 473, GP 1001, GP 1101, GP 1102, GP 1501 GP 1502, and GP 1705. A genotype GP 6 has been found resistant to *Fusarium* wilt and powdery mildew both. These new bulks have been retained for further yield evaluation.

Screening of lines for heat tolerance and disease resistance: Thirty genotypes of were screened for high temperature tolerance to extend the fresh pod availability beyond mid-March in north Indian plains. The genotypes GP 55, GP 916, GP 473, GP 912-II, and VP 438-2, were found promising for pod setting at high temperature but there potential is yet to be explored further.

Novel sources of resistance for Fusarium wilt resistance: Total 50 *Pisum* accessions including alien species, *viz., P. 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 sick pots developed by inoculating four virulent *Fop* isolates during Oct-Nov 2019. On the basis of two year experiment (2018 and 2019), eight accessions were found highly resistant against all four virulent *Fop* isolates comprising of 2 of *P. fulvum* (N-3, N13), 1of *P. elatius* (M2), 4 of *P. sativum* var. *elatius* (N-6, N 8, N 11, N 14) and 1 of *P. sativum* (M 13).

***Development of Fusarium wilt resistant line through introgression using exotic lines*:** Cross combinations using exotic lines (10 F_1s) were advanced in F_2 and two F_2 cross combinations were advanced in F_3. The F_2 populations of the cross combinations, *viz*., Arkel × *P. sativum* var. *hortense* (M-13), Arkel × *P. sativum* var. *elatius* (N-8), VRP-5 × *P. sativum* var. *elatius* (N-12), and VRP-6 × *P. sativum var. elatius* were raised under sick pots for *Fusarium* wilt screening. The first back cross generation, *viz*., Pusa Pragati × M-9, Kashi Uday × M-9, Matar Ageta-7 × M-5, and Matar Ageta-7 × M-9 were raised and advanced.

2.1.6. Malvaceous Crops

2.1.6.1 Okra

Promising hybrids: Newly developed okra hybrids, DOH-3 and DOH-7 recorded pod yield of 27 and 25 t/ha, respectively and were superior in pod quality coupled with resistance to YVMV and ELCV and tolerant to leaf hopper. Among the evaluated lines, DOV-92, Dov-9 and DOV-69 were found free from Bhendi Yellow Vein Mosaic Virus (YVMV) and Enation Leaf Curl Virus (ELCV) with yield of 19.3, 18.5 and 18 t/ha, respectively. DOV-69 recorded fruiting at shorter internode (< 6 cm) with robust fruiting habit. DOV-10, DOV-77 and DOV-88 were short fruited type (5-6 cm fruit length). Red fruited genotypes (DOV-17 and DOV-18) recorded high anthocyanin content (402 and 473 mg/100 g, respectively) and were found moderately resistant to YVMV.

Red fruited line okra DOV-18

One okra hybrid DOH-2 was promoted in AVT-II and one variety DOV-9 was entered in IET trial during 2019. A genic male sterile (GMS) line was selected from segregating population of Arka Nikita. The maintainer will be identified and would be transferred in the background of 66 and 92.

Fruits and plants of promising okra hybrid (DOH-3): resistant to YVMV and ELCV diseases and tolerance to leaf hopper.

***Identification of superior large cardamom genotypes*:** Survey was conducted in different parts of Sikkim to identify superior genotypes based on their yield and fruit quality characteristics. Ten superior genotypes have been identified and tagged for further evaluation.

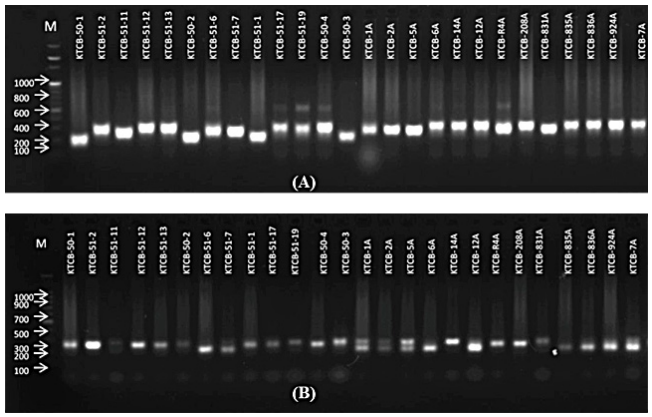
2.1.7 Temperate Vegetables

2.1.7.1 Cabbage

***Variety identified*:** A cabbage F_1 hybrid 'KTCBH-822' has been identified for release for Zone I (Humid Western Himalayan Region, *i.e.* Jammu & Kashmir, Himachal Pradesh and Uttarakhand) and Zone-VI (Arid Western Plains: Rajasthan, Gujarat, Haryana and Delhi) in the XXXVII Group Meeting of AICRP (VC) held at TNAU, Coimbatore during 22-25th June, 2019. The hybrid has dark green and waxy leaves, flat and very compact head covered with outer leaf. It matures in 70-75 days after transplanting and has very good field staying capacity after head formation. It has field tolerance to black rot disease. Average yield recorded in multi-location trials is 41.4 t/ha.

Cabbage F_1 hybrid 'KTCBH-822'

***Morphological and molecular characterization of 'Ogura' based CMS and DH lines*:** With the aim to select diverse parents for F_1 hybrid breeding, 26 cabbage genotypes (13 CMS and 13 DH) were subjected to molecular diversity analyses using 52 SSR markers. Out of which 26 primers were found highly polymorphic and were found useful to differentiate different genotypes under study. Based on the results of molecular characterization, the most divergent parents representing both CMS (KTCB-1A, KTCB-5A, KTCB-6A, KTCB-208A, KTCB-831A, KTCB-836A) and DH (KTCB-50-1, KTCB-50-3, KTCB-51-2, KTCB-51-19, KTCB-51-6) genotypes were selected for their further use in F_1 hybrid breeding. Furthermore, wide variations were observed among the selected CMS (6) and DH (5) genotypes for different qualitative and quantitative traits under study. Based on the mean performance for different quantitative traits, three CMS lines, *viz.*, KTCB-836A, KTCB-5A and KTCB-6A and two DH genotypes, *viz.*, KTCB-50-1 and KTCB-51-19 were found superior, which can be utilized in future heterosis breeding programmes.



PCR amplification profile of 26 genotypes of cabbage using SSR primer (A) BoSF062 and (B) BoSF1167; where, M = Molecular size marker (1 Kb ladder). Molecular sizes (in bp) are given on left

***Evaluation of inbred CMS and DH parental line-based hybrids*:** During the year 2018-19, 30 F_1 hybrids along with one standard check (Pusa Hybrid-81) were evaluated for different qualitative and quantitative

KTCB-1A × KTCB-50-1

KTCB-836A × KTCB-51-19

KTCB-836A × KTCB-51-2

Promising inbred CMS and DH parental line based cabbage hybrids

traits. Based on the mean performance for yield per hectare, six cross combinations, *viz*. KTCB-1A × KTCB-50-1 (586.82 q), KTCB-836A × KTCB-51-19 (568.93 q), KTCB-836A × KTCB-51-2 (557.27 q), KTCB-836A × KTCB-50-3 (527.90 q), KTCB-836A × KTCB-51-6 (517.08 q) and KTCB-836A × KTCB-50-1 (513.06 q) were found superior than the check cultivar (405.93 q). Hence, these hybrid combinations can further be tested at multi-locations before releasing as a substitute of the already existing cabbage hybrid varieties.

***Evaluation of F_1 seed yielding ability of 'Ogura'* based *CMS lines*:** The hybrid seed yielding ability of 10 '*Ogura*' based CMS lines were tested by crossing them with a common tester, *i.e.*, Golden Acre. Significant differences were obtained among the different CMS lines for seed yield per plant (g). the highest seed yield per plant was recorded by the CMS line KTCB-12A (32.07 g), which was found statistically *at par* with KTCB-83-1A (30.11 g) and KTCB-1A (29.73 g). While, lowest seed yield (13.33 g) was observed in the line KTCB-R6A followed by KTCB-R2A (15.17 g) and KTCB-R7A (15.33 g). Hence, keeping in view the commercial feasibility for hybrid seed production, CMS lines with higher seed setting can be used for F_1 hybrid development.

Entries contributed in AICRP (VC) trials: Two open-pollinated genotypes of red cabbage (KTCBR-3 and KTCBR-5) were contributed in AICRP (VC) IET trial during the year 2019. Besides this, two entries of open pollinated white cabbage (KTCB-52 and KTCB-121) were advanced to AVT-1 trial under AICRP (VC).

Introgression of* Diplotaxis catholica *and* Trachystoma *ballii male sterile cytoplasm: During summer season of 2019, BC_5 and BC_6 populations for the introgression of *Diplotaxis catholica* and *Trachystoma ballii* male sterile cytoplasms were developed into cabbage background through backcrossing and embryo rescue technique.

Introgression of β-carotene rich 'Or' gene into cabbage and broccoli: BC_2 populations of the introgressed β-carotene rich '*Or*' gene in cabbage (S 831) and broccoli (Pusa Broccoli KTS-1) were developed during summer, 2019 and are still under evaluation. The desired plants will be advanced to next generation through marker-assisted backcross selection.

2.1.7.2 Snowball cauliflower

Variety identified: One cauliflower F_1 hybrid, KTH-301 has been identified for commercial cultivation in XXXVII Group Meeting of AICRP (VC) held at TNAU, Coimbatore. This is the first CMS based F_1 hybrid in the mid-late group of cauliflower developed by Indian

Cauliflower F_1 hybrid 'KTH-301'

MD-19
(Creamy white compact curds)

MD-201
(Creamy white semi-compact curds)

DCH-8476/1476
(White compact curds

Promising CMS based hybrids of mid-season cauliflower

public sector. It was recommended for cultivation in the Zone I [Humid Western Himalayan Region, *i.e.* Jammu & Kashmir, Himachal Pradesh and Uttarakhand] and Zone-VI (Arid Western Plains: Rajasthan, Gujarat, Haryana and Delhi). This hybrid is suitable for cultivation in the mid-season with the harvesting of curd in the month of November-December. It has very compact white curd with average curd weight of 1.04 kg and average yield of 39.5 t/ha.

Evaluation of mid-season hybrids: Thirty CMS based hybrids of mid-season cauliflower received form ICAR-IARI, New Delhi were evaluated at Regional Station, Katrain, of which marketable yield of five hybrids,*viz.*, MD-19 (23.43 t/ha), MD-201 (21.24 t/ha), DCH-8476/1476 (21.12 t/ha), PSH DCH-8409 (20.57 t/ha) and DCH-8402 (14.80 t/ha) were found superior than the check cultivar PH-2 (11.22 t/ha). All these hybrids matured in the last week of December and had compact/ semi-compact white/ creamy-white attractive curds.

Entries contributed in AICRP (VC) trials: During the year 2019, two open-pollinated genotypes (KTCF-30 and KTCF-33) and two CMS based hybrids of mid-season (KTCF-23 and KTCF-40) cauliflower were contributed in AICRP (VC) IET trials. Besides this, three entries of open-pollinated mid-season genotype were advanced to AVT-1 (KTCF-2 & KTCF-4) and AVT-II (KT-37) trials under AICRP (VC).

Introgression of Diplotaxis catholica and Trachystoma ballii male sterile cytoplasm: During summer season of 2019, BC_5 and BC_6 populations were developed for the introgression of *D. catholica* and *T. ballii* male sterile cytoplasms into snowball cauliflower background through backcrossing and embryo rescue technique.

Introgression of β-carotene rich 'Or' and anthocyanin rich 'Pr' genes: BC_2 population of the introgressed β-carotene (*Or* gene) and anthocyanin (*Pr* gene) rich genes into 10 genotypes were developed during summer, 2019 and is still under evaluation. The desired plants will be advanced to next generation through marker-assisted backcross selection.

Introgression of fertility restorer gene (Rfo) into B. oleracea through inter-specific hybridization: The BC_1 population of introgressed fertility restorer gene (*Rfo*) into different genotypes of *B. oleracea* (cauliflower and cabbage) was screened with the help of fertility restorer gene specific SSR markers. The BC_1 plants carrying *Rfo* gene would be then backcrossed with their respective recurrent parents to get BC_2 progenies.

2.1.7.3 Capsicum

Variety identified KTC-1: Was identified and recommended in XXXVII Group Meeting of AICRP(VC) held at TNAU, Coimbatore during 22-25th June, 2019 for Zone-I. It is an early maturing (62 days) open-pollinated variety of capsicum developed by ICAR-IARI Regional Station, Katrain through pureline selection. The plants are medium statured (45.0 cm) and bear 6 fruits (av.) per plant with average fruit weight of 70 g. The fruit colour at marketable maturity is green and it turns to yellow at seed maturity. This variety is moderately resistant to phytophthora fruit rot and leaf bight diseases and yields about 20.2 t/ha in field conditions.

Fruits of capsicum variety 'KTC-1'

Hybrid evaluation: Fifty-three hybrids were evaluated for yield and quality traits. Among them, KTCH-13 (28.81 t/ha) followed by KTCH-48 (28.23 t/ha) and KTCH-23 (27.97 t/ha) were found most promising based on yield and fruit quality traits (shape, size and colour).

Transfer of fertility restorer gene: The BC_1 population of the introgressed fertility restorer gene into 10 genotypes was developed during the year 2019. During this year, it will be advanced to next generation by backcrossing with their respective recurrent parent.

2.1.8 Root and Bulbous crops

2.1.8.1 Temperate carrot

Hybrid evaluation: Ninety nine F_1 hybrids of temperate carrot developed by using 10 CMS lines were evaluated for yield and other horticultural traits against Pusa Nayanjyoti as check. A total of 6 hybrids out yielded the check cultivar (22.8 t/ha). Hybrid KT-98-2-A × NK recorded the highest yield of 30.8 t/ha followed by KT-98-2-A × IC-537826 (28.1 t/ha), KT-98-2-A × KS-33 (25.9 t/ha), KT-1-A × IC-593950 (23.5 t/ha) and KT-98-1-A × NK (24.1 t/ha).

Entries in AICRP (VC) trials: Two open-pollinated varieties, *viz*., KTTC-50 and KTTC-59 were contributed to IET during 2019 for testing under AICRP (VC) trials.

2.2 FRUIT CROPS

2.2.1 Mango

Evaluation of hybrids and germplasm: Mango hybrids (104) belonging to different cross combinations and germplasm (10) were evaluated for 23 physico-chemical traits. Among mango F_1 hybrids from Amrapali and Sensation cross, the maximum fruit weight was noted in H-11-2 (276.8 g) followed by H-1-11 (262.8 g), H-4-2 (26.6 g), H-1-5 (253.6 g), H-1-1 (232.3 g), H-3-2 (224.2 g), H-3-4 (207.2 g), NH-3-2 (202.1 g), and H-12-3 (200.6 g). Fruits of H-11-2, H-17-3, H-1-1, H-1-6, H-12-1, H-12-6, H-17-4, H-18-4, H-19-2, H-1-3 and H-8-11 had red colouration on the shoulder. The maximum total soluble solids (27.7°Brix) was estimated in H-3-14 followed by H-16-3 (27.0°Brix), while minimum was in NH-5-2 (14.4°Brix). The maximum pulp content (74.0%) was found in H-1-5 followed by H-1-3 (73.3%), H-4-8 (71.2%), H-1-14 (70.6%) and H-11-2 (69.8%). The colour coordinates were examined using Hunter Colour meter and blush on fruit shoulder was observed. The maximum '*L*' value was in H-12-7 (62.73), a value in H-1-1 (36.65), '*b*' value in H-9-8 (59.96). The pulp colour in mango hybrids indicated significant variation and maximum '*L*' value was noted in NH-7-1 (59.42), '*a*' value in NH-8-1 (38.95) and '*b*' value in H-11-3 (74.81). Hybrid 8-11 (Amrapali x Lal Sundari) showed field tolerance for floral mango malformation (10.5%).

Bearing tree of mango hybrid H-11-23-2

Among exotic mango germplasm, Eldon had the maximum fruit weight (295.0 g) followed by Primor-de-Amoreria (263.4 g) and Tommy Atkins (247.7 g).

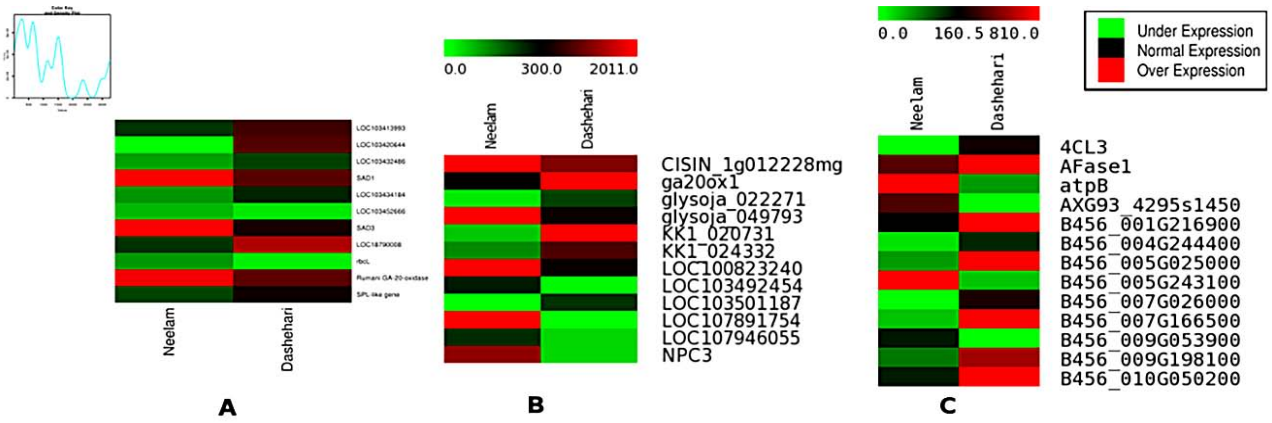
However, the minimum fruit weight was noted in Willard (80.4 g). These exotic germplasm had moderate TSS compared to indigenous germplasm. Among indigenous germplasm, Vanraj bore the biggest fruit (375.4 g) followed by Totapari (280.0 g). However, the minimum fruit weight was observed in Illaichi (50.35 g).

Polymophism studies using Novel Hyper Variable SSRs: A genome wide set of 114 hyper-variable mango SSR markers were screened and validated against a set of 24 diverse mango germplasm. Out of 114, 84 MSSRs were found to be polymorphic, 18 HMSSRs were monomorphic. However, 12 MSSRs could not be validated in the present set of mango genotypes as they did not amplify. Similarly, a set of 115 MSSRs were screened for polymorphism between parental mango genotypes, namely, Amrapali and Sensation. Out of which, 52 showed polymorphism among parental mango genotypes. These polymorphic SSRs have been further used for ascertaining the hybridity of progenies obtained from cross of Amrapali x Sensation. Total 94 hybrid progenies have been tested with polymorphic SSRs. SSR primer M109 (90.6%), M15 (89.5%) and M17 (84.3%) ascertained the hybridity of more than 84% of the progenies. These SSRs were found to be useful in establishing the parentage of progenies obtained by crossing of Amrapali and Sensation genotypes. These reliable SSRs having capability to ascertain the hybridity of progenies would be further used in screening of open-pollinated seedling in mango improvement programmes.

Functional and metabolic pathway analysis of the unigenes in regular (Neelum) and irregular (Dashehari) varieties: Functional and metabolic pathway analysis of the unigenes were studied in regular (Neelum) and irregular (Dashehari) mango varieties to understand alternate bearing in mango (*Mangifera indica* L.). Genes for various pathways like flowering, hormone, metabolic, alternate bearing *etc*. were extracted from the final annotation. Maximum numbers of genes were involved in metabolic process (1520). Whereas, minimum number of genes (5) were presented in flowering pathway (Table 1). Alternate bearing genes, *viz*., *SAD*1, *SAD*3 and *Rumani GA* 20 *oxidase* were up-regulated in mango variety Neelum. Whereas, *SPL* like gene was less accumulated in Neelum. Gene *ga20ox 1* and *KK1 020731* showed up-regulation in Dashehari. Whereas some other genes like *glysoja 049793* and *LOC100823240* were more expressed in Neelum. Moreover, gene related with metabolism also plays an important role in regulation of flowering. Some major genes like 4*CL*3, *B456-004G244400*, *B456-007G026000* were less accumulated in Neelam and showed steady expression in Dashehari. Whereas, gene *B456-009G053900* was less expressed in Dashehari. Only single gene, namely, *gbGBVW01004309.1* related with flowering showed differential expression in both the varieties.

Pathway statistics for differentially expressed genes in regular (Neelum) and irregular (Dashehari) bearing mango varieties

Pathway type	Total genes annotated	No. of up-regulated genes	No. of down-regulated genes	Differentially expressed genes (log2FC) annotated	Significant genes (pval< 0.05) annotated	Differentially expressed significant genes annotated (log2FC and pval<0.05)
Cellular component	15	0	5	5	9	5
Flowering	5	0	1	1	2	1
Hormones	199	20	34	54	111	54
Meristem	8	1	1	2	6	2
Metabolic process	1520	248	276	524	960	523
Oxidative stress	72	8	22	30	50	30
Oxidoreductase	838	146	188	334	572	334
Starvation	27	5	10	15	19	15
Alternate bearing	26	3	0	3	16	3



Differential gene expression pathways for various components using Heat Map. Pathways heat map for each class, illustrating the gene expression is shown separately A. Alternate bearing. B. Hormonal. and C. Metabolic.

2.2.2 Citrus

Evaluation of scion hybrids: Twenty citrus scion hybrids (pummelo x sweet orange) have been assessed for their growth, yield and fruit quality parameters. Hybrids SCSH-5-10/12, SCSH-9-10/12, SCSH-11-11/12 and SCSH-11-15/12 were found promising with respect to moderate fruit size, higher juice content and lower acidity. Fruit weight varied from 311.67 g (SCSH-15-20/12) to 526 g (SCSH-9-10/12). Juice recovery was ranged from 13.57% (SCSH-11-14/12) to 42.34% (SCSH-11-15/12). The lowest seeds/fruit were counted in SCSH-13-19/12 (12.67 seeds). Acidity of these hybrids varied from 0.70 to 1.56%. Similarly, growth performance of 23 hybrids of acid lime x lemon and lemon x acid lime developed through embryo rescue have been assessed for growth parameters. Plant height varied from 0.30 m (ACSH-7-12/18) to 1.10 m (ACSH-3-14/18), while canopy diameter ranged from 0.16 x 0.32 m in ACSH-7-13-18 to 1.35 x 1.50 m in ACSH. The hybridity was also confirmed using SSR markers.

Clonal selection in sweet orange: Twelve clones of 'Malta' sweet orange were evaluated with two local check varieties, *viz*., 'Pusa Sharad' and 'Pusa Round' for growth, yield and fruit quality traits. Plant height of selected clones varied from 4.51 m in MS-3 to 2.52 m in MS-17. Among these clones, fruit weight was ranged from 198.70 g in (MS-15) to 303.88 g (MS-3). Moreover, juice recovery ranged from 41.58% (MS-17) to 50.32% (MS-4). Clones such as MS-2, MS-4, MS-9 and MS-21 had juice recovery at par with check varieties. Clones MS-9, MS-3 and MS-15 produced significantly lesser seeds/fruit (<15) than check variety 'Pusa Sharad' (22.2 seeds/fruit) and 'Pusa Round' (19.6 seeds/fruit). The highest TSS was found in MS-8 (10.40^{0}Brix). Among these selections, the higher ascorbic acid was found in MS-3 (62.70 mg/100 ml juice) followed by MS-15 (59.15 mg/100 ml). Based on overall horticultural traits, MS-3, MS-2, MS-7 and MS-9 were found promising.

Clonal selection in acid lime: Thirty-three acid lime clones were assessed for yield and fruit quality traits with two check varieties. Clones ALC-4 (45.06), ALC-35 (44.47 g), and ALC-70 (44.20 g) had heavier fruits than Pusa Abhinav (43.69 g). Fruit length varied from 29.90 mm in ALC-50 to 49.33 mm in ALC-4. Furthermore, juice recovery was recorded highest in ALC-73 (57.60%) as compared Pusa Abhinav (46.36%) and lowest number of seeds (3.80 seeds/fruit) clone ALC-64. Among these clones, ALC-101 produced the highest fruit/tree (308.67 fruits/tree) against Pusa Abhinav (275.33 fruits) and Pusa Udit (264.67 fruits/tree). Based on yield and other horticultural traits ALC-11, ALC-24, ALC-64, ALC-83, ALC-101 and ALC-103 were found promising.

Clonal selection in lemon: Among different lemon clones, highest number of fruits (632.80 per tree) was noted in LS-1, which was comparable to Konkan Seedless (452.40 fruits/tree). During summer season, LS-1 recorded the highest fruit weight (74.43 g) and acidity (5.66%) and ascorbic acid content (49.49 mg/100 ml juice). The lowest seed number (8.60/ fruit), was recorded in LS-6.

Fruits of LS-1 lemon

Evaluation of pummelo clones: Five pummelo clones collected during the previous years were maintained in the field gene bank. Vegetative and reproductive characterization indicated the existence of high variability among them. IC numbers for these clones were obtained from the ICAR-NBPGR, New Delhi (Nos IC-628798 to IC-628802). Heavy fruiting was recorded in all the clones and was characterized for rind thickness and aril colour.

Aril colour and seed arrangement in promising pummelo clones

Evaluation of new sweet orange genotypes: Three sweet orange cultivars (Olinda, Vernia and Early Gold) and one Minneola were evaluated.The highest fruit weight was recorded with Olinda (221.28 g), which was statistically similar with Minneola and W-Murcott. W-Murcott had thin peel thickness (2.43 mm) and highest TSS (9.24°B), which was similar to Kinnow. The lowest number of seeds as recorded in Olinda (5.42/ fruit) followed by Vernia, Daisy and W-Murcott. The highest juice content was recorded in Minneola (54.57%).

Mutagenesis in Kinnow and sweet orange: Kinnow mutants were assessed for morphological, physiological and biochemical traits. Significant reduction in plant height was recorded in the mutant G-20-5 (1.62 m). The plant height (1.10 m) and canopy volume (0.76 m^3) of the second-generation EMS-M-3 exhibited dwarfness. Among the colchiploids, plant height was recorded lowest (1.9 m) in Col-1 followed by Col-2 (2.0 m). Fruits with thinner peel were observed in the mutants G-15-5 (3.16 mm) and G-18-3 (3.22 mm). The number of seeds/fruit was recorded lowest in the mutants G-6-1, G_9 and G-39-3 with an average number of 7-8 seeds/fruit as compared to 30-35 seeds in the WT (parent type). The mutants G-6-1 and G-9-4 had high juice recovery as that of parent genotype (58%). Average fruit yield was highest (65.00 kg/tree) in M-20-8, while lowest was recorded in mutant EMS-M-3. Amongst the colchiploids, fruit weight was recorded highest in Col-1 (212.00 g). The juice recovery was however, recorded maximum in Col-3 (42.0%), which also significantly had lower number of seeds/fruit (<12). Average yield/tree was varied between 25-40 kg/tree in the colchiploids. Foliar phtyo-hormone analysis of the mutants revealed higher IAA peak values in the mutants G-9-4 (92.92 ng/g) followed by G-8-3 (80.18 ng/g). The ABA concentration peaked in the mutants G-6-1 (349 ng/g) and G-7-2 (323.94 ng/g) as compared to the wild type (180.39 ng/g).

Dwraf plant of EMS-M-3

Fruits of (Col.-1)

Sweet orange: The mutants developed through different doses of gamma irradiation (15, 20, 25, 30, 35 and 40 Gray) revealed maximum (3.10 m) and minimum (1.00 m) plant height in the mutants SO-15-2 and SO-40-3, respectively. Observations on fruit weight was recorded maximum (280.90 g) in the mutant SO-15-7,

while minimum in SO-15-1 (110.98 g) but the TSS was highest (11.0°Brix). The juice recovery was recorded highest (60.52%) in SO-10-1 along with lower number of seeds per fruit (<13).

Characterization of colchiploids: A large variation was recorded in the colchiploids of Kinnow and Mosambi sweet orange with respect to plant height, canopy volume, stem girth and TCSA, but no definite trend was observed. High variation was also recorded for leaf sclerophylly characteristics amongst the colchiploids. The fruit characteristics exhibited a large variation in the 35 Kinnow and 15 Mosambi colchiploids. In Kinnow, the highest fruit weight (205 g) was observed in Ex-2-12 and lowest (120 g) in Ex-2-1. The lowest number of seeds (4.5 seeds/ fruit) was recorded in Ex-2-20. The fruit characteristics in Mosambi colchiploids did not vary much except for the rind thickness and seeds/fruit. The putative colchiploids were identified through flow cytometry, namely, Ex-1-7, Ex-2-6, Ex-1-2 and Ex-2-14, while two tetraploids were also confirmed (Ex-1-9 & Ex-1-5).

A B

Variation in Kinnow mandarin colchiploids for seed content and rind thickness.

A B

Variation in sweet orange cv. Mosambi colchiploids for seed content and rind thickness

2.2.3 Grape

Hybridization was attempted for achieving extra-early maturity, seedlessness, and improved fruit quality. About 290 panicles were crossed (about 25,966 flowers) in 42 cross combinations for both table and juice purposes. Similarly, 64 panicles (about 2,032 flowers) were crossed for rootstock development in two combinations involving *Vitis parviflora*, *V. champini* 'Dogridge' and *V. vinifera* 'Pusa Navrang' genotypes.

Grape hybrid 'Pusa Purple Seedless'

Identification of new hybrid: Pusa Purple Seedless (ER R_2 P_{36}) is a new hybrid developed through *in-ovulo* embryo rescue using 'Pearl of Csaba' and 'Beauty Seedless' in 2005. The plantlets were further multiplied *in vitro*, followed by hardening and field evaluation. It is a unique hybrid having extra-early berry ripening habit (75-78 days after full bloom), seedless, purple coloured, medium sized berries, with firm pulp. It is rich in bioactive compounds and nutraceutical properties including, *viz*., TSS (22°Brix), TSS/TA ratio (31.25), total monomeric anthocyanins (C3GE, mg kg^{-1}), total phenolics (124.22 GAE mg /100 g), total flavonoids (142.35 QE, mg /100 g), and antioxidant activity [DPPH (7.88 TE, µmol /g), CUPRAC (16.44 TE, µmol /g), FRAP (4.65 TE, µmol /g) and ABTS (5.67 TE µmol /g)]. The vine has moderate vigour and can be spur pruned. It is suitable for fresh consumption as well as juice making.

Evaluation of genotypes: Sixty-seven genotypes, including hybrids and varieties from seedless coloured/white, seeded coloured, seeded colourless groups were evaluated as per the Grape Descriptor

Hy. 16/2A-R1P9
(Banqui Abyad x Perlette)

Hy. 16/2A-R1P14
(Cardinal x Beauty Seedless)

Pusa Swarnika
(Hur x Cardinal)

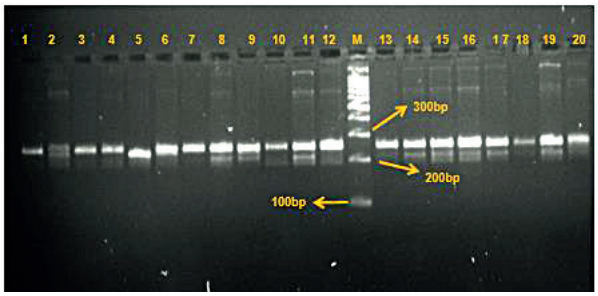
(Bioversity International). Seven hybrids were found promising in terms of high TSS and early maturity. Three seedless hybrids were harvested by 4th week of May 2019, ('ER-R_2P_{36}', 'ER-R_2P_{19}'and 'ER-R_2P_{16}') as compared to check varieties (Perlette, Beauty Seedless and Flame Seedless) Among the seeded hybrids with loose bunch bearing type (self-thinning), three, namely, 'Pusa Swarnika', '16/2A-R_1P_9'and '16/2A-R_1P_{14}'were harvested in the first week of June. Based on yield traits, 'Flame Seedless', 'Pusa Aditi' and 'Pusa Trishar' yielded maximum. The maximum bunch weight (675.5 g) was recorded in 'Hybrid 72-151' followed by 'Pusa 'Urvashi' (435.45 g), 'Pusa Aditi' (385.34 g) and 'Pusa Trishar' (355 g) as compared 'Perlette' (315 g). These genotypes were also assessed for their nutraceutical properties and maximum total monomeric anthocyanins were recorded in 'Pusa Navrang', followed by Hy. '16/2A-R_1P_{18}', '16/2A-R_4P_7', 'Punjab Purple', '16/2A-R_4P_{13}' and '16/2A-R_3P_{10}', which ranged from 686.22 to 972.7 mg kg^{-1}. The maximum phenolic fractions were detected in 'Pusa Navrang' followed by hybrid '16/2A-R_4P_7'. The fatty acid profile of 'Pusa Navrang' seed oil was also analyzed. Amino acid profiling of 'Pusa Navrang' seed oil detected 18 amino acids. The maximum amount was reported for glutamic acid (1.91 g/100 g) followed by glycine (1.37 g/100 g), aspartic acid (0.64 g/100 g) *etc*.

2.2.4 Guava

Hybridization in guava was attempted in 44 cross compatible combinations were tried using 1905 flowers. Final fruit set was noticed in only 30 cross combinations and the seeds upon sowing gave rise to 1,560 seedlings.

Evaluation of hybrids: Different guava hybrids were characterized based on morphological and physio-biochemical parameters and molecular markers. The maximum leaf length (14.87 cm) was recorded in Lalit followed by GH-2016-10 (13.93 cm), whereas minimum (8.13 cm) was in Purple Guava. The net photosynthetic rate was recorded highest in variety Shweta (9.63 µmol/m^2/s), total chlorophyll content was Lucknow-49 (1.69 mg/g FW) followed by GH-2016-2 (1.21 mg/g FW), while lowest (0.14 mg/g FW) in Purple Guava. Among the various biochemical traits studied, peroxidase activity was found highest (0.376 mmol/mg protein/min) in Lalit followed by GH-2016-7 (0.227 mmol/mg protein/min). Superoxide dismutase activity was highest (1.960 unit/mg protein/min) in Thai Guava followed by GH-2016-2 (1.863 unit/mg protein/min), while lowest (1.089 unit/mg protein/min) was in GH-2018-8. The highest stomata length (21.03 µm) was recorded in Allahabad Safeda followed by GH-2016-7 (21.89 µm), while lowest (8.570 µm) was in GH-2016-1.

Molecular characterization using 25 SSR markers, of which 9 primers showed considerable polymorphism. The allelic size ranged from 160 to 420 bp among the 9 SSR loci and a total of 30 alleles were amplified with an average of 3.33 alleles per SSR locus. The maximum expected heterozygosity (0.20) was

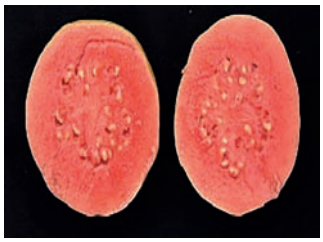


Amplification profile of SSR prime mpgCIR 13

M-100bp DNA ladder, 1. Plant Prabhat, 2. Punjab Pink, 3. Allahabad Safeda, 4. Lalit, 5. Shweta, 6. GH-2016-4, 7. L-49, 8. Hisar Surkha, 9., 10., GH-2016-8, 11. Thai Guava, 12. Purple Guava, 13. Akra Kiran, 14. GH-2016-2, 15. GH-2016-1, 16. GH-2016-7, 17. GH-2016-9, 18. GH-2016-3, 19. GH-2016-5, and 20. GH-2016-6

noted for SSR locus mpgCIR19, while minimum (0.05) for SSR locus mpgCIR14 with mean value of 0.03. The average PIC value was 0.49 of 9 SSR loci and the highest PIC (0.73) was recorded for locus, mpgCIR13, while minimum (0.34) for SSR mpgCIR16. The SSR loci, *viz*., mpgCIR14, mpgCIR13, mpgCIR01, mpgCIR05 and mpgCIR249 had PIC values greater than 0.50. The phylogenetic relationship among the guava varieties and hybrids showed two distinct clusters. The guava genotype GH-2016-3, which was stretching outside and remained separated from other clusters. Whereas, remaining genotypes grouped in different sub-clusters.

GH-2016-3



GH-2016-5

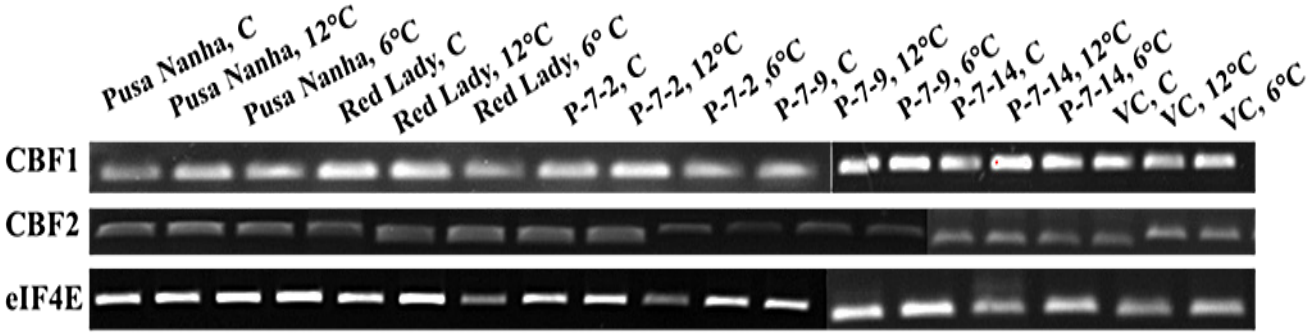
GH-2016-9

Fruits of promising guava hybrids under evaluation

2.2.5 Papaya

Evaluation of mutants: Five mutant papaya lines, *viz*., M 04, M 09, M 22, M 28 and M 33 were selected from two lower gamma irradiation doses, *i.e.* 0.1 and 0.15 kGy. These dwarf mutants had low bearing height in the M5 generation. Minimum plant height at first fruiting (95.24 cm), plant girth (62.56 mm), nodes to first flowering (38.36), days to flower initiation (72.64 days), length of middle internode (3.4 cm), and petiole length (52.12 cm) were noted in mutant, M04, while minimum plant spread in East-West direction (142.2 cm) and North-South direction (148.4 cm) was recorded in M 28, while maximum height at first fruiting (128.54 cm), plant girth (70.25 mm), nodes to first flowering (44.84), days to flower initiation (83.64), length of middle internode (4.4 cm), petiole length (65.74 cm) and plant spread in East-West (168.4 cm) and North-South (172.8 cm) directions were noted in control.

Heterosis studies: A total of eight papaya genotypes consisting three hybrids along with their five parents were evaluated. The better parent heterosis (BPH) and mid-parent heterosis (MPH) for vegetative and reproductive traits revealed that the petiole length, leaf length, leaf width and number of days required for flower initiation exhibited better parent heterosis in negative direction in all the hybrids. Hybrid Red Lady (Self) × P-9-5 exhibited positive heterosis for days to flower initiation. Negative heterobeltiosis and relative heterosis were also observed for the plant height at initiation of first flower in two hybrids {Red Lady (Self) × Pusa Nanha and PS 3 × P-7-9} while one hybrid, *i.e.*, Red Lady (Self) × P-9-5 showed positive heterobeltiosis (7.8%) and relative heterosis the (11.34%) for the trait. For plant height at first fruit maturity, only one hybrid {Red Lady (Self) × Pusa Nanha} showed negative better parent (-12.93%) and mid parent (-0.38%) heterosis, while for other two hybrids it was positive. The trait like stem diameter had significant heterobeltiosis, which was positive for the hybrid Red Lady (Self) × P-9-5 (2.95%) and negative for the other two hybrids. Number of fruits per plant being an important yield attributing trait showed positive heterobeltiosis for two hybrids, *i.e.*, Red Lady (Self) × Pusa Nanha (2.93%) and PS 3 × P-9-5 (22.13%). For yield, heterosis over the better parent ranged from 12.17% in PS 3 × P-9-5 to -8.49% in Red Lady (Self) × P-9-5, whereas heterosis over mid parent ranged from -6.18% in Red Lady (Self)



Semi-quantitative PCR of C-repeat binding factors (*CBF*1 and *CBF*2) under cold stress in papaya genotypes

× P-9-5 to 14.57% in Red Lady (Self) × Pusa Nanha. The heterobeltiosis and relative heterosis data for biochemical properties of fruit indicates the negative better parent and mid parent heterosis in all the hybrids for fruit TSS, whereas in case of total phenolic content, heterosis in positive direction was observed for all the hybrids. For total flavonoid content, one hybrid (Red Lady (Self) × P-9-5) displayed positive heterobeltiosis (4.09%) and relative heterosis (12.5%), while it was negative for the other two hybrids (Red Lady (Self) × Pusa Nanha and PS 3 × P-7-9). Data recorded for antioxidant activity through DPPH assay, exhibited positive significant heterobeltiosis in hybrid Red Lady (Self) × Pusa Nanha (128.36%) and Red Lady (Self) × P-9-5 (3.66%), whereas in case of relative heterosis, it was positive for all the hybrid progenies studied. Significant better parent heterosis in positive direction was observed for the total carotenoid content in only one hybrid *i.e.*, Red Lady (Self) ×Pusa Nanha (32.33%) while two of the hybrids were observed with positive mid parent heterosis, *i.e.*, Red Lady (Self) × Pusa Nanha (46.44%) and PS 3 × P-7-9 (24.97%) for the same trait. In case of lycopene content, the hybrids Red Lady (Self) × Pusa Nanha and Red Lady (Self) × P-9-5 exhibited significant positive heterobeltiosis (67.66 and 26.7%) and average heterosis (74.26 and 65.43%), whereas, it was negative for the hybrid PS 3 × P-9-5. Heterobeltiosis was positive for fruit firmness in only one hybrid,*i.e.*, PS 3 × P-7-9 (0.92%), whereas positive mid-parent heterosis was noted in Red Lady (Self) × Pusa Nanha (0.82%) and PS 3 ×P-7-9 (5.21%) hybrids.

***Expression profiling of C-repeat binding factors* (*CBFs*):** C-repeat binding factors (*CBF*s) play crucial role during the regulation of plant responses against environmental stresses especially cold stress. Six papaya genotypes (Pusa Nanha, Red Lady, P-7-2, P-7-9, P-7-14 and *Vasconcellea cundinamarcensis*) were selected for expression profiling of *CBFs*. *CBF*-1 is an early responsive transcription factor under cold stress and responsible for developing cold tolerance. Our findings suggest that *CBF*1 showed up regulation under cold stress treatment in leaves of all the six papaya genotypes, while *CBF*2 expression is inhibited under cold stress treatment. As the temperature decreased to 12°C and 6°C, the expression of *CBF2* was also decreased and the expression of *CpCBF2* was dramatically decreased at 2 days and remained at a lower level thereafter. These results indicated that *CpCBF2* may play a role in papaya genotypes, which was different from the other *CBF*s in plants. All these clearly explained the cold tolerance nature of *V. cundinamarcensis* and P-7-9 and cold susceptible nature of Red Lady.

2.2.6 Production Technologies of Fruit Crops

2.2.6.1 Mango

Rootstock research and canopy management: Three semi-vigorous mango varieties (Pusa Arunima, Pusa Surya and Amrapali) were evaluated on five polyemebryonic rootstocks (K-2, K-3, K-5, Kurakkan and Olour) for various horticultural traits. Extremely dwarf trees of Pusa Arunima (41.05 and 43.34%) lower than Olour and K-3) were found on K-2 rootstock. Both

K-2 and K-3 reduced the plant height in Pusa Surya by 37.19 and 18.60%, respectively than Olour. Significantly lower tree volume of Pusa Surya was found on K-2 and K-5 rootstock. Olour, K-2 and K-5 reduced tree volume in Amrapali. In Pusa Arunima, higher fruiting density (8.59 fruits /m^3 canopy volume) was found on K-2 rootstocks followed by K-5. In Amrapali, trees on K-2 and had the higher fruiting density (6.28 and 7.11 fruits /m^3canopy volume), respectively. In Pusa Arunima, the heaviest fruit (192.05 g) was found on K-3 rootstock. Rootstock did not affect fruit quality. Significantly highest fruit weight in Pusa Surya was recorded on K-2 rootstock (269.73 g) followed by Kurakkan (245.66 g). It had higher pulp and stone ratio (5.85:1) on K-2 rootstock, while Pusa Surya on Kurakkan had the highest acidity (0.49%). In Amrapali, heaviest fruits were produced on K-3 rootstock followed by Kurakkan rootstock. However, significantly higher pulp acidity (0.25%) and ascorbic acid content (28.07%) in Amrapali were recorded on Olour and K-5 rootstocks, respectively.

Similarly, growth, yield and fruit quality parameters of two commercial vigorous mango cultivars (Mallika and Dushehari) were assessed on three polyembryonic rootstocks, *i.e.* K-5, Kurakkan and Olour. Mallika was found taller on K-5 and Olour rootstocks. Dushehari on Olour was found vigorous followed by Kurakkan. Olour and Kurakkan rootstocks exhibited highest yield efficiency on Olour, along with heaviest fruits but there was not much influence on pulp content, pulp and stone ratio, TSS and titratatble acid content. Higher pulp and stone ratio and pulp acidity in Dushehari was noticed on Kurakkan rootstock.

2.2.6.2 Citrus

Effect of different rootstocks on growth and quality parameters Kinnow mandarin: Eight-year-old Kinnow mandarin raised on different rootstocks was evaluated with respect to their growth, fruit yield and quality. Rootstock imparted significant influence on plant height and canopy volume and it was recorded maximum on *Jatti khatti* rootstock (4.12 m; 25.52 m^3) followed by rough lemon (3.55 m; 20.31 m^3) and *Karna khatta* (3.00 m; 18.78 m^3). Fruiting density and yield efficiency was recorded high on *Jatti khatti* rootstock (28.04 m^3; 6.91) followed by sour orange (16.29 m^3; 3.86). Fruit weight (250.66 g) was recorded maximum on *Jatti khatti* rootstock followed by rough lemon (238.32 g) and *Karna khatta* (225.00 g). The juice recovery percentage was however, recorded maximum (56.00, 50.00, and 47.31%) on sour orange, Rangpur lime and *Jatti khatti* rootstocks, while minimum (32.38%) was recorded Carrizo citrange rootstock. Similarly, TSS was recorded maximum in Kinnow budded on Rangpur lime and *Jatti khatti* rootstocks (13.22°Brix). The average number of fruits/plant was recorded maximum on *Jatti khatti* (290) followed by rough lemon (257) and Troyer citrange (235), while it was minimum on Carrizo citrange rootstock (120).

2.2.6.3 Grapefruit

The tree growth of grapefruit cvs Marsh Seedless and Redblush was significantly influenced when budded on eight rootstocks. The trees of Marsh Seedless were more vigorous (220.32m^3) on sour orange rootstock. In Redblush, highest canopy volume (175.65 m^3) was recorded on RLC-4 rootstock. The highest fruit yield in Marsh Seedless (23.13 kg/tree) and Redblush (42.13 kg /tree) was contributed by *Billikichli* and RLC-4 rootstocks, respectively. The fruits of Marsh Seedless had the lowest peel thickness (3.81 mm) on *Jatti khatti* and sour orange rootstocks. The highest juice content (50.20%) was on RLC-4 rootstock followed by sour orange and rough lemon, while in Redblush had the highest juice content (50.40%) on *Billikichli* rootstock. Juice TSS was higher in Redblush followed by Marsh Seedless.

2.2.6.4 Sweet orange

The tree vigour of two newly released sweet orange cultivars, namely, Pusa Sharad and Pusa Round were significantly influenced due to different rootstocks. Rootstock RLC-7 was most vigorous rootstock, having canopy volume of 50.03 and 44.89 m^3, respectively, while it was lowest in Pusa Sharad on Yama Mikan and Pusa Round on C-35 rootstocks. The highest number of fruits per tree basis in Pusa Sharad (138.33) was recorded on RLC-6. All the fruit quality parameters were significantly influenced by both the rootstocks. RLC-6 and RLC-7 for Pusa Sharad; and Soh

Sarkar and RLC-7 for Pusa Round proved effective for producing larger size fruits. Except *Jatti khatti* for Pusa Sharad, all the rootstocks were found to produce fruits with low peel thickness in both the cultivars. The highest juice content (47.75%) in Pusa Sharad and Pusa Round (42.64%) were recorded on X-639 followed by Yama Mikan rootstocks. Pusa Sharad (9.17°B) and Pusa Round (9.20°B) had higher TSS on *Jatti khatti* and Yama Mikan rootstocks, respectively.

Developing soil nutrient profile of Darjeeling mandarin orchards: Soil samples were collected from different blocks of Kalimpong district in West Bengal. The pH ranged from 5.50 to 4.60, EC from 0.28 to 0.10, OC from 2.20 to 0.78%, N from 585.30 to 115.80 kg/ha, available phosphorus from 80 to 25 kg/ha, K ranged 285.00 to 90.00 kg/ha, B ranged from 0.97 to 0.11 ppm, Fe from 0.20 to 0.262 ppm, S from 0.07 to 0.35 ppm, Zn 0.10 to 0.11 ppm, Mn 11.19 to 6.00 ppm, and Cu 0.99 to 0.36 ppm. Interpretation of data would help in analyzing the decline in nutrient status in Darjeeling mandarin orchards.

Identifying causes of decline in Darjeeling mandarin: The study was undertaken with the objectives to assess reasons for decline in mandarin orchards by perceiving constraints of the growers. Ranking was given based on the severity of decline, the study shows that lack of quality planting material for re-plantation was ranked I and increased incidence of disease specifically viral diseases like CTV and bacterial disease like Citrus Greening was ranked II. These were the major reasons for citrus decline.

2.2.6.5 Grape

Two elicitors, *viz*., methyl jasmonate (MeJA) and benzothiadiazole (BTH) were used to improve the bioactive compounds in the cv. Pusa Navrang. Higher concentration of methyl jasmonate (10 and 15 mM) elicited better accumulation of total phenolics, total flavonoids, total monomeric anthocyanins and antioxidant (DPPH, FRAP and CUPRAC assays) activities. Similarly, application of 0.4 mM BTH at veraison stage as well as 3 day after it improved the berry qualities. However, quality parameters like total soluble solids, titratable acidity, pH and ascorbic acid contents along with the morpho-physical bunch properties of grape were least affected.

In an another study, bio-regulators & micronutrient namely, ethephon, abscisic acid and boric acid improved berry quality in grape genotypes, namely, Flame Seedless, Pusa Aditi and Pusa Swarnika. Ethephon at 400 ppm followed by ABA (200 ppm) were found effective for 'Flame Seedless' improving berry colour and quality, while boric acid (0.4%) for Pusa Swarnika and ethephon (300 ppm) for Pusa Aditi were most effective.

Effect of rootstocks on wine grape production: Grape cv. Syrah grafted on seven inter-specific grape rootstocks, namely, SO4, 110R, P1103, 140Ru, P1103, Fercal, 3309C and 41B were studied for their stionic influence. Syrah on P1103 produced berries having the earliest maturity, significantly longer bunches (length & width; 14.17 and 8.90 cm) as well as the highest yield (9.26 kg vine^{-1}). This rootstock also resulted in the maximum total phenols (158.43 mg 100 ml^{-1} GAE) and total flavonoids (83.5 mg 100 ml^{-1} QE) in berries, while rootstock 110 R induced the highest quantity of total phenols (298.60 mg 100 g^{-1} GAE) and flavonoids (14.48 mg g^{-1} QE) in leaves with very dense trichome, thus, imparting biotic stress resistance. This rootstock also produced the highest berry TSS (22.26^{0}Brix) and total monomeric anthocyanins (406 mg 100 g $^{-1}$) with low acidity (0.40%).

2.2.6.6 Kinnow

Kinnow mandarin exhibits poor flavedo-colour at harvest in National Capital Region. The efficacy of different concentrations and timings of spray of inhibitors of gibberellin biosynthesis such as prohexadione calcium (Pro-Ca) was investigated. Pro-Ca at 300 ppm resulted in decreased hue angle and increased fruit colour index and total carotenoids (38.3 mg kg^{-1}) in the flavedo, besides, fruit quality traits like TSS (10.12^{0}B), titratable acidity (0.79%) and ascorbic acid content (21.22 mg/100 g). The maximum

carotenoids content in juice (310 µg/100 ml) and peel (688 µg/100 ml) were recorded due to 300 ppm Pro-Ca.

Guava canopy management: Eight commercially prominent guava varieties from different growing regions, *viz*. Hisar Safeda, Thai Guava, Allahabad Safeda, Sardar (L-49), Lalit, Punjab Pink, Pant Prabhat and Shweta have been established at close spacings of 3x3 m and 4 x 4 m to standardize ideal plant canopy for intensive production. The canopy volume was recorded maximum in Punjab Pink and minimum in Thai Guava in 4 x 4 and 3 x 3 m spacings. Flowering was earliest in Shweta followed by Lalit and Allahabad Safeda. Maximum number of flowers/branch was recorded in Punjab Pink (37) followed by Shweta (33) and Sardar (27). The highest number of fruits was recorded in Punjab Pink (156.67 and 148.00) in 4x4 and 3 x 3 m spacings, respectively. Fruit weight was highest in Thai Guava followed by Pant Prabhat.

2.2.7 INM and Fruit Quality Improvement

2.2.7.1 Mango

Application of 100% recommended dose of fertilizers (RDF) alone and/or with AMF (250 g) and *Azotobacter* (250 g); 75% RDF along with AMF (250 g) and *Azotobacter* (250 g) and 50% RDF alongwith AMF (250 g) and *Azotobacter* (250 g) were studied on new mango hybrids, namely, Pusa Prtatibha, Pusa Arunima and Pusa Shreshth. The maximum plant height (4.24 m) was recorded in the treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 4.04 m in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g), while minimum (3.38 m) in control (T1). Among cultivars, maximum height (3.89 m) was noted in in Pusa Arunima, while minimum (3.51 m) was in Pusa Pratibha. Maximum canopy volume (40.22 m^3) was recorded in the treatment NPK 100% + AMF (250 g)+ *Azotobacter* (250 g) followed by 33.98 m^3 in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g), while minimum (20.70 m^3) in control (T1). Among cultivars, maximum canopy volume (44.39 m^3) was found in Pusa Arunima and minimum (14.90 m^3) in Pusa Pratibha. Maximum number of fruits per tree (17.99) was recorded in treatment NPK 100% + AMF (250g) + *Azotobacter* (250 g) followed by 16.93 in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g). Maximum fruit weight (195.38 g) was recorded in treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 187.66 g in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g). Among varieties the maximum fruit weight (189.82 g) was found in Pusa Arunima followed by Pusa Shreshth (183.08 g) and minimum (161.82 g) in Pusa Pratibha. Maximum fruit yield of (6.485 kg) was recorded in treatment NPK 100% + AMF (250 g)+ *Azotobacter* (250 g) followed by 6.012 kg in treatment NPK 75% + AMF (250g) + *Azotobacter* (250 g). Among varieties, the maximum yield (6.736 kg/tree) was found in Pusa Arunima followed by Pusa Shreshth (5.70 kg) and minimum (3.657 kg) in Pusa Pratibha (6-yr-old).

2.2.7.2 Biotic Stress Management

Management of guava wilt: Guava plants were screened for the efficacy of biological control agents for wilt caused by *Fusarium* sp. in pot experiment. The inoculum of *Fusarium oxysporum* cultures were artificially inoculated both in the pots as drench or injected in the plants. After fifteen days the cultures of biological control agents was inoculated and observed for the symptoms. However, plants exhibited the wilt symptoms under control; whereas those inoculated with *Trichoderma viride* and *Aspergilus niger* were found to be devoid of wilt symptoms.

Management of mango malformation: Liquid formulation of six *Trichoderma* strains was found promising against *Fusarium mangiferae*, the causal organism of mango malformation under *in vitro* and *in vivo* conditions.

Temperate fruits: The six strawberry genotypes, *viz.* Festival, Camarosa, Nabila, Kamila, Liaminia, and Fluvial were added to the existing germplasm. The fruiting was recorded in off-season under protected conditions at Shimla. The strawberry genotypes had significantly higher total soluble solids, anthocyanins and other antioxidant compounds. Surveys were undertaken in Kinnaur and Shimla districts of H.P. and collected different species in *Malus* (02), *viz*., *M. baccata* Kinnaur and *M. baccata* 'Rohru'. Besides, elite walnut

genotypes (04) were collected from Kalpa valley of Kinnaur district.

Application of forchlorfenuron / Sitofix / CPPU greatly stimulated fruit growth indicating that it can be a powerful tool for improving kiwi fruit cropping. Ten days after anthesis, when 10 ppm was applied to fruits by dipping them for about ten seconds in aqueous solution of the compound. CPPU applied fruits along with summer pruning increased size by 35-65 g over the control. IARI Regional Station, Shimla identified a unique walnut, which came into bearing after second year of its grafting having both lateral and terminal bearing habit. "Pusa Khor" bore almost 60% laterally and 40% fruits terminally; while all the fruits borne terminally by other walnut trees. Chip-budding methods gave higher success rate. Mutagenic treatment (radiation) on scion sticks of apricot, kiwi, apple, and pear was applied from NRL, IARI, New Delhi and grafted on different rootstocks and established in glasshouse. Data was recorded on growth and precocity on dwarfing rootstock in stone fruits.

Performance of Japanese plum varieties Black Amber, Satsuma, Mariposa, and Santa Rosa were evaluated. The highest fruit weight varied from 42.84-58.55 g with maximum in Santa Rosa (58.55). Pulp TSS varied from 14.8-20.5^{0}Brix with highest in Santarosa. Twenty five temperate type pomegranate accessions collected from ICAR-NRCP, Solapur were evaluated. Six genotypes (Boskalinisi, GR Pink, Spin Sakaharin, Shirin Anar, Kayaki Anar, AHPGC-3) fruited. The fruit weight varied from 157-176 g, while TSS from 13-17%.

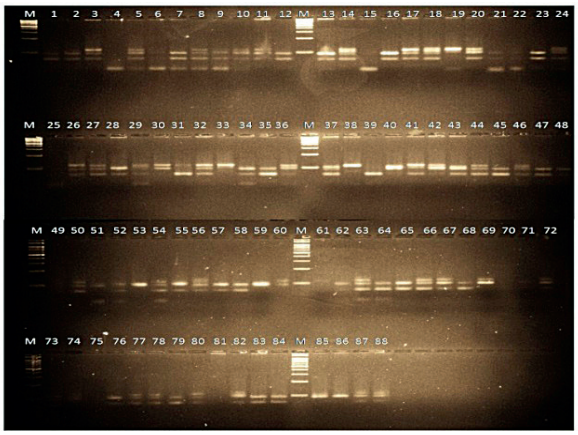
Off-season strawberry genotypes, *viz.*, Etna, Chandler, Belrubi, Sweet Charlie, Douglas, Shimla Delicious and Ofra were evaluated for fruit traits and quality parameters. Fruit weight varied from 11.22-18.53 g, TSS 8.6-11.4%, and vitamin-C from 46.1-49.2 mg/100 g pulp. Performance of peach and nectarine genotypes evaluated, fruit yield was maximum in Shan-e-Punjab (21.39 kg/tree), pulp thickness varied from 16.45-27.22 mm.

Crosses with different combination in apple were made and observation recorded on fruiting hybrids. Apple varietal trial on different rootstocks including Pusa Seb Mulvrint-101 was initiated. Saplings were transplanted and data on survival and growth were recorded. Rootstocks multiplied through mound layering and used for grafting in different cultivars of apple. Rootstock trial of stone fruits was initiated with different spacings in peaches, nectarine, cherry, apricot, almond, prune, plum *etc*. Data on growth and fruit characters was recorded. Mutagen treated (radiation) apricot, kiwi, apple, pear and walnut was established in field. Data on shoot growth was recorded as compared to original one. Apricot genotypes particularly drying types were evaluated for fruit and quality traits.

2.3 ORNAMENTAL CROPS

2.3.1 Rose

Characterization of Indian bred roses using SSRs: Genetic characterization of 88 rose genotypes was carried out using 102 SSR markers (Genomic and ESTs) of which 63 gave amplification. Out of these, 17 markers gave very high degree of polymorphism. Total number of polymorphic bands ranged from 3 – 80 across the 88 varieties. The primer 310 showed highest number of polymorphic bands. The molecular weight of the allelic bands varied from 120 bp (Primer 466) to 500 bp (Primer Rw25J16). Polymorphic information content of the primers ranged from -0.038 (Primer CL-172) to 0.823 (Rw1F9).



Amplification products of primer No. 466 of Rose varieties. Lane 1-88 represents different rose varieties as given in the Table. Lane M represents 50 bp DNA ladder

Identification of promising hybrids/ OP seedlings RH-24-2017: It is a Floribunda type hybrid of Barbara Bush × Jawala, producing dark pink coloured medium sized blooms. The plants are medium in height and bushy. It is most suitable for garden display purpose.

Flowers of RH-24-2017

RS-03-2017: It is an open-pollinated seedling of cv. Pink Parfait. It produces dark pink coloured medium sized blooms. The plants have bushy growth habit and are suitable for garden display purpose.

Flowers of RS-03-2017

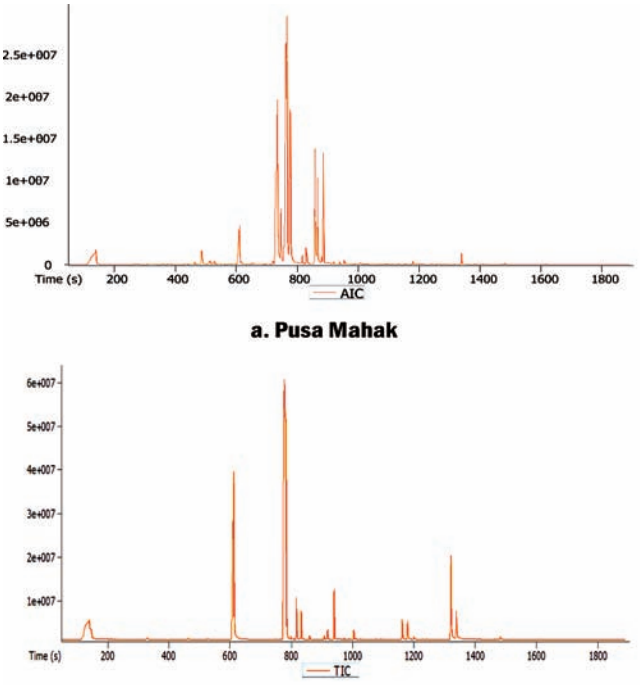
RH-19-2017: It is a Floribunda type hybrid between Dr. Bharat Ram × Rose Sherbet. The plants are short and narrow bushy. It produces pink coloured medium sized blooms, which have mild fragrant flowers, low petal shedding, compact and more flower anchorage. It is suitable for loose flower purpose and making garlands.

Flowers of RH-19-2017

RS-01-2016: It is an open-pollinated seedling of cv. Pusa Virangana. It produces pink coloured medium sized blooms. The plants have bushy growth habit and are suitable for garden display.

Flowers of RS-01-2016

Profiling of floral volatiles in fragrant roses: Variety Pusa Mahak was developed by selection from the open-pollinated seedlings of cv. Century Two, a bold and pink blooming rose used for garden display purpose. Effort was made for profiling the floral volatiles



Chromatogram showing headspace volatiles in (a) Pusa Mahak and (b) Century Two

using head space solid phase micro-extraction-2D gas chromatography time of flight mass spectrometry. The fragrance profiles of Pusa Mahak and Century Two were found to be quite distinct. About 82 compounds (55% terpenoids) were detected in Pusa Mahak and about 66 compounds (37% phenylpropanoids/ benzenoids)

in Century Two. Major components (≥5%) identified in Pusa Mahak were β-pinene (20%), β-citronellol (14%), 2- phenyl ethyl acetate (9.5%), 2-phenyl ethanol (8.3%), 3, 5-dimethoxytoluene (7.23%), geranial (7.23%) and α-myrcene (7%). The major constituents of headspace volatile of Century Two were 3,5-dimethoxytoluene (67%), 2-phenyl ethanol (19%) and theaspirane (4.5%). The difference in fragrance quality and intensity was attributed to the variation in the composition of headspace volatiles and different aroma impressions of specific compounds.

2.3.2 Chrysanthemum

Isolation of a novel chrysanthemum variant through Gamma ray induced mutation : Gamma ray irradiation (10, 15 and 20 Gy) of 14 cultivars, viz. Star Yellow, Star White, Pusa Anmol (yellow), Pusa Kesari, Vjay Kiran, Himanshu, Pusa Sona, Sadbhavana, White Prolific, Ajay, Datymed, Mother Teresa and Liliput was undertaken. A yellow coloured mutant from a white coloured spray type cv. Himanshu has been identified, having all traits with that of parents. It is best suited for pot cultivation.

RHS colour comparison of white mutant (7 C) compared to Himanshu (NN155 C)

In vivo screening of Chrysanthemum morifolium Ramat. varieties for salt tolerance: Six varieties, namely, Pusa Chitraksha, Lalit, Pusa Aditya, Basanti, Himanshu and Pusa Sona were grown in pots after exposing to different levels of NaCl (0, 50, 100, 150 and 200 mmol/l). Among the varieties, the maximum root length was observed in Pusa Aditya, it was minimum in Pusa Sonaat 200 mmol/l NaCl. The maximum reduction in the number of leaves per plant was recorded in Pusa Sona (57.00%), while was minimum (18.90%) in Pusa Aditya compared to control. The RWC and MSI were reduced with increase in salinity levels. The salinity stress reduced the MSI by 63.70 and 52.80% in Himanshu and Pusa Sona, respectively over control. The activities of the antioxidant enzymes got increased with rising salinity level. The maximum increase in the enzyme activity (catalase, peroxidase and superoxide dismutase) was noted in Pusa Aditya, Basanti, and Pusa Chitraksha, while minimum increment was noted in Pusa Sona and Himanshu. The leaf Na^+ and Cl^- contents increased, while K^+ and Ca^{2+}got reduced. At 200 mmol/l NaCl level, maximum accumulation of Na^+ and Cl^- was recorded in Pusa Sona and Himanshu. The maximum reduction in the K^+ and Ca^{2+} was found in Pusa Sona and Himanshu, while least in Pusa Aditya. The leaf proline content increased with the increase in salinity stress and reached maximum with 200 mmol/l NaCl treatment. The varieties like Pusa Aditya, Pusa Chitraksha, and Basanti accumulated higher proline at 200 mmol/l NaCl treatment.

2.3.3 Marigold

Vegetative propagation was successful upon treatment with IBA+NAA at 250 ppm each irrespective of seasons (rainy, winter and summer) for parameters like cutting survival (100, 97.50 and 99.17%), maximum shoot length (7.87, 7.78 and 7.73 cm), maximum root length (17, 9.10 and 8.67 cm), maximum number of primary roots per shoot (41.69, 37.25 and 36.83), maximum root fresh weight (0.789, 0.692 and 0.779 g), maximum root dry weight (0.130, 0.128 and 0.133 g), maximum shoot fresh weight (1.364, 1.371 and 1.352 g), maximum shoot dry weight (0.128, 0.139 and 0.125 g) and minimum days for root initiation (6.75, 7.42 and 7.00 days, respectively). Maintenance of mother plants in Arka Agni, Arka Bangara-2, Bidhan Marigold-1 and Bidhan Marigold-2 were best in treatment of shadenet (75%) + foliar spray + 3rd pinching, recording maximum values for parameters like plant spread, number of primary branches per plant, number of secondary branches per plant, stem diameter, and chlorophyll concentration.

Evaluation of flowering behavior in petalous male sterile genotypes during different seasons was


Rainy Season


Summer Season

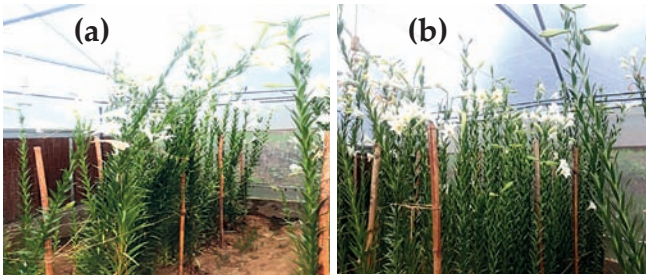

Winter Season

Flowering behaviour of petalous male sterile genotypes during different seasons

undertaken. In rainy season, Arka Bangara-2 took minimum duration for first flower bud initiation (29.07 days), whereas maximum flower yield per plant (547.20 g) was recorded in genotype Bidhan Marigold-1. During winter season, Arka Bangara-2 took minimum time to first flower bud initiation (34.93 days) and recorded maximum flower yield per plant (433.60 g). During summer season, Arka Bangara-2 took the minimum time (38.20 days) to first flower bud initiation and recorded maximum flower yield per plant (408.91 g).

2.3.4 Lilium

Evaluation of hybrids: Three station lilium hybrids were evaluated for growth and flowering under polyhouse. Maximum plant height (252.0 cm) was recorded in hybrid "No. 18 x Prato". Maximum number of flowers per stem (9.0), inflorescence length (35.7 cm) and leaf area (28.7 cm^2) were observed in hybrid "No. 18 x Brunello".



Inter specific lilium hybrids, a) No.18 x Prato, b) No.18 x Brunello

Similarly, the seedlings of eight inter-specific crosses made in 2018 were transplanted and evaluated for their growth and flowering under polyhouse. Hybrid-6 significantly took minimum number of days (142.0 days) to flowering. Plant height was recorded maximum (122.9 cm) in Hybrid-2. Number of flowers (3.0) and leaf area (23.6 cm^2) were found maximum in Hybrid-9. Maximum flower diameter (11.4 cm) was observed in Hybrid-4. Maximum flowering (65.31%) was found in Hybrid-2 followed by Hybrid-1 (63.16%) in first year seedling population. The results have offered opportunities in the development of seed propagated lilium that can flower from seed within a year.

Cross-compatibility in lilium cultivars: Based on the performance of different lily cultivars, 24 hybrid combinations were designed among 11 cultivars and pollinated a total of 149 flowers. Results demonstrated that most of the crosses in the same hybrid group were compatible but the number of seeds per fruit was very low or even as little as zero, However, inter-specific pollinations between Longiflorum Asiatic x Asiatic were less compatible. In general, cultivars fit as male parent were 'Blackout', 'Tresser' and 'Brunello'. In another distant hybridization, No. 18, a breeding line with low juvenility developed by the station crossed well with *Lilium speciosum* and lilium cv. Belem. In both the cross combinations good seed set was observed and had ahigh degree of compatibility.

Germplasm evaluation: Five cultivars were evaluated under polyhouse. Cultivar 'Pavia' significantly exhibited maximum (135.7 cm) plant height and bud length (12.1 cm), whereas, minimum plant height (97.8 cm) was found in "Montego Bay'. More number of flowers per stem (10.8) was recorded in cv. 'Eyeliner'. Maximum flower diameter (19.4 cm) was found in cv. 'Litoween'.

2.3.5 Iris

Performance of bulbous Iris: Ten bulbous iris genotypes were evaluated for growth and flowering. Cultivar 'Tel Star' significantly took minimum number of days to flowering (150.4 days) followed by 'Harmes Blue' (154.8 days). Plant height was recorded maximum (78.5 cm) in cv. 'Saturns' followed by 'Flash Light' (78.3 cm). Flower size was noticed higher (16.7 cm) in cv. 'Miss Shagun.

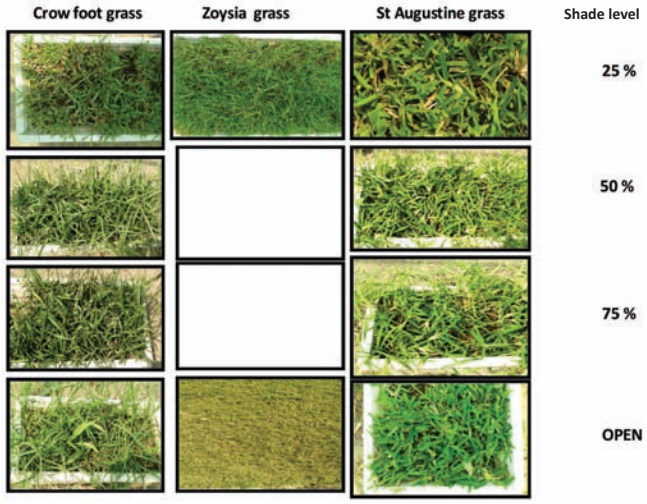
2.3.6 Ornamental kale

Evaluation of Double-haploid lines: Ten DH lines of ornamental kale developed by the Regional station Katrain through microspore culture were evaluated for uniformity and character detection. Wide character variability was obtained in the DH lines with respect to leaf shape and colour. All the lines consistently showed high uniformity. The OKDH -55 and OKDH -56 were found suitable for bedding or pot culture purpose, while OKDH -57, OKDH -29, OKDH -26 and OKDH -27 were found suitable for cut flower production.

a) OKDH -55 b) OKDH -56 c) OKDH -57
Performance of ornamental kale DH lines

2.3.7 Turf Grass management

Screening of different turf grasss pecies under different shade levels: Eight turf grass species, namely, St. Augustine, Crow foot grass, Zoysia grass, Bermuda grass, Bahia grass, Seashore paspalum, Centipede grass, and carpet grass were evaluated for different shade levels, *i.e.* 25, 50 and 75% and in open conditions. For most of the species leaf elongation was stronger under reduced irradiance compared to full sunlight. Grass coverage decreased under shading compared to open condition. At highest shade level, *i.e.* 75% turf species Crow foot grass, St. Augustine and Zoysia performed well as compared to others. Quality parameters like texture; colour etc. got reduced due to reduction in irradiance.



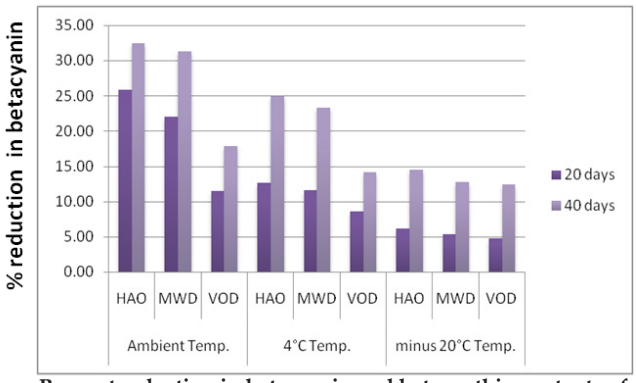
Performance of different grass species under different shade levels

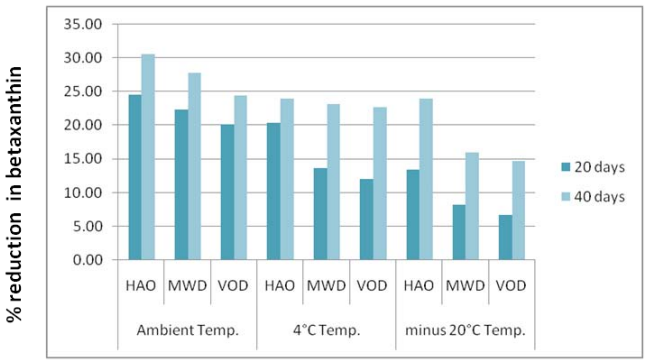
2.3.8 Standardization of fertilization doses in *Syngonium*

An experiment was conducted to study the effect of different fertilizers on growth and development of *Syngonium* with 14 different treatments comprising water soluble fertilizers, bio-fertilizers and commercial slow release fertilizers. Treatment T7 (water soluble fertilizer @ 2 g/kg soil + AMF @1.5 g/kg soil) recorded the best results with regards to number of leaves (28.17), leaf area (153.15 cm^2), leaf relative water content (95.76%), and overall plant presentability (95.67 points) in the potted syngonium. Soil analysis at the end of the experiment revealed that maximum electrical conductivity (0.60 dSm^{-1}), organic carbon (0.91%) and available phosphorus (177.68 kg/ha) was recorded in treatment T_7, while maximum available N (251.66 kg/ha) and available potassium (292.54 kg/ha) were recorded under T_8 treatment.

2.3.9 Standardization of drying and storage techniques in bougainvillea

The variety Spring Festival, which is having high content of betalains (betacyanin and betaxanthin) and their antioxidant activities were subjected to different drying and storage techniques such as sun drying, shade drying, hot air-oven drying, microwave drying





Per cent reduction in betacyanin and betaxanthin contents of vacuum-dried bougainvillea bracts after 20 and 40 days of storage.

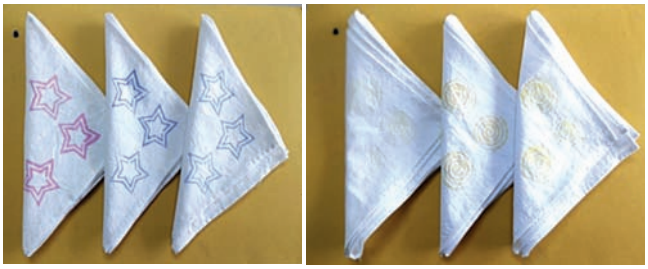
and vacuum drying at different storage temperatures (ambient, 4° and -20°C) and durations (0, 20, 40 days). The vacuum drying was observed to be better over other drying techniques for high retention of betalains and their antioxidant activities. Storage of vacuum dried bracts at -20°C for 40 day storage exhibited high retention of betalains and their antioxidant activities, which declined thereafter.

2.3.10 Extraction of natural dye from seasonal flowers

An attempt was made to extract natural dyes from annual flower crops, namely, *Linum* and *Coreopsis* in three different media, *i.e.* acidic, alcoholic and aqueous. Original colour of *Linum* flower was best extracted in acidic medium followed by aqueous medium, while in *Coreopsis* it was in alcoholic solvent followed by aqueous medium. The natural colour (dye) thus obtained was used for dyeing white cloth. In order to have good binding of dye, mordanting was done with 5% alum solution following three methods, pre-mordanting, simultaneous mordanting and post mordanting. It was observed that best colour fixation was obtained with pre-mordanting followed by simultaneous-mordanting technique. The value-added products were also prepared using the natural dyes.

Coreopsis

Linum



Block printed handkerchiefs with natural dye obtained from *Linum* and *Coreopsis*

2.3.11 Standardization of nutritional requirement in *Licoris*

At IARI Regional Station Kalimpong, an experiment was conducted using five graded doses of NPK, *i.e.* 50:50:50; 100:100:100; 200:200:200; 300:300:300 and 400:400:400 kg/ha. It was recorded that application of NPK (300:300:300) kg/ha increased leaves per plant (42.92cm), bulb diameter (3.75 cm), biomass (20.50g/ plant DW), spike length (35.50cm) and floret number (5.6/ clump) as compared to other treatments.

2.3.12 Standardization of growing media and nutrition in Easter lily

An experiment was conducted with four graded dose of NPK, *i.e.* (100:100:100), (200:150:100), (300:200:150) and (400:250:200) kg/ha and four growing media, *i.e.* coco peat, saw dust, leaf mould and vermiculite for optimisation of growing media and nutrition level for increase bulblet size. Growing of bulblet in coco peat with NPK (400:250:200 kg/ha) increased the bulblet size (3.10 cm) followed by NPK (400:250:250) kg/ha along with leaf mould medium (2.85 cm).

2.4 SEED PRODUCTION OF HORTICULTURAL CROPS

The production of quality seed of horticultural crops (Vegetables, Fruits & Flowers) at institute farm, and its regional stations and under farmer participatory seed production programme, respectively) at the Seed Production Unit. The crop-wise details of the production of various classes of seeds are given below.

2.4.1 Seed production in Vegetable Crops

Following is the detail of vegetable crops seed production by the IARI and its regional stations and seed production unit (2019).

Seed production of Vegetable crops during *Rabi* 2018-19 and summer/*Kharif* 2019

Type	No. of Crops	No. of Varieties	Seed Production (kg)			
			Nucleus	Breeder	IARI	Total
IARI, New Delhi	24	37	00.00	231.35	1425.65	1657.00
Seed Production Unit	19	24	00.00	481.00	5661.39	6142.39
IARI RS, Karnal	20	36	13.59	1043.96	521.37	1578.92
IARI RS, Katrain	16	32	125.00	26.50	2859.00	3010.50
RS, IARI Samastipur	12	15	0.00	00.00	1000.14	1000.14
Total	101	144	**138.59**	**1782.81**	**11467.55**	**13388.95**

2.4.2 Fruit crops

Following is the detail of fruit plants multiplied by the IARI during 2019.

Propagation of fruit crops (No.) during 2019

Sl.No.	Crop	Cultivar	IARI RS, Karnal	IARI, New Delhi	IARI RS, Samastipur	IARI RS, Kalimpong	IARI RS, Shimla	Total
1.	Mango	Amrapali	1341	1506	630	-	-	3477
2.	-do-	Mallika	643	881	250	-	-	1774
3.	-do-	Pusa Arunima	85	509	90	-	-	684
4.	-do-	Pusa Surya	93	118	-	-	-	211
5.	-do-	Pusa Pratibha	-	132	-	-	-	132
6.	-do-	Pusa Lalima	31	85	-	-	-	116
7.	-do-	Pusa Shrestha	19	138	-	-	-	157
8.	-do-	Pusa Pitamber	49	143	-	-	-	192
9.	-do-	Other cultivars	294	-	120	-	-	414
10.	-do-	Scion Sticks	-	750	-	-	-	750
11.	Lemon	Kagzi Kalan	2460	6150*	108	-	-	8718
12.	Acid Lime	Abhinav, Udit	-	435	-	-	-	435
13.	Sweet Orange	Pusa Round, Pusa Sharad	-	235	-	-	-	235
14.	-do-	Darjeeling Mandarin	-	-	-	1000	-	1000
15.	Grape	Pusa Varieties	-	620	-	-	-	620

15	Guava	Allahabad Safeda	361	-	-	-	-	361
16	Litchi	Sahi	-	-	90	-	-	90
17	Temperate fruits	Different fruits	-	-	-	-	3500	3500
18	Strawberry	Different varieties	-	-	-	-	4000	4000
19	Large Cardamom	Suckers	-	-	-	3000	-	3000
20	Papaya	Seedlings	304	2765	7798	-	-	10867
		Total	**5680**	**14467***	**9086**	**4,000**	**7500**	**40733**

*Including 2500 produced by SPU, IARI

2.4.3 Ornamental Crops

Following is the detail of ornamental crops, seed production by the IARI and its regional stations and Seed Production Unit in 2019.

Planting material production in ornamental crops at IARI and its Regional Station and Seed Production Unit, New Delhi

Sl. No.	Crop	Variety	Quantity (Appoox.)	Location
1.	Marigold	Pusa Arpita, Pusa Deep, Pusa Basanti	25 kg	IARI RS, Karnal
2.	Marigold	Pusa Narangi Gainda & Pusa Basanti	123 kg	Seed Production Unit, IARI, New Delhi
3.	Winter seasonal flowers	Different flowers	10 kg	IARI, New Delhi
4.	-do-	-do-	20 kg	IARI RS, Katrain
		Total	**178 kg**	
5.	Bougainvillea	All named varieties	5,000	IARI, New Delhi
6.	Rose plants	All named varieties	2,000	-do-
7.	Amaryllis	Pusa Suryakiran	5,000	-do-
8.	Lilium	Different varieties	2,000	IARI RS, Katrain
		Total	**13,000**	

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: Wild and related species of wheat, *viz.*, *Triticum militinae*, *T. timopheevi*, *T. turgidum*, *T. monococcum*, *T. spelta*, *Aegilops variabilis*, *Ae. umbellulata*, *Ae. speltoides*, *Ae. markgrafii*, *Ae. geniculata* and *Secale cereale* were maintained. The introgression lines (ILs) developed were maintained and screened against multiple diseases such as leaf rust, yellow rust, stem rust, Karnal bunt, head scab and spot blotch. Eighteen ILs derived from *T. militinae* and *S. cereale* were identified with resistance against at least two diseases. Four *T. militinae* derived ILs (TMD lines) *viz.*, TMD 10-8, TMD 11-5, TMD 11-6 and TMD 11-8) were found resistance against four of these diseases, Eight other TMD lines (6-5, 7-5, 7-6, 12-4, 12-8, 12-12, 13-4, 13-10) were showing resistant to three of the diseases. Three *Secale* derivatives (SCD-1, 7, 10) were found resistant to three diseases and one (SCD-11) against two diseases. These lines are excellent source for further mapping and utilization in breeding program. Recessive resistance genes for leaf and stem rusts in bread wheat IL Selection 212 (tentatively as *LrSel212* and *SrSel212*) have been mapped to the short arm of chromosome 2B separated by genetic distance of 16.4 cM. *wmc 474* was the closest marker located between two genes, 5.6 cM proximal to *LrSel212* and 10.8 cM distal to *SrSel212*.

Promising resistant germplasm for wheat leaf and stem rust: A brown and black rusts resistant wheat germplasm line "HS545" was developed from a cross HD2819/ HS435 using Bulk-Pedigree method of breeding. HS545 displayed resistant reaction to 21brown rust pathotypes including 77-8 and 77-10 known virulence for *Lr19* and *Lr28*, respectively. Similarly, it also showed resistant reaction against 15 black rust pathotypes at seedling stage. These results indicated the presence of broad spectrum resistance to brown and black rusts in HS545. Inheritance of resistance against 77-5 pathotype of brown rust was also studied. The cross "Agra Local/HS545" and its reciprocal cross "HS545/ Agra Local" displayed resistant reaction in F_1, indicating dominance of resistance over susceptible infection type. Among 391F_2 seedlings of these crosses, evaluated against 77-5 pathotype of brown rust, segregated into 278 resistant and 113 susceptible with good fit ($\chi^2_{3:1}$=2.96) against p-value (0.10-0.05) at 5% level of significance and 1d.f) to the expected ratio of 3R:1S, suggesting the presence of single dominant gene pair for controlling resistance against virulent pathotype 77-5. HS545 possess semi-erect growth habit, waxy leaf sheath, 94 cm plant height and matures in 157 days, tapering ear shape with brown glumes and awns at maturity. Grains are semi-hard, ovate in shape and amber in colour with 40 g thousand grain weight. Presence of brown and black rust resistance along with good agronomic features in HS545 would prove useful source for developing potential rust resistant genotypes and/ or serve as potent donor for harnessing new variability against new virulent pathotypes of leaf and stem rusts in wheat.

Pyramiding Lr19/Sr25 and Yr15 in background of HS240: Rust resistant wheat genotypes carrying genome of prominent wheat variety HS240 were developed by pyramiding *Lr19/Sr25* and *Yr15* using FLW20 and FLW13 as gene donors.The SCAR and SSR based molecular markers,*viz.*, *scs265*, *Xwmc221*, *PSY1-E1*, *Gb*linked to *Lr19/Sr25* and *Xbarc8* and *Xgwm11* linked to *Yr15* were used for validation of *Lr19/Sr25* and *Yr15* genes, respectively. The SSR based genome recovery in selected genotypes, WBM3682 and WBM3684 was 86.6 and 89.4%, respectively. Besides, 35k SNP array based analysis of genomic regions of HS240 also substantiated the results of genomic recovery estimated using microsatellites.

Barley germplasm evaluation: Among 377 barley breeding lines screened for yellow rust resistance, 107 were recorded as resistant at adult plant stage under natural condition. Among 19 breeding lines evaluated against M, Q, G, 24, 57, 6SO and 7SO races of yellow rust, 14 lines,*viz.*, BHS46, BHS366, BHS369, BHS371, BHS383, BHS384, BHS447, BHS462, BBM760, BBM762, BBM777, BBM781, BBM782 and BBM786 displayed resistant reaction against all the pathotypes at seedling stage under glasshouse conditions. These lines also showed resistance to stripe rust at rust hot spot Dhaulakuan and Bajaura under adult plant stage. Besides, 5 genotypes,*viz.*, BHS453, BHS463, BBM770, BLG5, BLG12 and BLG18 were also found to be resistant to yellow rust in these locations.

At Regional Station, Wellington, Tamil Nadu more than 6000 lines of wheat comprising synthetics, CIMMYT advance lines and RILs carrying different leaf, stem, yellow, head scab, blight resistance genes, PHS sources, barley, oats, Triticale and many wild species are continuously maintained and evaluated.

3.1.2 Rice

Evaluation of wild rice accessions: A set of 100 wild rice collections comprising *O. rufipogon*, *O. nivara*, *O. longistaminata*, *etc.*,were characterized for different traits. These lines were also inoculated with *Xanthomonas oryzae* pv.*oryzae* (*Xoo*), for identifying sources of Bacterial blight (BB) and also utilized inwide hybridization for introgression of useful traits.

Evaluation of rice germplasm for yield and other components related to yield stability: 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 its components such as number of tillers per plants, number of grains per panicle, spikelet fertility, 1000 grain weight and phenological traits days to 50% flowering and days to maturity during *kharif* 2018. Further, these lines were also inoculated for screening by different isolates of *Xanthomonas oryzae* pv. *oryzae* (*Xoo*), causal organism of bacterial blight (BB) and resistant lines were utilised in crossing.

3.1.3 Maize

Novel germplasm developed: Transposable elements (TE) play vital role in dynamic genome. In maize, a genetic stock (Pusa-TE-1) has been developed that harbours a TE in p1 gene that governs pericarp colour in maize. Here, p1 gene produces red colour in the pericarp. However, when the allele possesses TE, its function is disrupted leading to the colourless pericarp through which yellow endosperm becomes visible. However, when TE is excised from the p1 gene, its normal function is restored and it starts producing red colour in those respective cells. This gives a typical red coloured stripes - a signature of this TE. This genetic stock is quite useful for demonstration of the concept of 'jumping gene' to the students.

Pusa-TE-1 displaying coloured stripes in pericarp due to activity of TE

Turcicum leaf blight (TLB resistant)	Maydis leaf blight (MLB resistant)	Curvularia leaf spot (CLS resistant)	*Chilopartellus* tolerant	TLB + MLB resistant	MLB + CLS resistant	TLB + MLB + CLS resistant
HKI 163, DDM 207, DDM 309, PML 4, CDM 308	CDM 345, CDM 306, PML 80, CM 138	CDM 1306, PDM 188 CDM 305 PDM 4641	DDM 303, PML 23, CDM 351, CDM 329	PDM 4641, PDM 194-2, CDM 345 DIM 302	CDM 306 CDM 305	PDM 188 CDM 1305 PDM 4641

Identification biotic stress tolerant genotypes: A set of 100 newly developed inbreds against Turcicum Leaf Blight (TLB) and 25 inbreds against Maydis Leaf Blight MLB, Curvularia Leaf Spot (CLS) and shoot borer were screened under artificial epiphytotics.

Maintenance and utilization of germplasm: About 500 maize inbred lines including 200 introduced lines from CIMMYT and IIMR were maintained and promising ones are being used in developing new single cross hybrids. The TLB resistant and tolerant crosses were advanced to F_2 to develop mapping populations.

DUS characterization of maize inbreds: A total of 20 inbred lines have been characterized for 31 DUS traits. Significant variation was found among the inbreds for different characteristics.

Advancement of generation for new inbred development: About 30 F_2s, 40 F_3s and 60 F_4s were advanced to next generations. The TLB tolerant lines were advanced.

3.1.4 Mustard

Germplasm maintained: 519 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. The details of the *Brassica* germplasms arelisted hereunder.

Mustard germplasm maintained

Species	Number of accessions maintained
Brassica juncea	288
Brassica rapa	27
Brassica carinata	170
Brassica napus	16
Brassica nigra	7
R. caudatus	4
Eruca sativa	2
Lapidium spp.	2
Crambe spp.	2
S. alba	1

3.1.5 Flower & Ornamental Crops

Rose: Eleven varieties of rose, namely such as Dr R.R. Pal, Golden Afternoon, Gulzar, Nilambari, Shola, Rajhans, Swaraj, Belle of Punjab, Nav Sadabahar, Gold Medal and Jayanthi were collected from secondary sources to enrich the existing germplasm.

Potted plants: Twenty two new foliage potted plant species and varieties, namely,Pothos (Silver Streaks), Golden Money Plant, Milky dracaena (milky), Golden leaf Dracaena, Silver Queen Dracaena, *Spathiphyllum*, *Sensiveria trifasicata*, *Sensiveria cylinderica*, *Aglaoenema* (Pink), *Aglaoenema* (Butterfly), *Aglaoenema* (Silver queen), *Alpiniavariegata*, Never Never plant, Miniature *Syngonium* (Pink), Miniature *Syngonium* (Silver), *Diffenbachia*, *Rhoeo* sp., *Aralia* species, *Oxycardiu* variegated, *Pedilanthustit hymaloides*, *Schefflera* variegated, Zamia palm (Dwarf), and *Asparagus* sp. were added to existing germplasm.

Collection of indigenous bulbous flowering plants: To enrich the gene pool of indigenous bulbous flowering plants, several local species were collected by RS, Kalimpong, namely, Alpina-1; Curcuma-1; Hemarocallis-2; Hedychium-2;Hosta-2; Freesia-1; Canna-2; and Amaryllis-1.

3.1.6 FRUIT CROPS

3.1.6.1 Tropical and Sub-tropical Fruits

Mango: In Mango (*Mangifera indica* L.) 14 exotic cultivars, 65 indigenous cultivars/ varieties/ chance seedlings, 183 hybrid progenies and over 400

open-pollinated progenies of Amrapali are being maintained in field gene bank. Genotypes, namely, Amrapali, Mallika, Pusa Pratibha, Pusa Shershtha, Pusa Peetamber, Pusa Lalima, Pusa Arunima and Pusa Surya were exchanged with different research institutions, private and public nurseries, and ICAR-AICRP (Fruits) centers, SAUs and CAUs.

Citrus: At New Delhi different collections/varieties of acid lime (51 Nos.), lemon (16 Nos), sweet orange (27 Nos.), pummelo (25 Nos.), sweet lime (1 No.), man-made hybrids (3 Nos), tangerine (3 Nos), grapefruit (7 Nos), rough lemon (9 Nos), Rangapur lime (2 Nos), Attani (2 Nos), Obovoid (1 No.), Shunkokan (1 No.), Ainkujumisin (1 No.), rootstock hybrids (09), Yamamikan (intermedia) (1 No.), Alemow (1 No.), King mandarin (1 No.), Nagpur mandarin (1 No.), Billikichli (1 No.), Cleopatra mandarin (1 No.), sour orange (1 No.), citron (1 No.) and own raised hybrid progenies (350 Nos.)of rootstock and scion are being maintained/ evaluated. In Kinnow and sweet orange, around 36 mutants/ colchiploids are being evaluated. In pummelo, five collections were registered (IC Nos 628798-628802) with ICAR-NBPGR, New Delhi.

Grape: During the year, 118 genotypes including parents and hybrids have been conserved for further improvement besides 12 rootstocks and its hybrids. During the period, *Vitisvulpina* L. from Bharsar, Uttarakhand, *Vitisjaqumontii* and an exotic species *V. berlandierii* were collected and maintained for rootstock breeding. Several wild *Vitis* sp., *viz*., *V. ficifolia* (EC452206), *V. arizonica* (EC 452207), *V. amurensis* (EC452223) and *V. himalayana* were collected from ICAR-NBPGR RS, Phagli and planted in nursery. Rootstock genotypes, namely, Degrasset, SO4, and St. George were collected from PAU RRS, Bhatinda. During the period 13 hybrids/genotypes were registered (IC No. 628785- 628797) with ICAR-NBPGR, New Delhi.

Visis berlandarii

Vitis jacquemontii

Guava: In *Psidium guajava*, 35 genotypes, over 75 hybrids and one rootstock are being maintained. Beside these other species, namely, *P. pumilum*, *P. guinense*, *P. chinensis*, etc. are also being maintained.

Papaya: Over 24 inbreds (*Carica papaya*) are being maintained at IARI, New Delhi and 8 at IARI RS, Pune. Six wild relatives of papaya, namely, *Vasconcellea parviflora*, *V. monoica*, *V. quercifolia*, *V. goudotiana*, *V. stipulata* and *V. pubescens* were introduced from USDA through ICAR-NBPGR, New Delhi. These genotypes will be used for transferring biotic and abiotic stress tolerance. At Regional Station, Pune about 12 inbreds are being maintained.

Temperate Fruit Crops: At Regional Station, Shimla Apple (94 No.), pear (15 No.), peaches and nectarines (12 No.), prune and plum (7 No.), apricot (23 No.), strawberry (100 No.), kiwi fruit (7 No.), walnut (17 No.), almond (7 No.), persimmon, (5 No.), cherry (16 No.) and pomegranate (21 No.) are being evaluated/ maintained. Besides, two dozen hybrids in apple were evaluated at the station for different horticultural traits.

3.1.7 Vegetable Crops

Cauliflower: Fertile inbred lines (128) were evaluated in three different maturity groups, *viz*., early (64) and mid-early (36) and mid-late (28). Besides, 34 new inbred lines (F_4) were evaluated in early group (18) and mid-early group. For maintenance of 82 lines of early group, selfing and sibbing have been attempted in plants selected for horticultural traits. Besides, eight SI lines of early maturity group were evaluated for horticultural traits and attempted bud-pollination for their maintenance. Thirteen fixed CMS lines of early group were evaluated for horticultural traits and floral traits. In mid-group, seven CMS lines were evaluated for curd traits. Further, conversion of 30 elite inbred

lines using improved *Ogura* sterile cytoplasm and seven lines with *Eru(napus)* sterile cytoplasm have been advanced to BC_{5-8} stages. Profuse seed setting and seed yield was reported in both improved *Ogura* and *Eru(napus)* sterile cytoplasm based CMS lines but negligible in case of DC-394-41-5 (a different CMS cytoplasm). Further, 190 RILs (from PHJ/PS x BR-2/161/207/202) developed for black rot resistance were evaluated for horticultural traits (curd maturity, curd yield) during mid maturity group. Of them, 12 were promising for horticultural traits along with desirable level of resistance against black rot and downy mildew resistance.

Other *Brassica* vegetables: In broccoli, 24 varieties/ breeding lines were raised for advancing them in next generations (S_{4-6}/F_{5-7}). Two CMS lines DC-Brocco-64A and DC-Brocco-15A were also characterized for horticultural traits and selected plants were advanced to BC_5 generation. In tropical 'No Chill type' cabbage, two inbred lines (PA-1 and PA-2) and two CMS lines DC-PA-1A and DC-PA-2A were also raised and selected plants based on plant and head traits to maintain them.

Brinjal: A total of 25 working germplasm ware purified, evaluated and maintained, while 65 segregating progenies were advanced. Wild accessions were maintained and used in cross combinations. A total of 15 new lines of brinjal were collected from different parts of India for evaluation.

Cucumber: During spring summer season of 2019, 168 germplasm /advance breeding lines including 27 new collections and 16 tropical gynoecious lines were evaluated and promising lines were maintained.

Melon: One hundred thirty six germplasm of wild and cultivated relatives of muskmelon was collected from Rajasthan. One hundred twenty two germplasm of muskmelon were evaluated for horticultural traits and resistance against *Fusarium* wilt and these lines were maintained. Forty two muskmelon germplasm were screened in poly house for resistance against powdery mildew resistance and genotype EC751844-3 and oriental melon could be identified as source of resistance. Forty three genotypes of watermelon from *Citrullus lanatus* var. *lanatus*, var. *citroides* and *C. colocynthis* were evaluated and maintained.

Pumpkin: Fifty germplasm/ advanced breeding lines of pumpkin were evaluated and maintained. Pumpkin line DPU-84 having lemon yellow coloured flower as a potential morphological marker is maintained.

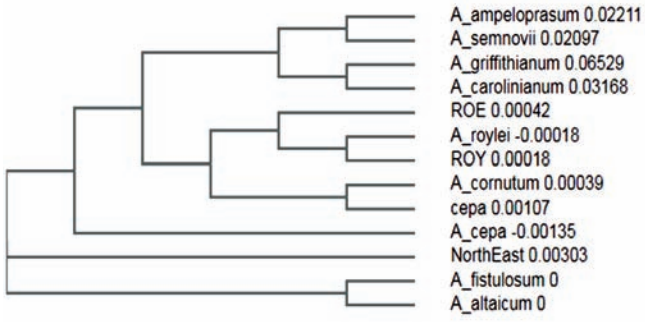
Longmelon and Round melon: Twelve germplasm/ advanced breeding lines each of long melon and round melon were maintained. Long melon lines DLM 19-2 with segmented leaf and DLM 14-1 & DLM 24-1 having dark green skin colour were maintained. Longmelon line DLM 19-2 with segmented leaf was crossed with Pusa Utkarsh to study the inheritance of segmented leaf character.

Carrot: Forty inbred lines were planted for maintenance and crossing programme. Selected roots of ten genotypes were planted for purification and further multiplication. Four CMS lines were found to be uniform and are being maintained.

Onion: Forty five germplasm lines, 320 breeding lines, 25 S2M1, 340 hybrids with parents, 45 exotic and 30 onion and 12 garlic varieties are being maintained.

Morphological and floral traits of a new cultivated *Allium* species

Based on the ITS barcoding, this species (North East) seems to be a cross between onion and *Allium fistulosum*. The chromosome number of the new species is also 16 (2n), which is equivalent to the chromosome number in onion and *A.fistulosum*. Further, studies are needed to authenticate the true identity of this new *Allium* species.



Establishment of North East *Allium* species identity based on ITS sequencing

Garden pea: One hundred germplasm lines including 17 imported lines from USA of garden pea were rejuvenated and maintained. Among these 10 lines were found resistant to powdery mildew and two new lines were bulked as GP 1805 and GP 1806 based on horticultural traits for yield and furtherevaluation.

Okra: Forty three selected wild okra accessions of different species, namely, *Abelmoschus angulosus*, *A. tetraphyllus*, *A. moschatus*, *A. caillei*, *A. ficulneus*, *A. mizoramensis* and A. *tuberculatus* were screened for YVMV and ELCV resistance. The F_1 and back cross populations of wild with cultivated in the background of Pusa A4, Pusa Bhindi-5 and DOV-92 were evaluated. The population which was free from YVMV and ELCV were selected. Advance cross combination of *A. moschatus* and *Abelmoschus angulosus*, namely, Am66-2 in the background of Pusa Bhindi-5, Am92-1 in the background of DOV-92 and Am4-1 in the background of Pusa A-4 were found resistant as well as had desirable fruit set with improved fruits type. Resistant plants from crosses of cultivated and *A. tetraphyllus* and *A. caillei* were selected for further generation advancement.

***Abelmoschusmoschatus* and *A. angulosus* derived lines**

At Regional Station, Katrain a good number of germplasm of different vegetable and ornamental crops are being maintained. The details are as follows:

Cabbage: About 165 germplasm including 12 DH lines, 7 self-incompatible lines and 32 CMS lines along with their respective maintainers were purified and maintained.

Cauliflower: A total of 166 germplasm lines of white cauliflower (50 CMS and 50 maintainers, 30 OP, 20 EC lines and 8 DH based CMS lines and 8 DH based maintainers) were purified and maintained during the year 2019. Besides these, five genotypes each of orange and purple coloured cauliflower were advanced to BC_2 generation at ICAR-IARI RS, Katrain.

Wild *Brassica*: 32 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*, *Rorippaislandica*, *Sisymbrium officinale*, *S. irio* and *S. orientale* collected from Kulluvalley were maintained and evaluated for insect resistance traits.

Capsicum: Three CMS lines of capsicum were maintained by crossing with their respective maintainers. Besides these, 50 other open-pollinated genotypes and 10 advanced breeding lines of chilli/ paprika were also maintained under polyhouse conditions.

Temperate carrot: About 70 germplasm lines including 27 EC and IC lines, and 20 CMS lines along with their respective maintainers were purified and maintained.

Broccoli: Total of 20 germplasm and 8 CMS lines along with their maintainer lines were purified and maintained.

Summer Squash: Thirty-five open-pollinated contrasting genotypes (green, orange, yellow, creamy white) were purified and maintained.

Onion (Long day): Forty advanced breeding lines of long day onion (red, yellow, white) were purified and maintained at ICAR-IARI RS, Katrain.

Temperate flowers: About 50 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 for crop improvement programme.

3.2 BIOSYSTEMATICS AND IDENTIFICATION SERVICES

3.2.1 Pathogen Diagnostics and Genetic Variability

Identification and maintenance of fungal cultures and specimens: About 50,460 fungal specimens at HCIO and 4075 fungal cultures at Indian Type Culture Collection (ITCC) were maintained under different preservative methods.Authentic fungal cultures of 570 fungal specimens were supplied to different scientists and institutions and 303 new cultures were identified.

***Taxonomy of Genus Cercospora in India*:** A study was conducted to provide an update that includes synonyms, morphological descriptions, illustrations, host range, geographical distribution and literature related to the *Cercospora* species present in India. The present study represents a compilation of 489 species of *Cercospora* associated with 603 host plants collected from several states in India between 1894 and 2018 and deposited in Herbarium Cryptogamae Indiae Orientalis (HCIO), New Delhi. Fifty eight plant species were found infected with *C. apii*, mainly belonging to the families of Asteraceae, Convolvulaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Polygonaceae, Solanaceae and Urticaceae.

***Genetic Diversity among Atheliarolfsii isolatesd of different host plants of Tripura region*:** Sixty isolates of fungus collected from yam, hibiscus, colocasia, brinjal, sunflower, kalmegh, balsam, spring coriander, neem, thumbe, tomato *etc.* in different region of Tripura were identified belonging to *Athelia rolfsii* on the basis of morphology and molecular biology. ITS sequences of different isolates showed that *A. rolfsii* had high genetic diversity.

Morphology and phylogeny based diversity analysis of agricultural important cryptic species of Fusarium solani species complex (FSSC): Seventy five isolates belonging to the FSSC were characterized based on morphological features and selected for molecular studies using translation elongation factor-1 (TEF-1α). Based on morphological features and phylogenetic analysis, all the isolates were classified into seven described cryptic species, *viz*., *Fusarium falciforme*, *F. petroliphilum*, *F. keratinoplasticum*, *F. metavorans*, *F. solani* f. sp. *pisi*, FSSC 5 and FSSC 21. The phylogenetic tree based on TEF-1α dataset clearly distinguished the closely related species and separated distinctly all taxa at morphological level. *Fusarium falciforme* was found as the most dominant cryptic species of *Fusarium solani* species complex present in India, which contributes alone more than 58% and causing disease to diverse agricultural crops.

3.2.2 Insects Systematics

Biosystematic studies on insects of economic importance: Maintenance of National Pusa Collection with 9,66,076 specimens in terms of curation, augmentation, deposition, loan of material etc. was continued. Specimens of 8 holotypes and 258 paratypes and 15,000 specimens belonging to 150 already known species were augmented to NPC.

***Identification service*:** A total of 2,266 specimens received from all over India were identified. The details are:Coleoptera: 157; Hymenoptera: 437; Diptera: 1068; Hemiptera: 340; Lepidoptera: 121; Others: 143.Survey and collections were made from 10 states of India. Almost all different crop groups in both vegetative as well as reproductive phases were covered during the

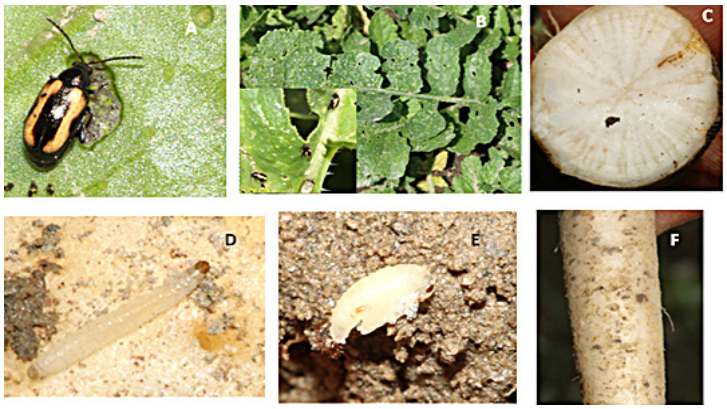
surveys. More than 20,000 specimens were collected and more than 700 field visuals on the various life stages and adults could be documented.

Coleoptera: A new species, *Lanelateranda manensis* sp. nov.was described from the Little Andaman Island located in the Andaman group of Islands, India. *Lanelater* Arnett is a new record for Andaman Islands. The new species differs from its congeners being much shiny, covered with longer golden yellow setae, slightly convex pronotum, and the median lobe of genitalia abruptly tapering near distal 1/3rd which is unique to this species. The adults of *L. andamanensis* sp. nov. resemble *L.attonitus* (Candeze,1874), in body shape and coloration of setae, but differs from it by the absence of spots on frons, pronotum not convex in middle and shallow groove at the base of prosternal spine. Genitalia of the new species is similar to *L. scutopentagonus* Vats & Kashyap, 1993, *L. glabrosus* Vats & Kashyap, 1993, *L. fuscipes* (Fabricius, 1775) and *L. cinereus* (Candeze, 1857) in having median lobe slightly longer than parameres. However, it differs from them in not having a weak subapical tooth, and the median lobe abruptly tapering near distal 1/3rd, and in having a slight bent near the distal 1/3rd, which is present only in the new species. *L. scutopentagonus* differs from the new species in having much narrower body shape, and surface densely covered with setae, and prosternal spine without a longitudinal groove at base; *L. glabrosus* and *L. fuscipes* differ by more convex and glabrous body surface, in addition to these the tip of median lobe of genitalia is round in *L. fuscipes* and truncated in *L. glabrosus*. Further, the new species is distinct from those in body plane and coloration of setae. The existing checklist was modified to include all the 20 species reported till date from Indian subcontinent.

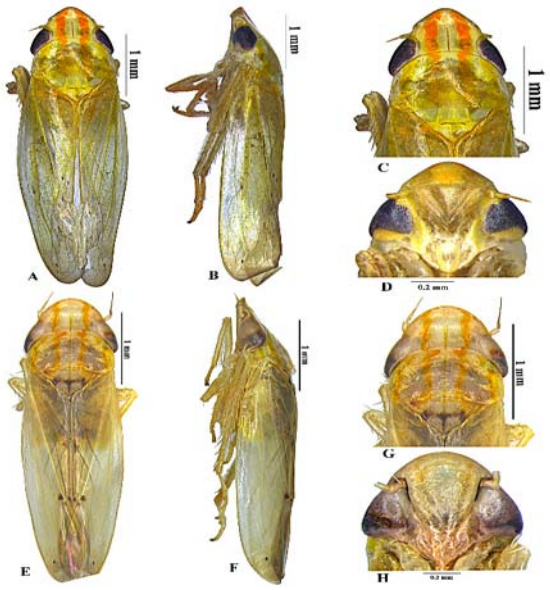
A survey of radish fields in outskirts of Delhi was conducted to diagnose a new pest attack during March, 2019. The pest was identified as *Phyllotretas triolata* (Fab.) (Coleoptera: Chrysomelidae). About 4-5 adult beetles were observed on each leaf of the plant at Palla in Haryana and Mayur Vihar in Delhi. Symptoms and stages of the pest were documented in detail.

Hemiptera: The phylogeny of the *Pseudosubhimalus* were investigated using of two different data sets, including 91 taxa and 3853 aligned nucleotide positions from the histone H3, 28S rDNA (D2 & D9_10 region). The results suggest the placement of genus in the tribe Ciacadulini, as it was clustered with *Cicadulini* genera. Relationships between genera of the Cicadulini were strongly supported and leads placement to tribe Cicadulini from Athysanini. Genus *Pseudosubhimalus* Ghauri was revised, and a new species *P. trilobatus* sp. nov. from Himachal Pradesh: Katrain was described from Indian subcontinent and deposited to National Pusa Collection, IARI, New Delhi.

A new species *Hishimonusadi* sp. nov. (Arunachal Pradesh: Pasighat) is described and illustrated from India. A modified checklist and annotated key has been provided for the all the 25 species reported till now from Indian sub-continent. Two new species of



Pest identified as *Phyllotreta striolata* (Fab.) (*Coleptera: Chrysomelidae*) at Palla in Haryana and Mayur Vihar in Delhi



A-H. Habitus of *Flatfronta*: **A-D.** *Flatfronta dibangi* **sp. nov.** A Habitus dorsal, **B.** Hibitus Lateral **C.** Head with pronotum. **D.** Facr; *F. uttara* **sp. nov.: E.** Habitus dorsal **F.** Habitus latcral, **G.** Head with pronotum, **H.** Face

the bamboo-feeding leafhopper genus *Flatfronta*, *F. dibangi*sp. nov. (Arunachal Pradesh: Basar) and *F. uttara*sp. nov. (Uttarakhand: Pantnagar) have been described and illustrated from India. A checklist and a key to known species of the genus has also been also provided. Types are deposited in the National Pusa Collection (NPC), ICAR-IARI, New Delhi.

Plant hopper *Cemus sauteri* (Muir) was recorded for the first time from Bilaspur (Himachal Pradesh), Raichur, Bidar (Karnataka). Earlier this species was recorded from China, Japan, Fiji and Srilanka. Plant hopper *Cemus zhitus* Kuoh was recorded for the first time from from Bilaspur (Himachal Pradesh), Raichur, Bidar (Karnataka), Hawalbag (Uttarkhand) and Malkhed forest (Maharashtra). Earlier this species was recorded in China.

Hymenoptera: Genus *Philotrypesis* with 14 reported species is the most diverse fig wasp genus in India. Present studies resulted in the transfer of *Philoverdanceravii* Priyadarsanan, 2000 to genus *Philotrypesis* and therefore a new combination, *i.e. Philotrypesisravii* comb. nov. was established. Three new species, *viz. Philotrypesis nigra* sp. nov., *P. robusta* sp. nov. and *P. viridis* sp. nov. were described based on both male and female specimens. While the first one was collected from fruits of *Ficus benjamina* L.from Arunachal Pradesh, the latter two were reared from *F. amplissima* Smith. from New Delhi. Additionally the previously unknown male of *Philotrypesis tridentata* Joseph, 1954 was also described. Thus currently 18 species of this genus are known from India. Further to differentiate both sexes of all *Philotrypesis* species reported from India an identification key for 18 species (including the new species) was formulated and which is so far the most comprehensive species level diagnostic key for the genus at global level. Further the host fig association of the Indian *Philotrypesis* species and incidence of male polymorphism was also studied.

Lepidoptera: Basil (*Ocimum basilicum* L.) an important aromatic plant is cultivated worldwide. For the first time, a Perilla leaf moth, *Pyrausta panopealis* (Walker, 1859) (Lepidoptera: Pyralidae) was found to cause economic damage to Basil in India. The identity of the pest species was determined through morphological and molecular techniques.

The fall army worm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) a destructive invasive insect pest of cereal crops native to American continent was recorded for the first time from Nepal (Nawalpur district) during May 2019 in collaboration with Nepal researchers.

Diptera: Studies on the phytophagous genus *Eumerus* (Diptera—Syrphidae) was continued. Redescription, molecular characterization and phylogeny of *Eumeru srufoscutellatus* (Diptera: Syrphidae) infecting riverlily (*Crinum vivparum*) and *E. figurans* infecting ginger was completed. Molecular phylogeny of *E. rufoscutellatus* was constructed (based on Maximum Likelihood method using MEGA7) to know its relation with *E. fumeralis* and *E. strigatus* which infest onion in other counties. It was found that *E. rufoscatellatus* did not cluster with the above two species group. *Eristalinustaeniops* (Wiedemann) was recorded from India from Palampur, Himachal Pradesh for the first time. It was redescribed with additional features of male genitalia. Further phylogenetic analysis of seven species of genus *Eristalinus* was completed.

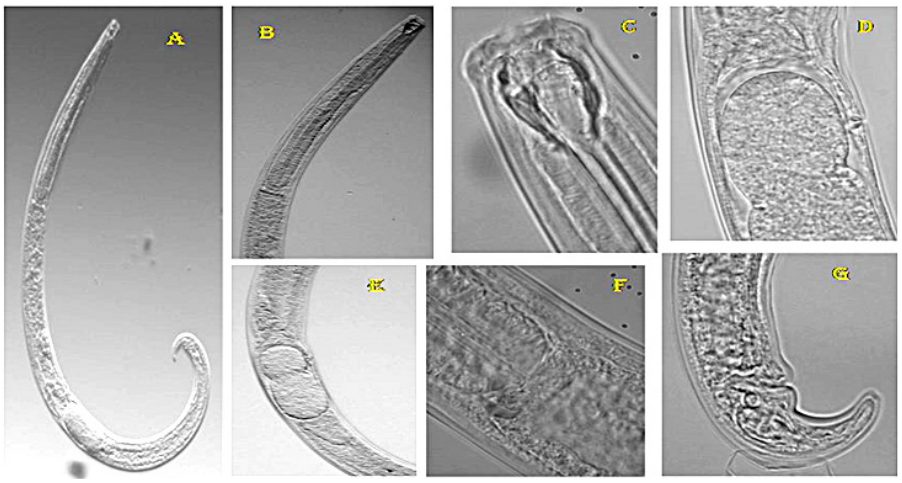
Intensive surveys were conducted to record the important native pollinators for radish seed production in Kullu Valley. Surveys conducted during flowering season recorded 32 species of flower visiting insects belonging to 5 orders and 14 families from seed production farms of IARI Regional Station Katrain. Of these, 11 species belonged to Hymenoptera, 15 to Diptera, 3 to Lepidoptera, 2 to Coleoptera and 1 to Hemiptera. Among the recorded flower visitors most efficient pollinator will be identified after studying flower visiting frequency and seed setting percentage due to single visit of pollinating species during the subsequent flowering seasons.

3.2.3 Nematode biosystematics

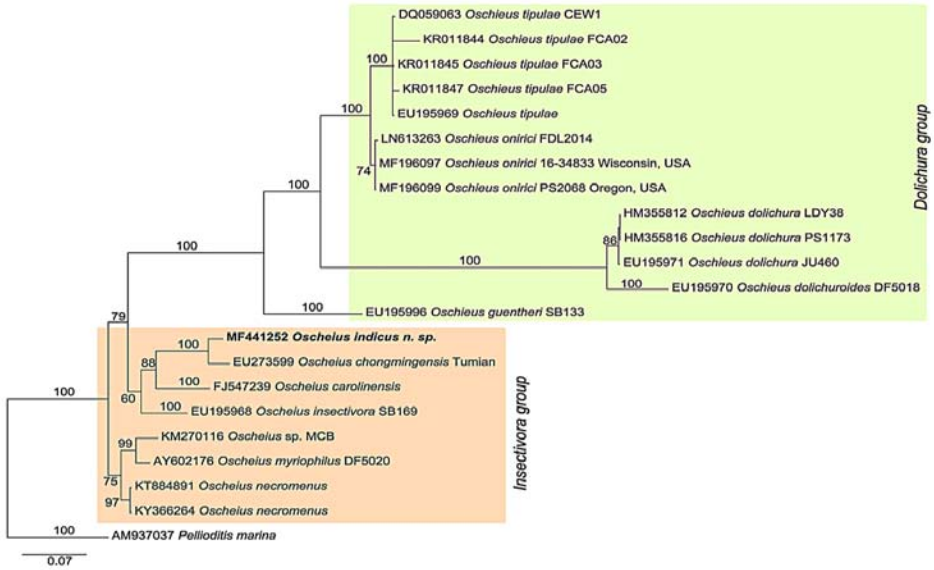
Identification of new species and diversity analysis: Nematode infested olive root samples received from six districts of Rajasthan and examination of root and perineal pattern study of mature females from each sample revealed infection of *Meloidogyne javanica*. However, the perineal patterns showed considerable variations. Samples analyzed from five districts of Jharkhand and 58 nematode genera belonging to 11 orders were identified; Tylenchida (13), Dorylaimida (12), Aphelenchida (2), Araeolaimida (6), Cephalobida (10), Chromadorida (1), Diplogastrida (1), Enoplida (2), Mononchida (3), Rhabditida (7), and Triplonchida (1). Among Tylenchida, the most abundant genus was *Meloidogyne*; other important genera were *Pratylenchus, Rotylenchulus, Hirschmanniella, Helicotylenchus, Tylenchorhynchus, Quinisulcius, Criconemoides, Tylenchus, Filenchus and Psilenchus*. Predatory nematodes belonging to the Mononchida include genera *Lotonchus, Mononchus* and *Mylonchulus* were less abundant in the rice ecosystem of Jharkhand.

A new species of a predatory nematode *Mylonchulus tuberosei* sp. n. (Nematoda: Mononchida) is identified based of morphological and morphometrics studies This new species was collected from rhizosphere of tuberose (*Polianthes tuberosa* L.) from Mr. Radhey Shyam's field of village Anwarpur, district Hapur (Uttar Pradesh).

Another new species of the genus *Oscheius* was described as *O. indicus*n. sp. on the basis of morphological and molecular data. The species was characterized by females having a medium-sized and slender body, four incisures each in the lateral fields with three minute warts, long rectum, nine pairs of papillae, a prominent double-flapped epipytigma on vulval opening, presence of open leptoderan bursa and crochet needle-shaped spicules. Morphological observations and molecular phylogenetic analysis suggested that *O. indicus* n. sp. was sufficiently different from any known species and was therefore proposed as a new species within the insectivora group.



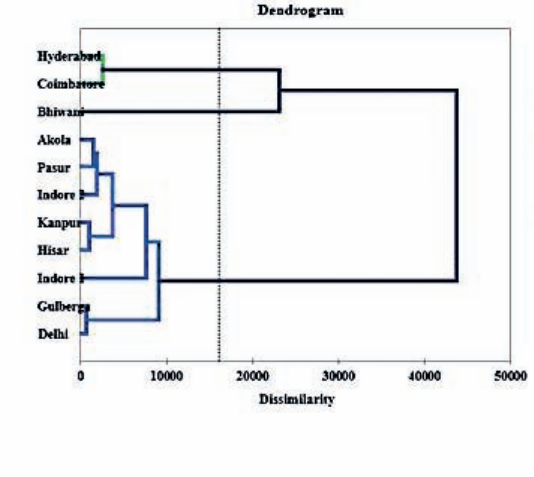
***Mylonchulus tuberosei* sp. n.A – Entire female; B – Pharyngeal region; C – Feeing apparatus; D –Vulval opening; E – Female reproductive system; F – Cardia; G - Tail**

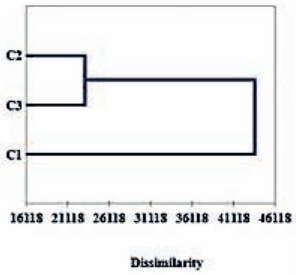


Molecular phylogenetic relationship of *Oscheius indicus* n. sp. (highlighted in bold) inferred using 28S D2/D3 extension region of 28 rDNA gene. Orange and green shaded boxes indicate insectivora and dolichura group, respectively.

Variability among Indian populations of Heterodera cajani: The cyst forming nematode, *Heterodera cajani* Koshy 1967 is a serious pest of pigeon pea in India. It infects several crops which include pigeonpea, soybean, mung, cowpea etc. Taxonomic studies were undertaken on 11 populations of *H. cajani* collected from 8 pulse-growing states of India *viz*. Haryana (Hisar, Bhiwani), Karnataka (Gulbarga), Madhya Pradesh (Indore-1 and Indore-2 infecting pigeon pea and soybean), Maharashtra (Akola), New Delhi (Delhi), Tamilnadu (Coimbatore and Pasur), Telangana (Hyderabad) and Uttar Pradesh (Kanpur). The Discriminate analysis and hierarchical cluster analysis, derived from Euclidean distance coefficients, Agglomerative Hierarchical Clustering (AHC) dissimilarity by Ward's method, based on morphometric characters of cysts, J2s and males from 11 populations gave phenological dendrogram with three categories (i) Cluster 1 comprising of Delhi, Hisar, Kanpur, Indore, Gulbarga, Pasur and Indore and (ii) Cluster 2 Coimbatore and Hyderabad and (iii) Cluster 3 Bhiwani population

Further, statistical analysis based on molecular characterization employing ITS, D2D3 and CO1 sequences of 11 *H. cajani* populations revealed a low nucleotide diversity and low-frequency of polymorphism among these populations.





Populations	Class
Delhi	1
Coimbatore	2
Hisar	1
Kanpur	1
Bhiwani	3
Indore 1	1
Hyderabad	2
Gulbarga	1
Pasur	1
Indore 2	1
Akola	1

Relationship among populations of Heteroderacajanion the basis of Agglomerative hierarchical clustering

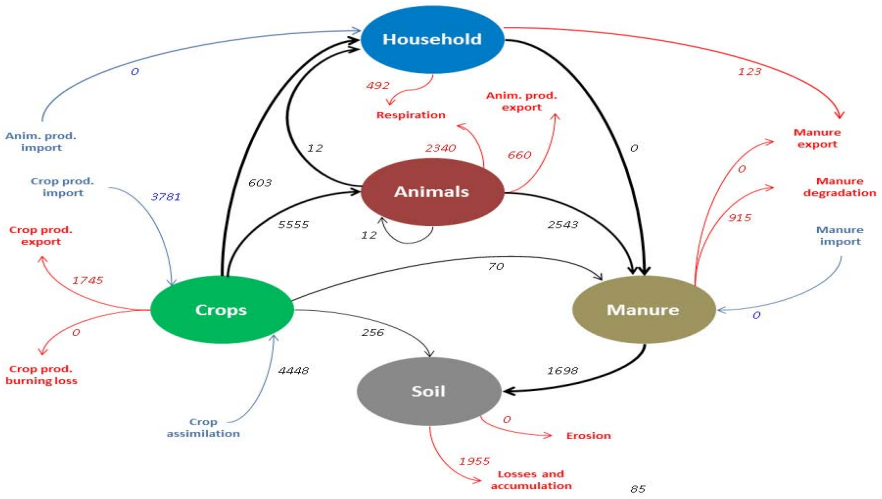
4. CROP AND NATURAL RESOURCE MANAGEMENT FOR SUSTAINABLE ENVIRONMENT

The Disciplines of the School of Natural Resource Management have made significant innovations towards enhancing the productivity, profitability, and sustainability of crops/ cropping systems. An integrated farming system model ensuring year-round income and employment of the small farmers has been developed. Precision nutrients management options using gadgets/ tools and bio-inoculants were advocated for enhancing nitrogen-use efficiency. Conservation agriculture-based cropping systems have been developed for higher productivity, resource-use efficiency, and adaptation and mitigation to climate change. Research on soil and nutrient management led to developing a rock phosphate (RP) enriched organic manure, which could save costly P fertilizer by 50%, and integrated nutrient management option that improved microbial diversity and resilience capacity against heat and moisture stress. Sensing devices for flow measurement and irrigation scheduling were developed for efficient water management. *Typha latifolia* and *Phragmites karka* were found more efficient for reducing multi-metals in waste water. Several promising agro-techniques were optimized for production of vegetables and horticultural crops under protected environment. Improved urea ammonium nitrate (UAN) applicator, pressurized aqua ferti seed drill, turner-cum-mixer for pit composting, variable rate fertilizer applicator and small-scale packaging machine for pulses were successfully developed and tested with better results. Novel processing technologies have been developed for enhancing the shelf life and nutritional value of various fruits and vegetables. Microbiological research led to the development of BGA-based composite liquid formulation for higher rice productivity, and a liquid BioIron formulation for increasing Fe content in wheat grain and straw. Bio-prospecting of rhizospheric and endophytic cyanobacterial diversity was done for increasing N uptake and rice yield. Seasonal climate change projections have been made for Indian region with global climate models. The use of urease inhibitor limus on neem coated urea could lead to an increase in wheat yield by 12.5% and reduction in nitrous oxide emission by 19.8%. Mitigation of methane emission in rice was achieved by using liquid formulation of methane oxidizing bacteria.

4.1 AGRONOMY

4.1.1 Integrated farming system for higher carbon recycling

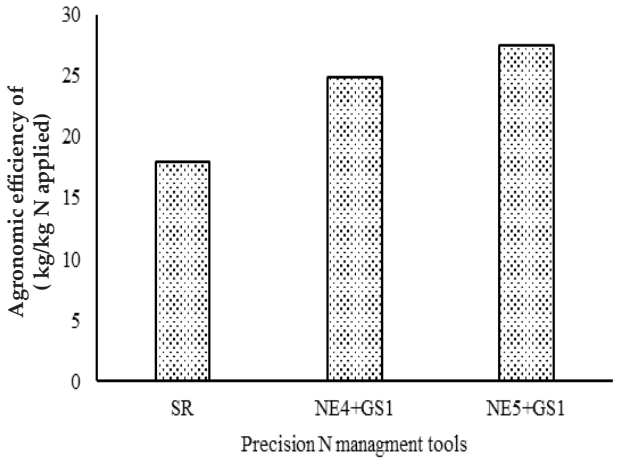
Integrated farming system (IFS) model has been developed with the concept of integration of multiple enterprises (crops, livestock, beekeeping, fisheries, *etc.*) in a farm house hold with the objective to ensure year-round income and employment to small holder having 1 ha irrigated land. Net annual income of model after three years was ₹ 3.79 lakh along with 628 man days. Among different enterprises maximum net income (₹ 1.62 lakh year^{-1}) was obtained from livestock (3 crossbreed cows). Carbon (C) recycling as an indicator of the system sustainability was assessed using farm design tool under crop-livestock module. Model predicted total carbon assimilation by the different crops grown was 4,448 kg year^{-1}. Further, carbon input from different crops to household needs and livestock enterprise was 603 and 5,555 kg annum^{-1}, respectively. Similar additions of carbon to the soil through crops and manure were 256 and 1698 kg annum^{-1}, respectively. Increasing C accumulation in soil indicates crop-livestock module has potential for improving soil health and bringing long- term sustainability of the system.



Carbon recycling under crop-livestock IFS model

4.1.2 Use of Nutrient expert® and Green Seeker in maize for higher N use efficiency

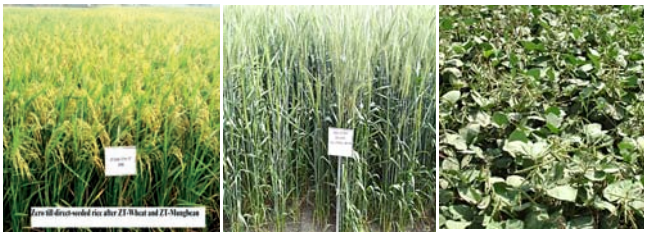
In order to achieve the higher N use efficiency decision support tools, *i.e.* Nutrient expert® (NE) and Green Seeker (GS) were evaluated in maize. Significantly higher agronomic efficiency and partial factor productivity of N in maize was observed due to application of basal and 1st split of N based on nutrient expert (NE) recommendation followed by NDVI based N using GS at Feekes 5-6 stages over state recommendation (SR). Integrated use of NE and GS also helped in curbing N leaching as indicated by lesser NO_3-N availability in lower profile.



Agronomic efficiency of N in maize influenced by different precision management tools

4.1.3 Conservation agriculture (CA) based direct-seeded rice-wheat-mungbean system

A long-term CA-based triple zero-till (ZT) system with three crops (rice, wheat, mungbean) residue, which involved ZT-DSR with summer mungbean residue (MR)–ZT wheat (ZTW) with rice residue (RR)–ZT summer mungbean (MB) with wheat residue (MR+ZTDSR-RR+ZTW-WR+ZTMB) had ~33.5% higher system productivity, besides saving of 25% N (amounting to 60 kg Nha^{-1}) in rice and wheat compared to conventional transplanted rice-wheat system. It also had higher water and energy productivity along with reduced greenhouse gas (GHG) emission.



Zero-till DSR, wheat and summer mungbean with previous crops residue in system

4.1.4 Conservation agriculture based cotton-wheat system as an alternative to rice-wheat system

The CA-based cotton-wheat system was found as a superior alternative to diversify the predominant rice-wheat system in the Indo-Gangetic Plains (IGP). The

zero till flat bed (ZTFB) and zero till permanent broad bed ZTPBB along with residue and 100% recommended N resulted in 15 and 13% higher system productivity, respectively as compared to conventional till system. The ZT PBB with residue and 75% N was comparable 100% recommended N use, indicating a saving of 25% N, amounting to 67.5 kg N ha^{-1} in the system.

4.1.5 Conservation agriculture based pigeon pea-wheat system as a promising crop diversification option for rice-wheat system

CA-based pigeon pea-wheat system grown under ZT flat bed with residue (ZTFB+R) and permanent broad bed with residue (PBB+R) were superior to conventional tillage (CT) grown rice- wheat system. The ZTFB +R and PBB+R resulted in ~19 and ~18% higher system productivity over CT system

Pigeon pea and wheat crops grown under the zero-till permanent broad bed with residue

4.1.6 Summer green-manuring and sulphur fertilization under basmati rice–durum wheat system

Under basmati rice–durum wheat cropping sequence, the highest grain yield of rice (~4.49 t/ha) and wheat (~5.27 t/ha) were recorded due to direct and residual effect of *dhaincha* green manuring. The application of bentonite (90% sulphur) @ 40 kg/ha to rice recorded ~8–8.74% higher rice grain yield, whereas the highest wheat yield (~5.66 t/ha) was recorded when the same was applied to both rice and wheat crop (~35.7% higher over control).

4.1.7 Enhancing farm income through crop diversification under limited water use

Different promising cropping systems including agri-horti systems were evaluated under limited irrigation situation. Among these, maximum system productivity (5.89 t/ha) and net returns (₹ 1.93 lakh ha^{-1}) were recorded with babycorn-chickpea cropping system followed by babycorn-barley.

Baby corn and chickpea grown under agri-horti systems

4.1.8 Sustainable crop intensification through conservation agriculture and pulse integration under rainfed systems

The highest chickpea equivalent seed yield (1473 kg ha^{-1}) was recorded with zero tillage + residue mulch (ZT + RM). Increase in chickpea equivalent yield was recorded by 4.86 and 30.8% with 4 t/ha residue than 3 and 2 tha^{-1}residues, respectively. Among the crops, chickpea grown after pearlmillet recorded significantly higher grain yield (1594 kg/ha), which led to 54 and 27.8% increment over lentil and barley, respectively. Among tillage, ZT + RM registered the highest net returns (₹ 31,923 ha^{-1}), benefit: cost ratio (0.88) and water use efficiency (8.51 kg ha^{-1}/ ha-mm), whereas CT recorded the lowest net returns (₹ 20,271/ha),

Chickpea and barley grown under zero tillage + residue mulch

benefit: cost ratio (0.64) and water use efficiency (6.51 kg ha^{-1}-mm).

4.1.9 Evaluation of ZnO nanoparticle embedded N:P:K (15:15:15) complex fertilizer in wheat

The evaluation of ZnO nanoparticle embedded N:P:K (15:15:15) complex fertilizer in wheat suggested that 100% NPK [100% RDK through ZnO nanoparticle embedded N:P:K (15:15:15) and 75% NPK [75% RDK through ZnO nanoparticle embedded N:P:K (15:15:15) produced statistically at par grain yield. Thus, 25% NPK can be saved under 75% NPK through ZnO nanoparticle embedded N:P:K (15:15:15) complex fertilizer. Relatively higher nutrient use efficiency indices, net returns and B: C ratio were also recorded under this treatment over 100% NPK [100% RDK through N: P:K (15:15:15) complex fertilizer].

4.1.10 Evaluation of wheat varieties at different sowing dates

In a field trial, diverse wheat varieties *viz*., HS 562, HD 2967, HD 3086, HI 1544, MACS 6222 and WR 544 were evaluated under four dates of sowing *viz*., 5th November, 25th November, 15th December and 5th January to find out the performance under changing climatic scenario during 2017-18. Results indicated that 25th November sowing recorded maximum (grain 5.27 and biological 12.98 t/ha) yields during first year but in second year 5th November sowing gave highest wheat grain and biological yield (5.74 and 12.46 t ha^{-1}). In case of wheat varieties, HI 1544 produced maximum grain (5.09 and 5.55 t ha^{-1}) and biological yields (12.42 and 13.98 t ha^{-1}) in both the years, which were significantly higher than rest of the varieties.

4.1.11 Performance of wheat in different tillage and crop establishment, residue and nutrient management options

The results of the field study revealed that all the growth attributes, effective tillers m^{-2}, other yield attributes, grain yield and biological yields were higher in conventional tillage-raised bed (CT-RB) and conventional tillage-flat bed (CT-FB) as compared to zero tillage flat bed and raised bed. Among residue and nutrient management treatments, significantly higher growth, yield attributes and yields were recorded with the application of residue @ 3 t ha^{-1} + RDF as compared to the other treatment combinations of no-residue, no NPK fertilizer or sub-optimal NPK use.

4.1.12 Evaluation of different *rabi* crop genotypes for higher productivity and profitability under rainfed condition

Three pulse crops *i.e.* chickpea (cv. Shubhra and Ujjawala), lentil (cv. Pusa Vaibhav and Shivalik) and grass pea (cv. Rajendra Khesari 1 and Prateek) were evaluated under different tillage and residue management practices. Maximum growth, yield attributes and yield of pulses were under conservation agriculture with 3 t ha^{-1} rice residue. Among the different varieties grown maximum grain yield was obtained with chickpea cv. Ujjawala, grass pea cv. Prateek across the tillage and residue management options. However, lentil cv. Shivalik performed well in conventional agriculture practice and cv. Pusa Vaibhav in conservation agriculture. Noticeably *Fusarium* wilt problem was observed more in chick pea cv. Ujjawala grown under conventional agriculture while no such disease was noticed when it was grown with conservation agriculture along with 3 t ha^{-1} residue.

4.2 SOIL MANAGEMENT

4.2.1 Nature of clay-humus complexes as affected by long-term integrated nutrient management

The FTIR spectra of clay, humus and clay-humus of soil samples indicated that humus had more adsorbed water led to strong water absorption band of these complexes due to inorganic cations. FTIR adsorption bands at 1713 cm^{-1}(C=O stretching of COOH and ketonic C=O), 1609 /cm (aromatic C=C), and 1217 cm^{-1} (C-O stretching and OH deformation of COOH groups) was observed in humic acid. However, the reactive functional groups at these bands were reduced in clay–humus complex due to polymerization between clay and humus, which shifted towards a broad absorption

band at 1026 cm^{-1}. This alteration of humic acid peak in clay–humus complex indicated the involvement of ketones, carboxyl and amide moieties in complexation with octahedral OH of the clay minerals leading to stabilizing of carbon in humic acid through clay-humus bonding.

4.2.2 Assessment of maximum carbon carrying capacity and nutrient release pattern in major soil orders of India

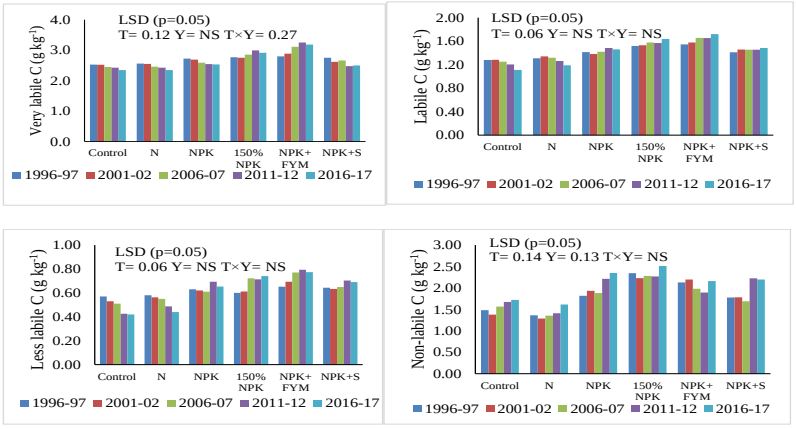
The maximum carbon carrying capacity (C_m) of Inceptisol (Ludhiana), Mollisol (Pantnagar), Vertisol (Jabalpur) and Alfisol (Ranchi) was assessed using carbon saturation model. For this purpose, soil data as generated in long-term manorial trial with 100%NPK, 50%NPK+50%N-FYM, 50%NPK+50%N-GM (green manuring) and 50%NPK+50%N-WS (wheat straw incorporation) continuing in the above soil orders since 1983 were used. The decay rate constant k, which was estimated as 0.0012, 0.0030, 0.000062 and 0.00067 yr^{-1} for Inceptisol, Mollisol, Vertisol and Alfisol, respectively. The C loss from native SOC over last 30 years of cultivation was 0.12, 0.30, 0.0062 and 0.067% of the initial SOC content. The annual C input required to maintain SOC in equilibrium (A_E) was 1.49, 2.29, 0.034, 0.621 Mg ha^{-1} yr^{-1}in Inceptisol, Mollisol, Vertisol and Alfisol, respectively. The C_m was estimated to be 49.7, 66.6, 56.8 and 50.7 Mg ha^{-1} (0–60 cm) in Inceptisol, Mollisol, Vertisol and Alfisol, respectively. Among the soils, the Mollisol had highest C_m followed by Vertisol, Alfisol and Inceptisol. Further, release kinetics of major nutrients (N, P and S) were studied in soil, collected from LTFEs under rice-wheat and maize-wheat cropping systems. Results indicated the highest microbial activity in NPK+FYM treatment followed by NPK+straw and NPK+GM. Among the soil orders, Mollisol had the highest value of mineralizable N at 0 and 360 days of incubation and lowest was with Alfisol but in Inceptisol had the highest value at 30 and 90 days of incubation.

4.2.3 Effect of pre-treatment on the identification of clay minerals

From each soil order, clay (with pre-treatment) and colloidal organo-mineral fraction (COMF) (without pre-treatment) were isolated and the XRD analyses and semi-quantification of minerals were done following standard procedures. Results indicated that chlorite peak was distorted due to chemical pre-treatment with large amounts of H_2O_2 for removal of organic matter from Mollisol. It can be concluded that identification and semi-quantification of clay minerals by XRD can be done with reasonable accuracy even without chemical pre-treatment in Alfisol, dominated by kaolinite rich interstratified minerals (KRM) and illite rich interstratified minerals (IRM).

4.2.4 Quality of soil organic carbon (SOC) under long-term manuring and fertilization

Results of 46-year old long-term experiment at New Delhi indicated that SOC pools of higher lability *viz*. very labile, labile and less labile SOC increased



Temporal changes in very labile, labile, less labile and non-labile C under long-term application of fertilizer and manures

significantly over the years under 150% NPK and NPK+FYM. On the contrary, control and N alone registered a decrease in these SOC pools (Figure 12). The NPK+FYM registered the highest quantity of humic acids (HA), with higher E4/E6 ratios compared with that extracted from 150% NPK. Fourier transform-infra red spectra registered presence of characteristic bands/ peaks at wave numbers 3200-3600 cm^{-1}, 2915-2925 cm^{-1}, 1620-1640 cm^{-1} and 1200 -1230 cm^{-1} due to functional groups present in HA structure. The HA extracted from NPK+FYM showed lower total acidity, along with lesser carboxylic and phenolic groups compared with those extracted from NPK or 150% NPK. Therefore, NPK+FYM improved both quality and quantity of SOC under intensive cropping.

4.2.5 Phosphorus dynamics under long-term fertilization and manuring

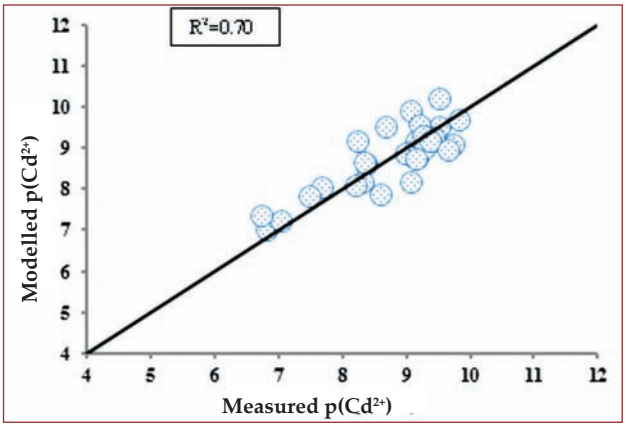
Results of long-term nutrient management practices under soybean-wheat indicated manure decreased P fixation in plots having manure application (230 mg kg^{-1}) as compared to other treatments. On the other hand, adsorption maxima recorded for the no-P plots was 476 mg kg^{-1}, which showed an increasing trend. Application of lime with 100% NPK also showed a positive impact on reduction of P fixation (405 to 361 mg kg^{-1}) over 100% NPK alone in surface depth. The extent of P desorbed was largest with 100% NPK + FYM treatment. Results clearly reveals that the application of P fertilizer as well as inclusion of lime and FYM in fertilization schedule proved to be effective in reducing P fixation by soils and increasing desorption potential.

4.2.6 Microbial abundance, resistance and resilience to abiotic stress

Effect of long-term nutrient management on microbial abundance, resistance and resilience in an Alfisol under abiotic stress condition was assessed in soybean. Soil samples were collected and exposed for two different stress, *i.e.* (i) heat (48 °C temperature for 24 h) (ii) moisture (air dry soil moisture content 1.2%) and incubated for 60 days at 28 °C with optimal moisture content (2/3rd water holding capacity). Results indicated that dehydrogenase activity is a good indicator of soil abiotic stress. The application of FYM with balanced NPK was the most effective in improving the biochemical and microbial population as well as resistance and resilience capacity of biological functions in soil against the heat and moisture stress.

4.2.7 Efficacy of solubility model and Baker soil test in predicting free metal ion activity in contaminated soils

Free ion activity has been considered as the most potent index of availability of metals in soil. Reference free metal ion activities were determined using the geochemical speciation model WHAM-VII following extraction of soil solution with porous Rhizon samplers from the rhizosphere of growing plants. Free ion activities (-log10 values), *viz.* pZn^{2+}, pCu^{2+}, pNi^{2+}, pPb^{2+} and pCd^{2+} as measured by the Baker soil test, were 10.1 ± 1.12, 13.4 ± 1.23, 12.9 ± 0.85, 11.6 ± 0.74 and 12.6 ± 2.26, respectively. Solubility model based on soil properties could explain the variation in pZn^{2+}, pCu^{2+}, pNi^{2+}, pPb^{2+} and pCd^{2+} to the extent of 84, 52, 73, 60 and 70%, respectively. Modelling approach was found superior compared to that based on the Baker soil test solution.



Comparison of observed and predicted $p(M^{2+})$ in soil solution on 1:1 line

Modelled $p(M^{2+})$ values were calculated by independently parameterizing Freundlich equation as a function of soil pH, WBC, and EDTA-extractable metals for Zn, Cu, Ni, Pb and Cd; 'measured' values were derived from analysis of the soil pore water under spinach crop and subsequent speciation with WHAM VII.

4.2.8 Impact of long-term application of sewage-sludge on soil health and metal content in wheat

Long-term application of sludge and inorganic fertilizers on wheat grain yield showed that the maximum yield was recorded with 100% NPK with 2.5 t ha^{-1} sewage sludge, which was equivalent to yield obtained with 25 and 50% N substituted by sludge plus NPK. Therefore, up to 50% substitution of N fertilizer with sludge can be recommended without compromising the yield of wheat. Consumption of wheat grain is not likely to induce any health hazard to consumers as the values of hazard quotient (HQ) for Ni, Pb and Cd were with safe limit. Potential N mineralization of sludge amended soil was higher compared, without sludge amended soils, though N mineralization capacity did not increased with increasing dose of sludge.

4.2.9 Enhancing nitrogen use efficiency using nano clay polymer composites (NCPCs) based fertilizer products

For enhancing use efficiency of N, five treatments comprising of control, 100% recommended dose of nitrogen applied through urea, Urea Ammonium Nitrate (UAN) as well as NCPC loaded with urea and UAN were assessed using three rice genotypes IR 64, Nagina 22 and MTU 1010. Results indicated that the treatment NCPC loaded with UAN performed better as compared to other treatments irrespective of the genotypes. This treatment was more effective in increasing the grain yield, nitrogen uptake, agronomic use efficiency and apparent nitrogen recovery by 36.9, 51.0, 64.2, and 92.0% over prilled urea, respectively whereas the physiological use efficiency decreased by 12.6% over urea. A field experiment on wheat crop was also conducted using nano clay polymer composites (NCPC) and nano clay bio-polymer composites (NCBPC), respectively as a slow release carrier of nitrogenous fertilizer. Results indicated that 25% of recommended dose of N can be saved if N is applied through NCPC or NCBPC without compromising yield.

4.2.10 Impact of microbial intervention on transformations of phosphorus in soil

Phosphate solubilizing microorganisms (PSMs) were used to solubilize the fixed P in two soils (acid soil of Assam having pH 4.23 with available P of 8.59 kg ha^{-1} and alkaline soil of Delhi having pH 8.30 with available P of 22.5 kg ha^{-1}). Result indicated that phosphate solubilizing fungi (PSF) decreased the Al and Fe bound P in acid soils. In addition to these two fractions, significant amount of P was also solubilized in Ca bound fraction in alkaline soil. This was also reflected in P uptake and yield of soybean. Hence, biological intervention proved to be effective in enhancing P availability in soils.

4.2.11 Rock phosphate enriched organic manure as a source of P under maize-wheat system

Rock phosphate (RP) enriched organic manure commonly known as phosphate rich organic manure (PROM) was prepared using high-grade RP (31.5% total P_2O_5), pressmud and spent wash. Significantly highest yield of maize and wheat as well uptake of N, P and K were observed under 50% P through DAP+50% P through PROM indicating 50% DAP use can be curtailed through combined application of DAP and PROM.

4.2.12 Soil test crop response based integrated fertilizer prescription for mustard

Soil test crop response correlation studies were carried out for the development of integrated fertilizer prescription of N, P and S for targeted yield of mustard. The mean nutrient requirement for the production of 100 kg of mustard grain was 3.94, 1.14 and 1.48 kg of N, P and S, respectively. The contribution of nutrients from soil, fertilizer and farm yard manure (FYM) were 22.2, 36.3 and 7.6% for nitrogen, 59.2, 59.0 and 2.5% for phosphorus, and 49.5, 56.3 and 3.3% for sulphur, respectively. Using this information, fertilizer prescription equations and fertilizer recommendation for targeted yield of mustard could be developed in range of soil test values of N, P and S and with and without integration with FYM.

Soil test based fertilizer prescription equations for targeted yield of mustard

Fertilization programme	Fertilizer prescription equation
NPS alone	FN = 10.90T – 0.62 SN
	FP = 1.94T – 1.0 SP
	FS = 2.64T – 0.88 SS
NPS + FYM	FN = 10.90T – 0.62 SN – 0. 20 FYM
	FP = 1.94T – 1.0 SP – 0.04 FYM
	FS = 2.64T – 0.88 SS – 0.06 FYM

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

4.2.13 Zinc dynamics under long-term fertilization and manuring in maize-wheat system

Result revealed that continuous application of NPK+Zn increased the water soluble plus exchangeable, carbonate bound, oxide bound, residual and total Zn, whereas NPK+FYM enriched the organically bound Zn. Application NPK+FYM reduced the carbonate and oxide bound Zn as compared to other treatments. Residual Zn remained unaffected due to long-term fertilization and manuring, except NPK+Zn. Adsorption maxima and affinity coefficient of Langmuir equation for Zn adsorption followed the order: Control = N alone > NP = NPK > 150% NPK > NPK+FYM = NPK+Zn. The cumulative desorption of adsorbed Zn during four consecutive steps was highest in soil under NPK+FYM (55.3 µg g^{-1}) and lowest in control (18.3 µg g^{-1}). Application of FYM could reduce the affinity of Zn for different soil constituents in soil, which in turn enhanced its availability.

4.2.14 Nutrient management protocols and organic C mineralization under CA

Application of 75 kg N ha^{-1} as basal along with 4 t crop residue (CR) ha^{-1} and GS-based N use (02 split) under 25% available soil moisture depletion (ASMD) is the most efficient N management protocol during the initial years under CA. After 3 years of continuous CA, basal N application can be omitted under irrigation at 25% ASMD and GS-based split N application. Similarly, application of 4 t CR ha^{-1} along with only 40 kg P_2O_5 ha^{-1}, phosphorus solubilizing bacteria (PSB and AM) had equal yield to the plots receiving 4 t CR ha^{-1} and 80 kg P_2O_5 ha^{-1} indicating 50% P fertilizer savings under CA based system. Application of 4 t CR ha^{-1} along with only 30 kg K_2O ha^{-1}and KSB was also equal to the plots receiving 4 t CR ha^{-1} and 60 kg K_2O ha^{-1} in terms of system productivity indicating 50% K fertilizer savings under CA.

Soil carbon mineralization study carried out at two temperature regimes (25 and 35 °C) using the soils from 8-year-old CA based system indicated that the highest cumulative carbon (Ct) mineralization occurred in plots having triple zero tillage with residue which was also significantly higher as compared to triple zero tillage without residue and control (no- N,P, K).

4.3 WATER MANAGEMENT

4.3.1 Hydrogel performance in broccoli

Experiment was carried out to study the performance of hydrogel (Pusa Gel and SPG-1118), methods of application (soil and root dip) and irrigation method (conventional and drip) in broccoli. ET_{crop} was estimated to be in the range of 200 to 210 mm. The maximum peak consumptive use rate was 3.8 mm day^{-1} and highest yield recorded was 25.83 t ha^{-1}.Newly developed SPG-1118 gave 2 and 10% higher yield as compared to P-Gel and control plot, respectively.

4.3.2 Development of sensing devices for flow measurement and irrigation scheduling

An integrated sensing device using the capacitance-based soil moisture sensor, plant canopy temperature sensor besides the ambient temperature and humidity sensor was fabricated. The digital display unit and microcontroller enabled the system to display the ambient temperature, plant canopy temperature

besides calculated thermal indices, which would assist the decision on scheduling irrigation. The developed device was calibrated for soil moisture sensor at 0-15 cm depth and compared with the gravimetric method resulted in coefficient of determination (R^2) of 0.84. Besides this, a digital water measuring device was developed to measure irrigation water supplied in open field channels of canal command. The device consisted of a modified flume and the digital sensing system with display unit to measure the flow depth, discharge and volume of water supplied to cropped field. Designed device was standardized and calibrated in the hydraulic flume testing facility to develop the depth and discharge rating curve. The fitted equation of the rating curve was embedded in the digital sensing system through programmed code to display the flow depth and subsequent discharge rate.

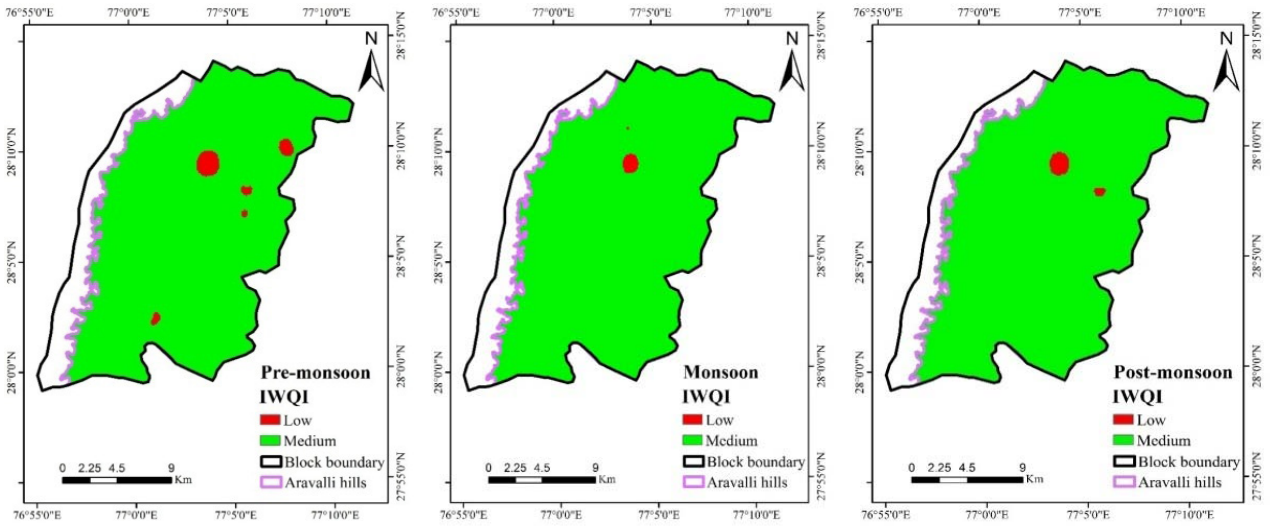
Further, the fabricated device was tested in the open channel and the measured discharge rate was in close agreement with the observed discharge corroborated with prediction error statistics R^2 (0.99) and Mean Absolute Percentage Error (4.3).

4.3.3 Water and nitrogen distribution in soil under drip fertigation in lettuce

Results indicated that the available nitrogen content in soil was higher near emitter in upper surface (0-15 cm) in all the treatments and reduced with distance and depth from emitter. Urea ammonium nitrate (UAN) and calcium nitrate (CN) applied plots showed higher nitrogen content after 24 hours of fertigation. Soil moisture content was found to be higher near emitter as compared to deeper points and water content reduced on outer surfaces of wetting front. The highest yield was recorded in plots fertilized with UAN at 60 kg Nha^{-1} (37.6 t ha^{-1}) followed by UAN at 40 kg N ha^{-1} (36.4 t ha^{-1}), NCU at 60 kg N ha^{-1} (34.4 t ha^{-1}) and NCU at 40 kg N ha^{-1} (32.9 t ha^{-1}), respectively. It was observed that application of UAN led to 25 - 30 percent of nitrogen saving with same yield.

4.3.4 Spatio-temporal evaluation of water quality in water harvesting structures in Nuh, Haryana

The mean pH, EC, turbidity, calcium and magnesium, chloride, sodium, potassium, SAR, and TDS of water were within the permissible limit in Nuh block, Mewat, Haryana. However, carbonate, bicarbonate and RSC contents were above the permissible limits. Water harvesting structures (WHSs) fed with R+C+S, showed substantially higher BOD. Out of the 80 WHSs, 75 WHSs were listed under medium category of suitability during pre-monsoon and 78 WHSs each during monsoon and post-monsoon period. Overall, the majority of the WHSs in Nuh block were moderately suitable for irrigation. It can

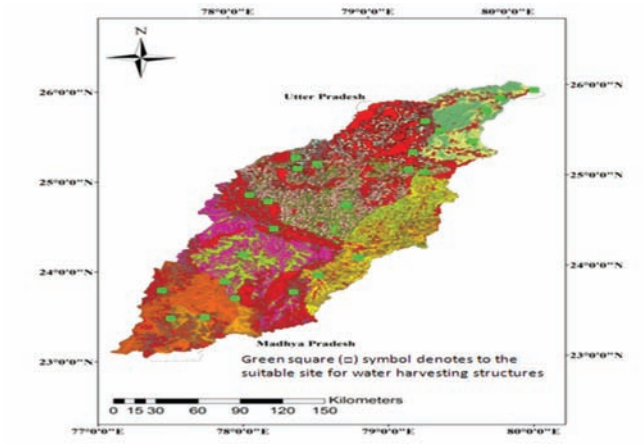


Spatio-temporal variability of IWQI in *Nuh* block, Mewat, Haryana

be recommended to avoid direct inflow of village sewage and canal water to WHS by installing suitable eco-friendly water treatment plant, desilting of ponds besides adoption of integrated farming system approachfor improving water quality.

4.3.5 Composite hydrologic index for groundwater recharge in Betwa river basin

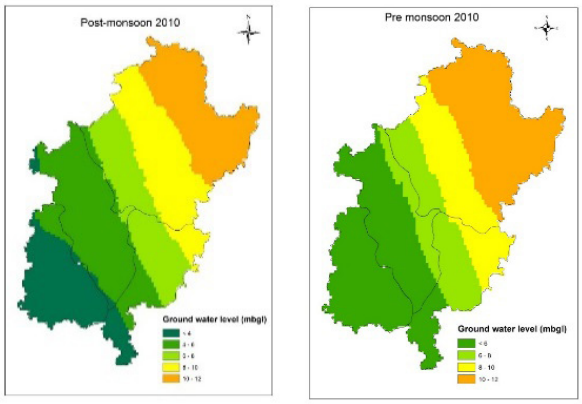
Composite hydrologic indices (CHI) were developed for evaluating the recharge potential in the Betwa river basin. The prospect of groundwater recharge was assessed in relation to soil type, slope, rainfall runoff ratio and ET. Groundwater recharge potential zone of the basin can be divided into four grades, *viz.* very good, good, moderate and low based on the four factors that affect groundwater recharge. Very good ground water with high infiltration rate than clay and clay loam soil. Composite hydrologic indices (CHI) for the study area were found to vary from 0.01 to 1. The suitable site for water harvesting structure in each Hydrologic Response Unit (HRU) having possibilities to increase the groundwater level is shown.



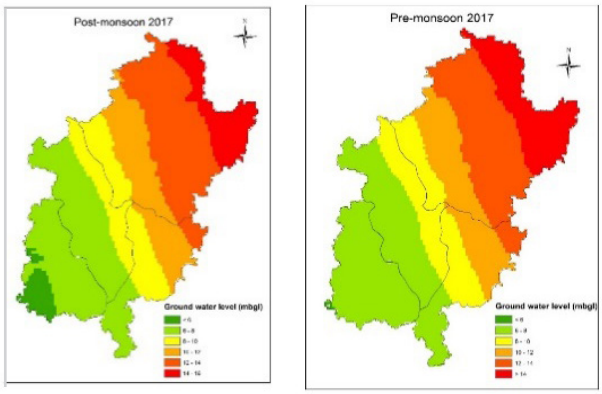
Suitable sites of targeting water harvesting structures in Betwa basin

4.3.6 Spatio-temporal variability of water table depth in Pitamberpur watershed, U.P.

Ground water recharge from selected rainwater harvesting structures in the *Pitamberpur* watershed in the J. P Nagar of Uttar Pradesh, were estimated and the spatio-temporal variability map was generated using ArcGIS.



a. 2010 (Pre and Post Monsoon)



b. 2017 (Pre and Post Monsoon)

Spatio-temporal variability of water table depth in Pitamberpur Watershed, UP during 2010 and 2017

4.3.7 Evaluation of CERES-wheat model of DSSAT under changing climate

CERES-wheat model of DSSAT was calibrated and validated using data of wheat cultivar HD-2967 with three dates of sowing and five irrigation. The validated model performance was in line with the observed grain yield corroborated by the root mean square error (RMSE) of 0.035 and degree of agreement (d) 0.98 under five irrigation regimes. Further the validated model indicated yield decline by 6 to 22% and 8 to 16% with increase in temperature from 1 to 3^0C under full and deficit irrigation regimes, respectively. Whereas, reduction in temperature from -1 to -3^0C showed an increase in yield by 10 to 28% and 7 to 20% under full and deficit irrigation, respectively. Similarly, the increase in solar radiation from +1 to +3 $MJm^{-2}d^{-1}$ resulted in yield increase by 5 to 12% and 3 to 7% and

decline in same range resulted in yield decrease by 7 to 24% and 6 to 17.5% under full and deficit irrigation, respectively. Further, effect of enhanced level of CO_2 from 500 to 800 ppm simulated increase in yield by 7 to 24% and 6 to 19% under irrigated and deficit irrigation, respectively. Moreover, the combined effect of increasing temperature and CO_2 concentration revealed that highest yield was obtained at higher level of CO_2 concentration with 1^0C increase in temperature. But, rise in temperature by $+3^0$C, besides doubled CO_2 concentration of 800 ppm resulted in only 2% increase of yield under full irrigation and 4.4% yield decline under deficit irrigation.

4.3.8 Multi-metal reduction potential of the macrophyte consortia in up-scaled mesocosmic wetlands

The metal sequestration potential of 4-shortlisted macrophyte combinations [*viz. Typha latifolia* + *Phragmites karka* (TA); *Phragmites karka* + *Arundo* donax (PA); Arundo donax + Typha latifolia (AT) and *Vetiver zizinoids* + *Typha latifolia* (VT)] from metal spiked waste water of IARI was compared in the up-scaled experimental mesocosms wetlands. Investigations revealed non-significant differences in their metal reduction potentials. However, long term data indicated *Typha* (T) and *Phragmites* (P) to be out-competing the other macrophytes (*viz. Arundo* and *Vachha*), in each of the aforementioned mixed culture macrocosmic systems. It was observed that layered planting of typha instead of mixed planting is suitable to harness their full multi-metal reduction potential. Besides this, 100 microbial strains were isolated from the aforementioned mixed cultured multi-metal spiked mesocosms. These were subjected to minimum inhibitory concentration (MIC) analysis for Ni (10-50 ppm), Cr (10-300 ppm) and Pb (10-300 ppm) besides assessment for their multi-metal reduction potential (at 10 ppm Ni, Cr, Pb concentrations). Analysis assisted in shortlisting of 21 promising bacterial isolates for remediating multi-metal polluted wastewaters through bio-augmentation of wetland ecosystem.

4.3.9 Standardization of chitosan and calcium alginate bead making technology for heavy metal reduction from wastewaters

Five different bead making protocols which are generally used for making chitosan based beads were investigated and the developed beads were evaluated for their size, strength, functional group and structure based on the Fourier Transformed Infrared Spectroscopy (FTIR) and X-Ray diffraction (XRD) analysis. Out of tested five different bead making protocols, only the one using lingo-sulphonate was found to be of any practical significance. Moreover, XRD analysis of the beads developed through this protocol indicated a good cross linkage of the chitosan and lingo-sulphonates. FTIR analysis of the beads, on the other hand, confirmed the presence of hydroxyl, amine and the amide groups which can act as polymeric chelating ligands for the chemi-sorption of heavy metals. Studies on the use of the calcium alginate alone and the a for ementioned standardized chitosan coated calcium alginate beads for their heavy metal remediation and regeneration potential from saline and non-saline waters were also successfully designed and implemented.

4.3.10 Essential oil yield and quality of lemongrass under waste water irrigation

Untreated wastewater contained 17.5, 3.97 and 14.8 mg L^{-1} and treated had 7.5, 1.06 and 5.45 mg L^{-1} of N, P and K, respectively. Total herbage of lemon grass irrigated with untreated wastewater was the maximum and 15% higher as compared to groundwater. Similarly, essential oil yield produced by using untreated wastewater was 11 and 16% higher compared to treated wastewater and groundwater irrigation, respectively. As compared to untreated wastewater, the treated wastewater has reduced Ni and Pb accumulation by 22-23%. Soil organic carbon and available N, P, Ni and Pb contents of soil were also more with untreated wastewater irrigation as compared to groundwater irrigated soil. Heavy metal concentrations in essential oil were not detectable indicating that its presence in oil is not influenced either by water quality or nutrient doses.

4.3.11 Performance of new wheat genotypes under restricted irrigation conditions

Five wheat genotypes, *viz.*, DDW 47, DBW 110, HI 8627, MP 3288 and UAS 466 were evaluated at different irrigation schedules under limited irrigation conditions. Irrigation at CRI + boot leaf stage had significantly higher grain (3.63 t ha^{-1}) and biological yields (8.49 t ha^{-1}) over other irrigation scheduling. Genotypes, MP 3288 recorded the maximum grain and biological yield (3.09 t ha^{-1} and 7.11 t ha^{-1}, respectively) which was significantly at par with HI 8627 but significantly higher over rest of the genotypes.

4.4 PROTECTED CULTIVATION TECHNOLOGIES

4.4.1 Vegetable Crobs

4.4.1.1 Standardization of agro-techniques for tomato production under low cost protected condition

An experiment was conducted on tomato production under insect proof net house and polyhouse. The maximum fruit yield (28.0 kg), net return (₹ 87.0) and B: C ratio (1:2.84)/m^2 were recorded in commercial hybrid No. 74-560 followed by GS-600 and Heem Sohna in the best combination of 2nd week of August planting with optimum dose of NPK @ 35:15:40 kg 1000 m^2.

Tomato production under insect proof ne house

4.4.1.2 Standardization of low cost agro-techniques for coloured capsicum production

In a study conducted to standardize the agro-techniques for coloured capsicum production the maximum fruit yield (8.80 kg), net return (₹ 85.4) and B: C ratio (₹ 1:2.65)/m^2 was recorded in commercial hybrid followed by KSP-1070 and BSS-518, while in baby capsicum, maximum fruit yield (8.30 kg) per sqm in variety Solan Bharpoor were recorded in the best combination of 3rd week of August planting with optimum dose of NPK @ 30:15:35 kg per 1000 m^2.

Capsicum production under insect proof net house

4.4.1.3 Genetic improvement of tomato suitable for protected environment

Total 98 diverse tomato accessions were collected from different sources and raised for evaluation under protected conditions for yield and other horticultural traits.The tomato accessions No.292,293,172, 123,177, 112, 115, 117, 181, 182, 206, and 304 were found highly suitable for protected conditions. A slow ripening yellow coloured genotype No. 68 with good bearing ability, fruit size and keeping quality was also identified. These accessions have TSS ranging from 4.5 to 6.6^{0}Brix and lycopene ranging from 4.4 to 4.8 mg/100 g with average fruit weight ranging from 85-130 g. Among the cherry tomato accessions, No. 214, 220, 262, 305 and 597 were found most promising. Cherry tomato and 305 recorded TSS 10.3^{0}Brix and 4.8 mg/100 g lycopene and No. 220 and no. 214 recorded TSS 9.5^0 and 9.0^{0}Brix and total carotenoids 5.22 and 4.80mg /100 g, respectively. Tomato hybrids made in the previous year were also evaluated for yield and horticultural traits. The crosses H-30,H-42,H-71, H-110, H-193, H-198, H-173, H-199, H-202, H-210, H-212,H-261, H-277, H-278, H-286 and H-288 were found promising,

while in cherry tomato hybrids H-126 and H-200 were found promising. Twenty three genotypes were characterized for quality parameters and No. 206, No. 57-1, No. 304, No. 123, No. 249 and No .207 were found suitable for processing. Genotypes 206 and Hybrid No. 42 & 71 were also evaluated at farmers field at Alwar (Rajasthan) and Palwal (Haryana).

4.4.1.4 Development of new Pak-choi lines

Five lines/accessions of exotic leafy vegetable, Pak-choi were collected, purified and maintained. The collection Pak-choi No.1 is found suitable for commercial cultivation. The per plant weight varied from 500-800 g. It becomes harvestable 55 days after transplanting. Pak-choi No. 1 was also evaluated at ICAR Research Complex for NEH Region, Imphal, Manipur.

Pachoi No. 1 (Pusa Pride) and field evaluation trial in N-E state

4.4.1.5 Off-season production technique for long melon (*Kakari*) in polyhouse

An experiment was conducted for off-season *kakari* production during September 2019 to December 2020 under polyhouse conditions. The variety Chandralekha was transplanted on the spacing 30x50 cm and applying optimum dose of NPK @ 25:17:26 kg/1000 m^2 in polyhouse conditions. After and before transplanting recommended package of practices was followed along with daily hand pollination during morning hours (7-8 AM). The maximum number of fruits per plant observed was 4, with an average fruit weight of 442 g, length 83 cm and diameter 3.40 cm. The total harvested fruit yield was 2.25 kg/plant and 8.90 kg/m^2 with good quality. The cost of cultivation was calculated as ₹ 276/m^2. The net return was calculated as ₹ 316/m^2. The B: C ratio of *kakari* production under polyhouse was 1:1.95.

4.4.1.6 Agro-techniques for off-season bitter gourd production under protected structures

A trial was conducted on off-season bitter gourd production during August 2019 to December 2020 under net-house and naturally ventilated polyhouse conditions. Recommended production technology and GAP protocol was employed along with fertigation scheduling. Daily hand pollination was undertaken during morning hours (8-9 AM). The new variety of bitter gourd (Pusa Rasdar)was grown and maximum fruit yield (13.75 kg)was recorded, with net return of ₹ 222 and B:C ratio 1:2.23 per m^2 in the best combination of 2nd week of August planting with closer spacing 20x50 cm and optimum dose of NPK @ 25:17:26 kg/1000m^2. These combinations were found economically suitable for growing bitter gourd under insect-proof net-house as compared to the naturally ventilated polyhouse.

Off-season bitter gourd (Pusa Rasdar) production under polyhouse

4.4.2 Flower crops

4.4.2.1 Studies on influence of long days (LD) PAR in chrysanthemum flower induction using smart LEDs

The experiment was conducted with chrysanthemum variety, Zembla self-rooted cuttings grown under long days (LD = 15h) using smart LEDs @ 110 µmole sec^{-1} for 12 days, transplanted in a semi-climate controlled greenhouse under an additional photoperiod applied @ 4 h daily. An early (65 days) crop was obtained which yielded quality stems (107.5

An early chrysanthemum crop under the infuence of long days (LD) PAR using LEDs

cm long), flower diameter (9.7 cm across) and longer vase-life (13.5 days) at room temperature. The average leaf area calculated was maximum (258 cm^2) along with a significantly high number of leaves (37) per stem as compared to the plants (26) grown with no additional light.

4.4.2.2 Screening of African marigold and chrysanthemum varieties for extending flowering season

Five IARI bred marigold varieties (Pusa Deep, Pusa Arpita, Pusa Narangi Gainda, Pusa Basanti Gainda and Pusa Bahar) and two hybrids (Astha and Tennis Ball). The flowering was early in September and first harvesting was done September 24 in Pusa Deep followed by Tennis Ball (12th Oct), Astha (15th Oct), Pusa Narangi Gainda (21st Nov), Pusa Basanti Gainda (10th Dec), Pusa Arpita (5th Jan) and Pusa Bahar (26th Jan). However, the flower yield was recorded maximum (3.2 kg/m^2) in Pusa Arpita followed by Aastha (2.7 kg/m^2). Pusa Basanti Gainda recorded with lowest flower yield (1.2 kg/m^2) followed by Pusa Bahar (1.5 kg/m^2). Five each single (Thai Chen Queen, Yellow Star, White Star and Zembla) and spray (Autumn Glaze, Golden Ball, Novelty Pink, Viking Yellowand Moonlight) types chrysanthemum were evaluated. Among these, Zembla, Thai Chen Queen, Moonlight, Autumn Glaze and Novelty Pink could flower consecutively in the secondary flush of growth under long days as summer crop.

4.4.2.3 Evaluation of rose, variety Top Secret under low-cost polyhouse

Rose variety, Top Secret was planted in a low cost small size (220 m^2) naturally ventilated polyhouse @ 12 plants/m^2 and evaluated for the performance. It was observed that the plants took a long time (92 days) for establishment resulting from the heading back at 60 days of transplanting. It was noted that a maximum of average 7 shoots/ sprout were recorded with average stem length (72 cm) and the maximum being 112

Evaluation of african marigold and chrysanthemum varieties for round the year cultivation.

cm. However, the bud size having 2.2 cm diameter remained maximum leading to the flower size of 7.8 cm across diameter.

Rose (top Secret) under low cost polyhouse

The climate profile is being studied which remained at par with ambient with a relative humidity ranging from 26 to 42% except in rainy days (>90% during July 5 to Sept 16). Whereas, the quality of flowering stems was recorded highest in terms of stem length (98 cm) and flower size (9.7 cm across diameter) during the months October-November in 2019.

4.4.3 Fertigation, greenhouse structure and design development.

4.4.3.1 Design and development of indigenous greenhouse aeroponics system for lettuce

An aeroponic system was developed assisted with a mist environment. The system was indigenously designed with a standard dimension of 2.5 m x 1.25 m x 1 m. The body of aeroponic system was made with 'wood plastic compose' (WPC) to avoid fungal and other infections. Styrofoam was used as covering material and to make the plant root zone opaque thus maintaining the dark conditions for healthy root growth. Nine cone jet hollow ceramic spray nozzles were used for misting with a standard spacing of 50 cm apart. The nozzles used have the characteristic feature of ultra-low water usage of 27-30 LPH and produce 80^0 uniform misting angles for droplet size in the range of 40-50 micron at 4-6 bar operating pressure. Total 48 lettuce seedlings were planted at 20 cm x 30 cm spacing, plant to plant and row to row, respectively. The produce was harvested from 35 days onwards till 60 days after transplanting.

4.4.3.2 Sensor controlled fertigation scheduling experiment on winter green leafy vegetables

Winter green leafy vegetables lettuce, pokchoi & Chinese cabbage were grown with drip fertigation in open field during Nov 19 to Feb 20. Conditional fertigation strategy was used to control the experiment with various sensors like tensiometer, EC and pH. 15 and 30 cm depth tensiometers were used for irrigation scheduling. Tensiometers readings varied from 12-280 centibars during the entire duration of experiment. 22 centibar tensiometer reading was found to be the ideal set point for start of irrigation for winter green leafy vegetables. Drip irrigation lateral pipe of 16 mm with inline dripper of 2 litres per hour discharge capacity was found to be the most suitable combination. Fertigation Ec & pH varied from 1.6-2.4 dS/m and 6.7-7.2 respectively during the entire duration.

Sensor controlled drip fertigation for winter season green vegetables

4.4.3.3 Drip-fertigation technology for growing sweet pepper inside polyhouse:

Study was conducted during 2017-18, 2018-19 and 2019-20 to investigate the effects of different combinations of irrigation and fertigation levels on the

Capsicum crop inside naturally ventilated polyhouse with new cladding material under evaluation

growth of polyhouse sweet peppers, assessing yield and water use efficiency (WUE). Using the drip-fertigation technology, three alternative irrigation levels at 100, 80, and 60% ET_c (V, $V_{0.8}$ and $V_{0.6}$) were combined with three fertigation levels at 100, 80 and 60% (F, $F_{0.8}$ and $F_{0.6}$), resulting in 9 combination treatments. The results show that different supplies of water and fertigation had a significant impact on the yield and WUE. Average monthly evaporation in the polyhouse was 101.6 mm compared to 322.5 mm occurred in the open field condition which was 68.4% less as compared to outside of the polyhouse. The treatments of $V_{0.80}F_{0.80}$, $V_{0.60}F_{0.80}$ gave better yield maintaining the "source-sink" relationship of peppers. They increased the economic yield and WUE. Polyhouse sweet peppers produced in the semi-arid regions, the combination of $V_{0.80}F_{0.80}$ resulted in the highest economic yield of 12.85 kg m^{-2}. In view of limited water resources in the area, we recommend the $V_{0.60}F_{0.80}$ combination treatment, since it could obtain the optimal economic yield and WUE were 9 and 4% less than the maximum, respectively.

4.4.3.4 Design of bamboo shade nethouse suitable for semi-arid regions

Bamboo shade net polyhouse is one the technique for off-season cultivation, better quality and increase in production of vegetables for small and marginal farmers and easily available in locally available resources. The design need to be made to overcome overheating in summer and overcooling in winter when used in warm, arid regions. The climate inside the protected structure is governed by the soil inside, which constitutes the major thermal mass the 'greenhouse' effect itself, which can be controlled mainly by ventilation in most greenhouses; the crop's transpiration, which has a dominant effect on temperature and vapor-pressure deficit. Shade net structure of (14 m x 30 m) was designed and erected using bamboo and cost of construction was estimated as ₹ 450 / m^2.

4.5 AGRICULTURAL ENGINEERING

4.5.1 Upscaled solar refrigerated evaporatively cooled structures for storage of perishables

An innovative stand-alone, battery less, off-grid, solar-refrigerated evaporative-cooled (SREC) mesh-fabric structure developed at IARI was upscaled and evaluated for storage of perishables. The concept of SREC structure has been built at IARI and

(SREC) structures at village Picholiya, Rajasthan

demonstrated among user and currently being used by farmers at village Picholiya, District Ajmer, Rajasthan. The structure of size 3x3x3 m having capacity of 2000 kg produce. It can easily achieve daytime temperatures as low as ~5-10°C and nighttime temperatures below 14°C, when the daily ambient maximum temperature is approximately 45°C, through the combined effects of evaporative cooling and solar refrigeration.

4.5.2 Customization of biomass management technologies for on-farm demonstration

A number of divisional technologies were customized, fabricated and installed at KVK Ambala for on-farm demonstration of agri-residue management. The technologies included customized complete feed block making machine operated by diesel engine, compost turner cum mixer, compost sieving machine, power chaff cutter and Urea Molasses Mineral Block (UMMB). For housing of these technologies, two sheds of size 8 m x 5 m x3.5 m and 20 m x 5 m x 3.5 m were also erected at KVK Ambala. Through these package of technologies and commercially available technologies (baler, staw rake and happy seeder), in-situ and ex-situ management of paddy straw is being demonstrated as solution to the problem of paddy straw burning.


Complete animal feed block making technologies installed at KVK Ambala

Animal feed block making technology was further upscaled by designing a low capacity block making machine for marginal and small holders having low quantity of biomass/feed material. The manual operations takes 21 stokes for producing one block. This 1 hp (1Ø) electrically powered machine can produce 20 blocks per hour. The block of size is 13 cm x 13 cm x 9 cm. The theoretical capacity of the machine is 10 kg hr^{-1}.

4.5.3 Impact of divisional technologies

A number of divisional technologies were also disseminated to different regions of country ranging from NEH region to central and southern states of the country leading to revenue generation to the tune of ₹ 179.0 lakh.

Technology disseminated	No. of units	Location
Wheel hand hoe	1730	NEH Region; Indore (Madhya Pradesh); Kalimpong (West Bengal); Malda (West Bengal)
Pedal operated paddy thresher	648	
Peregrinated paddy seeder	416	
Safety gadgets for chaff cutter	152	
Aqua-ferti seed drill	13	Raipur (Chhattisgarh)
Mobile feed block machine	1	ICAR-CISH,RRS, Malda, West Bengal
Feed and fodder mixer	1	
Feed and fodder crusher	1	
Pusa basmati rice thresher	4	
Pusa Compost Turner cum Mixer	1	Krishi Vigyan Kendra, Sheoupur, Madhya Pradesh
Pusa Automatic Compost Sieving Machine	2	

4.5.4 Urea ammonium nitrate (UAN) applicator

Based on field observation, design refinements were made in UAN Applicator. The design drawing of improved prototype was prepared and two units were manufactured. The developed UAN applicator consisted of two important components i.e rotary fertilizer distributor and slit type furrow opener. The slit furrow opener was designed to place the metered quantity of fertilizer at a depth of 9-11 cm maintaining a vertical gap of more than 3 cm between seed and fertilizer. One unit of developed technology was handed over to National Fertilizer Ltd (Funding agency) by the Institute on Dec. 6, 2019 in the Division of Agricultural Engineering.

UAN Applicator

4.5.5 Pressurized aqua ferti seed drill

A pressurized Aqua Ferti. multi crop Seed drill was developed for dryland areas for pulses and oil seed sowing. It consisted 11 furrow openers and fitted with two storage tanks each of 500 litre capacity. The components of developed pressurized aqueous fertilizer metering system are PTO operated piston pump, circular distributor and pressure control valve and pressure relief nozzles. The machine can be operated by 55 hp tractor and has a field capacity of 0.23 ha hr^{-1} and 74% field efficiency with a sowing depth of 2.5-3 cm.

4.5.6 Turner cum mixer for pit composting

A tractor operated turner cum mixer for pit composting was developed for turning and mixing of the raw materials. It consisted of two 460 mm long horizontal blades for cutting and loosing of the material and two 1460 mm long vertical blades for shredding and mixing. The working depth of the tuner cum mixer is 1.0 m with operational diameter of 1.0 to handle approx. 1.0 m^3 of material during turning. A centralized auger system helps in simultaneous lifting and mixing the materials.

Pressurized aqua ferti. Seed dril

Turner-cum mixer for pit composting

4.5.7 Fertilizer band placement applicator cum weeder for row crops

Self propelled fertilizer band placement applicator cum weeder was developed for inter row weeding and fertilizer band placement in wide spaced crops in one go. The applicator is powered by 8 hp petrol engine and has maximum working width of 60 cm. The machine consists of one rotary unit for weeding and a fertilizer unit with two side furrow openers. The side furrow openers facilitate the placement of granular fertilizer in bands at optimum depth from root and cover two side rows. The machine works on the principle of active (rotary) and passive tillage (fertilizer placement) with matching width between two rows.

Fertilizer band placement applicator cum weeders

4.5.8 Variable rate fertilizer applicator

Tractor drawn variable rate fertilizer applicator was developed and evaluated. The flutted roller was used for dispensing fertilizer in the variable rate fertilizer applictor. An embeded system consisiting of microcontroller, DC motor, rotary encoder, linear actuator with feed back system was developed for use in VRFA. Independent battery power (24V) was used to operate the embeded system retofitted to the existing flutted roller. The VRFA works automatically by the function of different components in syncronized manner with path planing algorithm.

Variable rate fertilizer applicator

4.5.9 Sub-soil compaction amelioration study at farmers' field

To mitigate the ill-effects of subsoil compaction due to continuous tillage, an experiment was laid at farmer's field. The study involved five treatments- Control (no sub-soiling) , sub-soiling at 1.0 m spacing, sub-soiling at 1.5 m spacing , cross sub-soiling at 1.0 m spacing and cross Sub-soiling at 1.5 m spacing in complete randomized block design. During the experiment, effect of sub soiling on different soil properties and crop growth parameters was studied. It was recommended that sub-soiling either at 1.0 or 1.5 m spacing has potential for improving productivity of rice-wheat cropping system by mitigating sub-soil compaction.

4.5.10 Tool holder for partial upper limb disability

A tool holder for sickle with partially amputee hand was developed for especially abled person. The original handle of hand tool was removed, and a knuckled stud is fixed on the handle holder. In prosthetic part holding chuck is firmly fitted with locking nut. The knuckled stud is inserted in the holding chuck and the locking nut tightens the tool firmly.Use of plastic materialsfor making tool holder reduced the weight for comfortable operations. The weight of the device is 300g and provision was made for angular movement (15^0) on each side.

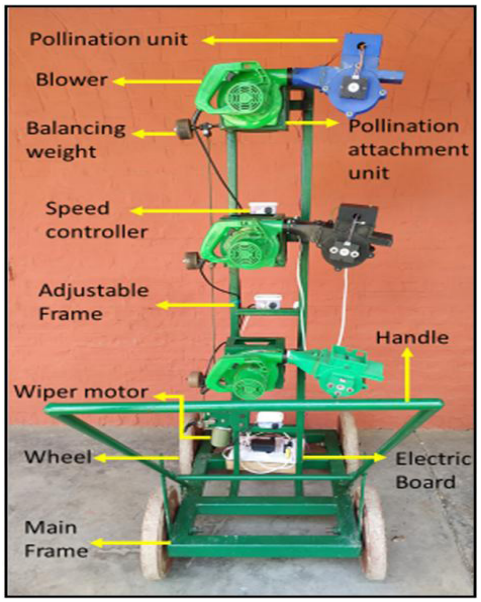
Tool holder for partial upper limb disability

4.5.11 Battery operated variable height platform

A battery-operated variable height platform was designed and developed. A four wheel hydraulically controlled variable height platform was powered with four 12 volt batteries for above shoulder working. The dimensions of the equipment are 1800 x 900 x 1700 mm.

Battery operated variable height platform

It has a provision of 60 cm lift. This is equipped with steering and braking system for smooth operation in greenhouses.



Pollinator for greenhouse

4.5.12 Pollinator for greenhouse

A mechanical device for pollination was developed with pulsating air jet which gently shakes the flower for pollination. It was movable in the alleys of greenhouse, which facilitated the operation and reduced the human drudgery of manually operated portable pollinators. It consists of a mainframe (500 x 750 mm) to facilitate movement between rows of crops and to cover width of flowering band. Performance of developed pollinator in terms of pollination efficiency, yield and human efforts was compared with manual pollination. The maximum pollination efficiency with highest desirability value of 1 was found (83.66%) at air flow rate of 1.99 $m^3 min^{-1}$ at pulsation frequency of 23.50 Hz and exposure time of 19.4 seconds.

4.5.13 Digital meter for custom hiring charges of agricultural operations

The digital meter was developed for custom hiring charges consists of two oval gear flow sensor. One for measurement of fuel quantities in the main fuel flow line after the feed pump and filter whereas another for return line fuel flow before the inlet of fuel tank. The actual fuel consumption of agricultural operation is the difference of the fuel flows in both lines. In one complete rotation of gears approximately 0.37 ml of fuel was passed. A magnetic Hall Effect sensor was used to detect the pulse with the help of developed programming code in Arduino IDE which is based on C^{++} high-level language.

4.5.14 Phase change material (PCM) based hybrid solar dryer for herbs and spices

A phase change material (PCM) based solar dryer was developed consisting of collector of area 0.64m^2 and three trays of 0.42 m^2 of area each in the drying chamber. The dryer consists of a real time data acquisition system for recording the temperature, humidity and moisture loss. Collector was also filled with 20 kg paraffin wax as a latent heat storage material for continuous drying after sunshine. The developed solar dryer provides a promising alternative for continual drying of other herbs and spices.

PCM based hybrid solar dryer

4.5.15 Small-scale packaging machine for pulses

A medium capacity form-fill sealing machine was developed for packaging of pulses. For 0.5 and 1 kg packet, 380 mm roll width and 20 mm longitudinal seam was provided. Capacity of hopper is 25 kg. Vibratory feeder is attached with load cell-based weighing system for weight measurement. The system is automized with the help of micro-controller and automatic timer

Small-scale packaging machine for pulses

Cumin Destalker

4.5.16 Cumin destalker

A cumin destalking machine was designed and developed. The unit is based on centrifugal principle and consists of two acrylic plates (30") fixed horizontally. Top plate is fixed while lower plate rotates; provision has been made to adjust the clearance between the plates as per the length of cumin. As the cumin poses poor flow properties, a vibratory feeder is fitted with the unit for uniform uninterrupted feeding of cumin. The cumin fed between the plates at the centre experiences centrifugal force and tends to stand on its tips while it travels towards periphery. It is due to this action the stalk of cumin detaches.

4.6 FOOD SCIENCE AND POST HARVEST TECHNOLOGY

4.6.1 Influence of exotic and indigenously developed particle films on apple and pomegranate

Trial on the use of exotic (Surround) and indigenously developed particle film (PCS-4) were revisited in apple cv. Royal Delicious and pomegranate cv. Kandhari along with control. 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

Effect of Surround and PCS-4 particles films on apple fruits

Particle film	San Jose scale	Apple scab	Bitter pit (%)	Hunter 'a' value	Phenolic content (mg100 ml^{-1}GAE)
Surround	2.2 ±0.2%	2.4±0.4%	1.6±0.3%	54.2±0.4	118.4±2.0
PCS-4	2.8 ±0.3%	2.3±0.3%	1.8±0.4%	55.6±0.2	116.2±2.2
Control	26.5 ±0.3%	14.8±0.3%	8.2 ±0.4%	38.5±0.2	106.6±2.5

Effect of pre-harvest sprays of Surround and PCS-4 particles films on pomegranate fruits

Particle film	Sun burn (%)	Fruit cracking (%)	Hunter 'a' value	Total anthocyanin content (mgL^{-1})	Phenolic content (mg 100 ml^{-1} GAE)
Surround	3.8± 1.4	2.9 ± 0.4	62.3±1.2	126.4±2.3	121.4±2.2
PCS-4	3.5± 1.2	2.8± 0.4	59.6±1.4	125.2±2.2	119.8±2.6
Control	18.4± 1.0	18.8 ± 1.2	42.8±1.6	112.4±2.1	110.2±2.1

incidence of diseases or insect-pests the treated apple of pomegranates either with Surround or indigenously developed particle film (PCS-4) was non-significant.

4.6.2 Effect of pre-harvest fruit bagging on Kinnow mandarin fruits

The results revealed that bagging improved the fruit size of Kinnow (228.2 g) in comparison to non-bagged fruits. Further, bruising was also reduced by bagging (5.2%) over non-bagged fruits (46.6 %). Similarly, there was improvement in ascorbic acid content (22.2 mg100 g $^{-1}$ pulp) and TSS (12 %) of the fruits over non-bagged fruits. Furthermore, the incidence of granulation (0.6%) was significantly reduced by pre-harvest fruit bagging.

Influence of pre-harvest fruit bagging on Kinnow mandarin

Attribute	Bagged	Non-bagged
Fruit weight (g)	232.6	186.8 g
TSS (%)	12.6	10.2
Ascorbic acid content (mg/100g pulp)	24.3	18.8
Bruised fruits (%)	4.2	44.4
Granulation (%)	0.8	5.8

4.6.3 Postharvest spray treatment of ethrel and gum arabic for enhancing shelf-life of banana

Physiologically mature green banana were dipped or sprayed with ethrel @ 2000 ppm and gum acacia @ 2% either alone or in combination. Treated fruits were kept at room temperature (25 ± 2^{0}C and RH 62% ± 2) for ripening. Combined application of gum acacia and ethrel spray given the best results over dipping among all the applied treatment. The spray treated (ethrel +gum acacia) fruits shown higher shelf-life (4 days), lesser occurrence of finger drop and anthracnose over dipping treatment during 10 days of storage.

Control Treated

Combine effect of ethrel and gum Arabic spray treatment on incidence of anthracnose, brown spot and finger drop of banana

4.6.4 Standardization of protocol for osmotic dehydration of apricot

Dehydrated apricots are high calorific products and considered rich in vitamins and minerals. Accordingly, six cultivars of apricot *viz.* CITH-1, CITH-2, CITH-3, Gold Cot, Roxana and Shakarpara were evaluated for dehydration suitability. Osmotic dehydration of fruits consisting of dipping in prepared fruits in 70° Brix sucrose syrup containing 2,000 ppm potassium metabisulphite (KMS) for 24 h followed by cabinet air drying (55 °C) to desired moisture (20±0.5 %) gave better dried product with good colour and appeal. Dried whole or halved fruits after removal of stones were preferred over whole fruits with stones in respect to appearance, texture and overall acceptability. Among different cultivars of apricot; cv. Roxana followed by CITH-2 were found better with respect to yield as well as quality of dried product.

4.6.5 Storage study of dehydrated spine gourd slices

To standardize the storage conditions for dehydrated spine gourd slices, were packed in three types of packaging material *viz* 200g LDPE (low density polyethylene) and HDPE (high density polyethylene) and 260 g ALPE (aluminium laminated polyethylene) pouches and stored at room temperature and low temperature for 6 months. Result revealed that samples packed in 260g ALPE pouches followed by storage at low temperature retain better nutritional quality in respect of ascorbic acid, antioxidant, total chlorophyll content, sensory score and least gain of moisture during storage followed by samples packed in 200g HDPE pouches stored at LT and RT during storage.

4.6.6 Influence of hexanal in extending postharvest storage life of apple

The influence of different concentrations of aqueous hexanal (0.01%, 0.02% and 0.03% v/v) as a dip treatment for 2, 3 and 4 min and also as vapour (120, 240 and 360 µl kg^{-1}) for 2h and 4h was tested on apple fruit. Apple fruits given application of 0.01% hexanal applied as dip treatment for 3 min soaking time retained higher firmness, reduced decay and improved the overall quality of the fruit upto 3 month storage under 1-2°C. Fumigation of freshly harvested fruit with hexanal vapour @ 360µL kg^{-1} for 2 h was also found to be an acceptable alternative to reduce decay and maintain overall fruit quality. Thus, post-harvest application of hexanal both as dip and vapour treatment holds promise in prolonging postharvest storage life and preserving quality of apple cv. 'Royal Delicious'.

4.6.7 Infusion of micronutrients in the pre-cut cauliflower under vacuum

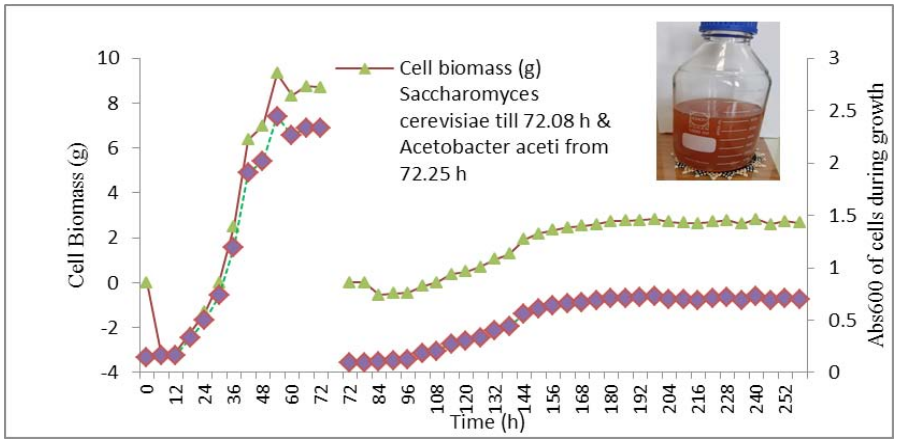
Minimally processed cauliflower cv. Pusa Sharad was infused with the micronutrient iron and the macronutrient calcium. Although imbibition in half cut florets was higher due to increased surface area, but the shelf life was limited, therefore, infusion studies were continued in whole florets. Iron solution on surface of cauliflowers got oxidized and resulted in slight discoloration. In case of infusion with calcium, pre-cut florets after exposing to vacuum for 15 minute .showed a 13 to 80% increase in the calcium content as compared to control. Florets were shelf stable upto 10 days under 10°C. Thus, vacuum impregnation is a potential method to increase the nutritional value of the pre-cut vegetables.

4.6.8 Vacuum impregnation of citrus phenolics in ash gourd slices

Box-Behnken design successfully employed to optimize the vacuum impregnation (VI) in ash gourd slices. Different processing variables (blanching time, vacuum pressure and vacuum time) affected the infusion rate and thus the overall quality of the vegetable matrix. The kinetic model study revealed the correlation between all three variables and the mass transfer of phenolic compounds. VI process variables (blanching time (2.21 min); vacuum pressure (432.31 mbar) and time (28.18 min) prompted the maximum infusion of polyphenolic extract. Phenolics impregnation via VI could lead to nearly 300% increase in TPC of ash gourd. The model kinetic study using Fick's model, Fito and Chiralt's model and Peleg constant revealed 450 mbar vacuum pressure exhibited higher effective diffusivity values (Deff) for TPC.

4.6.9 Spectrophotometric method to analyze acetic acid in fruit vinegar

Acetic acid was produced by *Acetobacter* strains in an Acetobacter medium supplemented with calcium carbonate and 'C' source. Acetic acid produced by *Acetobacter aceti* MTCC 2109 with glucose as substrate



Vinegar produced from fruit juice blends of phalsa and cantaloupe showing growth of *Saccharomyces cerevisiae* and *Acetobacter aceti* monitored during the process.

was 399 mg 100 ml^{-1}, whereas *Acetobacter aceti* NRRL 2317 gave out 363 mg 100 ml^{-1} acetic acid with mannitol as substrate, in 4 days and 11 days, respectively. In the spectroscopic detection of organic acid (acetic acid), sample volume was reacted with acidified ethylene glycol to form an esterified product which was then converted into hydroxamic acid that developed colour in presence of ferric chloride (reagent). The coloured complex of hydroxamic acid was detected at UV Abs 200, in the concentration range of 1 mg to 10 mg acetic acid. The polynomial equation curve fit (2nd order equation y = -0.0077 x2 + 0.1356 x + 0.0079 with R^2 = 0.9886) was used for estimation.

Acetobacter aceti MTCC 2109 produced 3.017 % (equiv to 3168 mg%) acetic acid in 216 h, from fruit juice blend of phalsa and cantaloupe (60:40 ratio blend). The biomass growth of the two inoculates in the process of vinegar production was modelled using Gompertz equation. *Saccharomyces cerevisiae* helped in adding flavours to the final product. The maximal specific growth rate of *Saccharomyces cerevisiae* and *A.aceti* were 0.483 h^{-1} and 0.061 h^{-1}, whereas their lag times were 22 h and 29 h respectively, in the fruit juice fermentation medium. Vinegar rich in anthocyanins (45 mg/L) was produced that had a total acidity of 4.98 % having a pH 3.19, yielding 89 % vinegar after decantation of cell mass and a good health drink.

4.6.10 Development of candied citrus peels from Kinnow mandarin

Shelf stable candied citrus peels were developed using peel (waste) of Kinnow mandarin. Blanching time, sugar concentration, infusion times were the three influencing process variables for standardization of the product. Blanching of pierced peel significantly helps in reducing the astringency of citrus peels. In the process of candied citrus peels development inverted sucrose acted as texturizing, preserving, sweetening, lustre agent. The RGB value of developed candied citrus peel was 250, 76, 6. A decrease in 'L' and 'b' value and increase in 'a' value in comparison with raw citrus peel showed an increase reddish and dark tinge of the developed candied citrus peel product.

Candied citrus peels of Kinnow mandarin

4.6.11 Formulation of lowfat gluten-free quinoa muffins

The sensory evaluation and textural studies revealed that incorporation of quinoa in muffins was acceptable upto 70% with no undue off-flavour or taste. In quinoa muffins, natural dietary fibre, psyllium husk was used as a fat replacer. Fat was replaced by psyllium husk at 20, 33 and 50% level of fat in the control muffins. It was possible to reduce fat from 22.45% in control muffins to 13.49% by incorporation of psyllium husk without any adverse effects on volume rise, texture and sensory attributes. Rather, acceptability of the muffins was further enhanced by using psyllium husk as fat replacer and source of dietary fibre.

Quinoa muffins

4.6.12 Formulation of quinoa-pearl millet baked snack

Gluten free baked snack with quinoa and pearl millet flours was formulated. The final formulation

contained 25% quinoa and 10% pearl millet flour along with rice and potato. The baked snack has 13.27% fat and 10.5% protein. The snack had 6.4 mg/ 100g iron, 2.85 mg 100 g^{-1} zinc and 453 mg 100 g^{-1} calcium. Shelf life studies of the snack upon packaging in metallized laminated packages have revealed its shelf life to be 4 months.

4.6.13 Development of roasted onion flakes

Three thermal methods *viz*. single pass tray drying, single pass microwave oven heating and a two stage heating including first tray drying followed by microwave oven drying were applied for development of roasted onion flakes. Heating in both single passes and two stage processes significantly influenced the textural and physic-chemical properties of onion flakes. Two stage heating (1st stage heating in tray dryer at 60°C up to 30% moisture and 2nd stage heating in microwave oven up to 2-3% moisture) was found better in terms of improving crunchy texture and reducing time of heating. Pusa White Round and Pusa White Flat were found better for making crunchy onion flakes.

Crunchy onion flakes

4.7 MICROBIOLOGY

4.7.1 BGA based composite liquid inoculant for sustaining crop productivity and soil health improvement

The BGA based composite liquid formulation (LF) on paddy was evaluated in farmers' fields in the villages of Dadhota, Amarpur and Katesra in Palwal district, Haryana. The intervention of both carrier based BGA biofertilizer and BGA based composite liquid formulation resulted in an average increase of 7.9% and 7.1% in grain yield respectively. The performance of both formulations (carrier based and liquid formulations) were at par but farmers preferred liquid formulation for easy application procedure and enhanced shelf-life.

4.7.2 Bioprospecting rhizospheric and endophytic cyanobacterial diversity amongst rice genotypes for N uptake and crop yield

New cyanobacteria C1(N fixer) and C2(N-fixing, P-solubilizer) with established bioinoculants applied in field showed an increase in plant growth (plant height, tillers per m^2), yield parameters (panicle length, grains per panicle, grain weight) and soil enzyme activity. Plots treated with *Azotobacter* and BGA inoculations showed best response in terms of plant growth and yield followed by C1, C2 and PSB inoculated plots. BGA treated plots showed best response for alkaline phosphatase (71 µg p-nitrophenol released·h–1·g–1 soil) and dehydrogenase activities (10.82 TPF g–1 d-1).

Effect of BGA biofertilizer in farmers' field at different villages in Haryana

Paddy variety	Bio-fertilizers	Yield (q/acre)		Increase in yield (%)	Total number of demonstrations	Total area covered (acre)
		Without bio- fertilizer application	With bio- fertilizer application			
PB 1509	BGA Carrier based	14.60	15.75	7.88	14	14.0
PB 1637	BGA liquid formulation	16.15	17.30	7.12	14	14.0
Total	--	--	--	7.50	28	28

4.7.3 Bio-control agents (BCA) and their impact on rhizospheric microbial communities under soybean-wheat cropping system

The effect of bacterial inoculants, host genotypes and growth stages of the host on rhizospheric microbial community in terms of soil enzymes and microbial biomass C in soybean and wheat crops were evaluated. Impact of different BCA on soybean rhizospheric microbial community was evaluated through qPCR using 16S rDNA, *nosZ* and *nifH* genes as biological markers. It revealed that BCA inoculants had significant impact on the functional genes of soybean. Fluorescent pseudomonads isolated from the rhizospheres of BCA inoculated soybean varied in their antagonistic potential, as well as in other PGP traits.

4.7.4 Conservation Agriculture (CA) influences spore inoculum level of arbuscular mycorrhizal fungi (AMF)

Inoculum level of indigenous AMF in IARI field under CA was measured in order to rate the nutrient mobilizing potential of soil. In general, CA recorded higher number of AMF spores than conventional till (CT) wheat. Per cent increase in spore population was 88-140% and 45% in CA and CT within a span of 68 days of crop growth respectively. Spore inoculum density of AMF under zero till direct-seeded rice with wheat residue were highest (11 spores per gram of dry soil) and statistically significant ($P \leq 0.05$). The native AMF isolates were categorized into three morphotypes on the basis of spore diameter and designated as 'A' (> 250 µm), 'B' (106- 250 µm) and 'C' (53-106 µm). Population of spore morphotype 'C' was maximum followed by 'B' and 'A'.

4.7.5 Characterization of EPS for enhancing water holding capacity (WHC) of soil through *Anabaena* and *Nostoc* strains

The exopolysaccharides (EPSs) produced by cyanobacteria are important constituents for the development of biofilm through association of microbial communities in various habitats. They are formed on solid surface and act as a reservoir of water and nutrients, which can severely diminish water infiltration by inducing surface sealing and pore clogging and increase nutrient availability. *Anabaena* sp. CCC 745 produced two types, namely capsular polysaccharide (CPS) and released polysaccharide (RPS). These were purified using Size Exclusion Chromatography (SEC). Molecular weight of CPS and RPS were 30.29 and 19.57 KDa, respectively. The carbohydrate was the main component for both EPSs, which are heteropolysaccharide and composed of glucose, xylose, rhamnose, and glucuronic acid. The backbone of both EPSs was made of [→4)-Glcp-(1→] and →4)-Rhap-(1→ linkage. The charges of both EPSs were found negative. The aqueous solution of both EPSs exhibited classically pseudoplastic fluid behaviour. EPS and RPS from *Anabaena* sp CCC-746 was also characterized in similar fashion.

Mole fraction of monosaccharide present in CPS and RPS after SEC

S.N.	Monosaccharide	mol (%)	
		CPS	RPS
1	Glucose	32.53	32.87
2	Xylose	32.58	32.52
3	Glucuronic acid	11.48	16.97
4	Rhamnose	22.24	16.32
5	Others	1.17	1.32
6	Total	100.00	100.00

4.7.6 Enhancing microbe mediated nutrient cycling under non-flooded (aerobic) and flooded (anaerobic) conditions for improved productivity in rice-wheat cropping sequence

Soil application of zinc and inorganic N fertilizer with and without biofertilizers were examined for microbial activities in two rice cultivars (Pusa Basmati 1509 and DRR Dhan 45). Fe reduction varied from 90 to 160 µg Fe^{2+} g^{-1} soil d^{-1}. The rhizospheres of DRR Dhan 45 had higher concentrations of reduced Fe due to soil application of zinc with or without biofertilizers such as B1-4, and biofilmed inoculants at 60 days after transplanting. The composition of microbial communities based on the taxonomic groups (16S rRNA genes of *Alphaproteobacteria*, *Betaproteobacteria*,

Actinobacteria, *Firmicutes*, *Bacteroidetes* and *Acidobacteria*) was determined by the qPCR assays. The gene copies of 16S rRNA *Betaproteobacteria* were higher in the ranges of 10^6 to 10^8 g^{-1} soil, compared to other phyla examined. The application of N as RDF led to highest gene copies of 2.9×10^8 g^{-1} soil. Both the application of zinc and bioinoculants led to characteristic changes in the gene copies of *Betaproteobacteria* in the rhizospheres of cv. Pusa Basmati 1509 and cv. DRR Dhan 45. The abundances of 16S rRNA gene copies of *Actinobacteria* ranged from 10^2 to 10^5 g^{-1} soil, with highest abundance (8.6×10^5 g^{-1} soil) in RDF. The compositions of microbial communities in terms of total bacterial-, archaeal, and cyanobacterial 16S rRNA gene copies were characteristically different from that with other fertilizer management practices in both the cultivars.

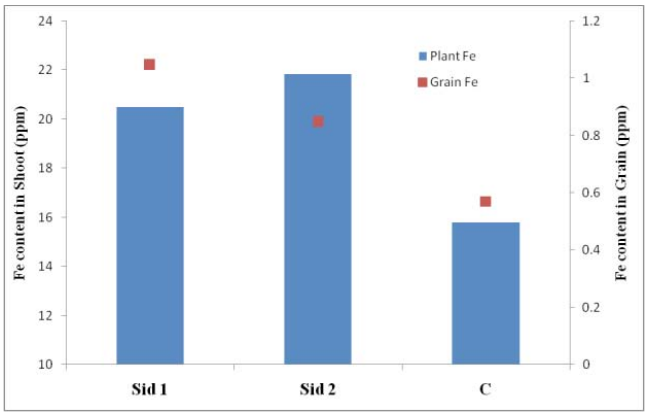
4.7.7 Microbes mediated water stress alleviation in crops

The effect of inoculation of moisture stress tolerant *Bacillus megaterium* on the growth and physiology of the turmeric (*Curcuma longa)* exposed to moisture stress, imposed by withholding water supply) was studied. Inoculation improved plant height and fresh rhizome weight, chlorophyll, phenol contents, ascorbate peroxidase and auxins. A positive impact of the *Bacillus megaterium* inoculation on the plant metabolism enabled it to tide over the moisture stress under field conditions.

4.7.8 Bacterial endophytes for plant growth promotion

Iron deficiency is a serious problem in calcareous and alkaline soils (pH > 7.5) where iron forms oxyhydroxide polymers of very low solubility. Microbial siderophores are known to influence the Fe availability as it chelates ferric ions and make it available for itself and the plant system.

Two bacteria producing different chemotypes of siderophores were used for raising wheat crop under field conditions. They were Sid 1:catecholate type siderophore producing *Pantoea agglomerans* with Fe chelation efficiency-3.3ng$Fe^{59}$$mg^{-1}$ siderophore; and Sid 2: hydroxymate type siderophore producing *Pseudomonas plecoglosida* with Fe chelation efficiency-2.9ng$Fe^{59}$$mg^{-1}$ siderophore. Fe content in wheat shoot and grain was increased by 29.9 and 83.5%, respectively due to Sid 1, and by 38.2 and 48.6%, respectively due to Sid 2 over control treatment. A liquid BioIron formulation has been developed using a consortium (1:1) of both Sid 1 and Sid 2 isolates.



Effeect of Sid-1 and Sid-2 on Fe contant in wheat spoty

4.7.9 Exploring functional diversity of *Azospirillum* for application in rainfed pearl millet

A second year field trial was conducted in *kharif* 2019 with pearl millet variety RHB173 with 75% RDN and bacterial inoculations. Treatment with *Azospirillum* spp strains resulted in higher shoot fresh biomass (2-14% increase over unioculated control with 75% RDN), root biomass (up to 36% increase over unioculated control with 75% RDN). Bacterial inoculation, with strain Azo38 performing best in terms of overall plant growth and grain yield (8% increase over control with 100% RDF), indicating its potential application in rainfed pearlmillet.

4.7.10 *Azolla* biomass as feed supplement and value added product for improving nutritional quality of lactating Murrah buffaloes

Green and red *Azolla* consist of 73.5% and 67.4% saturated fatty acids, respectively. A feeding trial was conducted for assessing the effect of incorporating

sun-dried powder of green aquatic fern *Azolla* (*Azolla microphylla*) in diet of lactating Murrah buffaloes. After three weeks of preliminary feeding a digestion test was conducted for assessing nutrient utilization. Results indicated positive response on digestibility of dry matter (P<0.05), organic matter (P<0.05), neutral detergent fiber (P=0.01) and acid detergent fiber (P=0.015), while the digestibility of crude protein and ether extract remained unaffected (P>0.05). Improvement in digestibility of different nutrients without influencing the intake of nutrients indicated the importance of dried *Azolla* in the ration of lactating Murrah buffaloes.

4.7.11 Utilization of agri-residues for production of industrially important biopolymer poly-β-hydroxyalkanoates by microorganisms

Two potential halophilic PHB producing isolates, *Halomonas* sp LB7 and *Bacillus cereus* 2S4R1 were selected, growth media using saccharified paddy straw leachate was formulated with optimized C: N and batch fermentation parameters were standardized. Optimized fermentation parameters for maximum PHB recovery were found to be pH 7.0, DO 100%, air flow rate 1.0 vvm, temperature 30°C and 20% carbon source concentration. The isolate produced 8.71 g L^{-1} CDM (cell dry mass) and 6.24 g L^{-1} PHB. FTIR analysis of the produced polymer also confirmed the presence of characteristic marker ester carbonyl band for polyhydroxyalkanoates.

4.7.12. Production of biofuels/value added products from lignocellulosic wastes rice straw

Rice straw is highly recalcitrant due to lignin-carbohydrate complex and high ash. It has to be deconstructed to access sugars, which can be converted to high value products. An improvised NaOH pretreatment coupled with acidified waterwash was applied to retrieve high cellulose and lignin. More than 80% cellulose was recovered in pretreated solids and >65% lignins recovered from acidification of alkali prehydrolysates/washwaters. Enzymatic hydrolysis of solids with commercial cellulases yielded ~5.5% and 3.3% sugar syrups which can be fermented to value added chemicals. *Saccharomyces cerevisiae* LN produced 0.508 g g^{-1} and 0.403 g g^{-1} ethanol (fermentation efficiency 77-97%) from hydrolysates within 24 h consuming all glucose while xylose was unutilised. It showed that this process can potentially yield 130 L ethanol and ~100 kg lignin from 1.0 tonne rice straw with limited water. Lignin recovered was under-valued and underutilized byproduct. Therefore, lignin degrading organisms (bacteria, fungi, actinomycetes) were isolated through enrichment culture (minimal medium containing 0.1% lignin and 0.25% glucose; pH 5.0 and 8.0) at different temperatures. Four different strains of bacteria and three different fungi were purified and tested for production of lignin degrading enzymes (Laccases and Lignin peroxidases Lip). All bacteria showed very good zones showing LiP production. Two fungal strains showed high laccase production.

4.7.13 Limited nitrogen application with microbial inoculation can accelerate *in situ* degradation of paddy straw

A consortium of two lignocellulolytic fungi, namely *Coprinopsis cinerea* LA2 and *Cyathus stercoreus* ITCC 3745 were applied in field for *in situ* degradation of rice straw. Highest population of bacteria (8.46 log cfu/g soil), fungi (4.97 log cfu/g soil), phosphate solubilizing bacteria (5.12 log cfu/g soil), cellulose degrading microorganisms (4.92 log cfu/g soil), *Nitrosomonas* and *Nitrobacter* (3.3 and 0.65 log cfu/g soil) were observed with the microbial consortium applied with limited N (i.e., straw + microbial inoculation @ 3 kg ha^{-1} + urea @ 30 kg ha^{-1}) at 30 days. This treatment also registered significantly higher activities of extracellular hydrolytic enzymes (cellulase, xylanase, β-glucosidase). Again, soil microbial activity in terms of dehydrogenase, FDA hydrolase, alkaline phosphatase, peroxidase, urease, and microbial biomass carbon (562.7 mg/kg soil) was also highest in this treatment.

4.7.14 On-farm demonstration of Pusa decomposer and microbial inoculants

In-situ application of Pusa decomposer on paddy residue was demonstrated in farmers' fields of villages Badwasni (Sonepat), Thakurdwara (Mukerian),

Nangalbhoor (Pathankot), Bhangwa (Gurdaspur), Bal & Kohali (Amritsar), and Pheowa (Kurushetra). The liquid culture was inoculated @ 10 litres per acre and field was ploughed with rotavator and wheat was sown after 15 days. Demonstrations were also carried out at KVK Panipat, Mohali, Ujwa and Saharanpur for farmers. In collaboration with MNREGA a large scale demonstration was held at village Puranpur, Pilibhit for pit composting of various residues.

Farmers' participatory on-farm trials (OFT) on carrier based as well as liquid formulation bio-fertilizers, namely, blue green algae (BGA), *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate solubilizing bacteria (PSB), AM fungi and Azolla were conducted in farmers' fields in collaboration with 21 KVKs located in 12 states (J&K, Punjab, Bihar, Jharkhand, Gujarat, Rajasthan, Chhatishgarh, Odisha, Madhya Pradesh, Uttar Pradesh, Uttarakhand and West Bengal). Crops included food, pulse, oilseed, vegetable, plantation crops. The feedback received from the farmers depicts that integrated application of BGA and other biofertilizers are cost-effective, eco-friendly and easy to use. Average increase in rice grain yield across the locations due to application of BGA and PSB varied between 3.4-8.5% over the farmers' practices. Biofertilizer applied plots had bolder and shiny rice grains, and less lodging. BGA application led to marked improvement in soil physical condition and saved 10-25 kg N/ ha. In pulses, increase in yield due to *Rhizobium* inoculation was 11.4-16.8% in green gram, 10.6-15.4% in chickpea and 10.8-16.7% in field pea. Also considerable increment in yield (3.2-7.6%) was found in brinjal due to biofertilizer inoculation. Liquid formulations of *Azotobacter*, *Azospirillum*, ZnSB and KSB were found user-friendly, effective and potential sources of crop nutrition in rice, brinjal and other crops at different locations in India. Inoculation of these liquid formulations increased wheat grain yield by 4.8-12.5%, 3.4-10.2%, 3.5-7.2% and 2.4-5.6%, respectively over the farmers' practices across the locations.

4.7.15 Bioresources

Whole genome sequence of *Azotobacter chroococcum* W5 (MTCC 25045) an indigenous free living diazotroph has been deposited at DDBJ/EMBL/GenBank under Bioproject ID: PRJNA610299. This bacterium has been isolated from wheat rhizosphere long back and has been recommended as a Biofertilizer for many crops, including vegetables, agronomically tested and evaluated. The strain has been formulated as liquid formulation with a shelf life of more than 2 years, and the technology has been commercialized and applied for patent. Seven oleaginous yeasts have been submitted to NBAIM, Mau, *viz*: *Trichosporon mycotoxinivorans S2* (NAIMCC-F-03902); *Candida tropicalis Pe1* (NAIMCC-F-03903); *Candida dubliniensis Pe2*(NAIMCC-F-03904); *Meyerozyma caribbica Pe3* (NAIMCC-F-03905); *Candida tropicalis Po2* (NAIMCC-F-03906); *Candida tropicalis L2* (NAIMCC-F-03907); *Candida quercitrusa L3* (NAIMCC-F-03908). 16S rRNA sequences of fifteen siderophore chemotyped bacterial isolates (Accession No. MK253238- MK253251) and 10 heavy metal remediating bacterial isolates (Accession No. MN524169-MN524178) have been deposited in NCBI. Besides, partially characterized and identified 30 unialgal freshwater cyanobacteria cultures belonging to 12 genera have been deposited at BGA Germplasm, CCUBGA, IARI, New Delhi, which is repository and service centre for fresh water blue green algae maintained in unialgal condition.

4.8 CESCRA

4.8.1 Climate change projections for Indian agriculture

Seasonal climate change projections for Indian region were derived from the bias corrected probabilistic ensemble of 33 global climate models. Based on the analysis it is projected that rise in minimum temperatures will be more than rise in maximum temperatures with increased variability. The rise in temperatures will be more during rabi than during kharif season.It is projected that rise in temperatures will be more in northern parts of India than in southern parts.The rainfall projections, indicate an increase during kharif and rabi seasons with increased variability. This analysis indicated a

progressive climate change and variability in kharif and rabi seasons in India towards the end of the century.

4.8.2 Climate change impacts and adaptations in rice and wheat

Climate change is projected to affect the wheat productivity by -3.2 to 5.3% in 2020 (2010-2039); -8.4 to -19.3% in 2050 (2040-2069); and -18.9 to -41% in 2080 (2070-2099) under different representative concentration pathways (RCPs). States like Bihar, Jharkhand, West Bengal are particularly vulnerable. More inter-annual variability in wheat yield is projected. Adaptation will improve the yield at state level in the range of 10 to 40% in major wheat growing states. However, many current management options may become unsuitable in future climates to sustain wheat yield. Developing short-duration heat tolerant varieties is important for sustaining wheat yield in central India. The irrigated rice yield during kharif season is projected to be affected by approximately -3%, -2 to 3.5% and 2 to 5% in 2020, 2050 and 2080 climate scenarios, respectively in all RCPs. The spatial variation indicated that in the states of Haryana, Karnataka, Kerala, Maharashtra, Tamil Nadu and West Bengal significant negative impacts are projected without adaptation. Growing short duration varieties with improved nutrient and water management can enhance the productivity up to 28% till 2050 climate scenarios but with significant inter-annual and spatial variations. Rainfed rice productivity is projected to change in the range of 7 to -28% in 2020; 2 to -20% in 2050 and -10 to -47% in 2080 climate scenarios in different RCPs with significant spatial variation. It is projected that growing short duration stress tolerant high yielding varieties can improve the yield up to 28% in rainfed rice regions in India till 2050 scenario. But to sustain rainfed rice yieldsbeyond 2050, high yielding heat and water stress tolerant varieties need to be developed. In addition, field level water managementwill be crucial.

4.8.3 Greenhouse gas emission in organic and inorganic grown rice-wheat-mung bean system

Experimental results showed highercumulative methane(CH_4) and carbon dioxide(CO_2) emission from rice-wheat-mungbean systems under organic plots where FYM + crop residue (CR) + biofertiliser (B) and vermicompost (VC) +CR+B were applied compared to conventional inorganicfertilized plots. Global warming potential (GWP) of various treatments varied from 602.3 to 1869.9, 569.7 to 1703.6, and 568.8 to 1665.0 kg CO_2 eq. ha^{-1} during rice, wheat and mungbean,respectively. Among soil properties, SOC exhibited positive and significant relationships with CH_4 and CO_2 flux from rice, wheat and mungbean crops. Similarly, N_2O flux was also had positive correlation with total N, NO_3^--N, and NH_4^+-N. Soil microbial biomass carbon (MBC) had positive association with CH_4 and CO_2 flux from rice, wheat and mungbean crops. Soil enzymes like dehydrogenase, α-and β-glucosidase were positively correlated with CO_2 and CH_4 emission.

4.8.4 Greenhouse gas mitigation through different fertilizer management options

Recommended dose of fertilizer (RDF) reduced 24-29% methane emission in rice at Varanasi. Methane

Global warming potential and yield of rice-wheat system in Varanasi under different fertilizer treatments

Treatments	Rice (Var. Swarna Sub-1)			Wheat (HUW 234)		Rice- wheat system
	CH_4 (kg ha^{-1})	N_2O (kg ha^{-1})	Yield (t ha^{-1})	N_2O (kg ha^{-1})	Yield (t ha^{-1})	GWP (kg CO_2 eq ha^{-1})
Control (no fertilizer)	12.81	0.52	2.80	0.533	1.8	634.0
Farmer practice (NCU, 121:74:00)	20.85	1.23	5.80	1.353	5.5	1290.9
RDF (+Microbial culture)	14.78	1.19	7.10	1.159	6.11	1069.5
RDF (NCU)	15.78	1.15	7.00	1.153	6.17	1080.7
Polymer coated urea	14.27	1.02	7.15	0.976	6.05	951.5

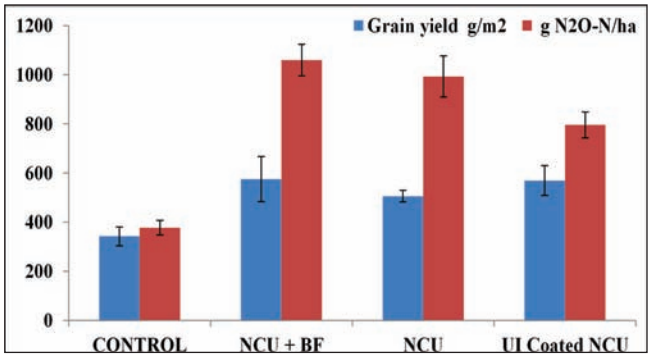
emission was reduced by 6.3 and 9.5 % with microbial intervention and polymer coated urea, respectively in rice compared to RDF. A reduction of 17.16%, 15.6% and 26.3% in global warming potential (GWP) was observed with microbial intervention, RDF and application of polymer coated urea, respectively compared to farmers practice in rice-wheat system The grain yield was increased by 17.1-22.4% in rice and by 9-11% in wheat with microbial intervention, RDF and application of polymer coated urea treatments compared to farmers practice.

4.8.5 Mitigating methane using microbial interventions

A field experiment was conducted in rice using liquid formulation of MNL7 and MaAL 69 consortium of methane oxidizing bacteria (MOB) through seedling root dip technology and as spray formulation at tillering and panicle initiation stage in four rice varieties of Pusa -44, IR-64, CR Dhan 310 and MTU 1010 and their effect on methane emission from rice soil was quantified (Table).The presence of methane oxidizing bacteria (methanotrophs) reduced methane by 7 to 11% under the different rice varieties.

4.8.6 Reducing nitrous oxide emissions in wheat

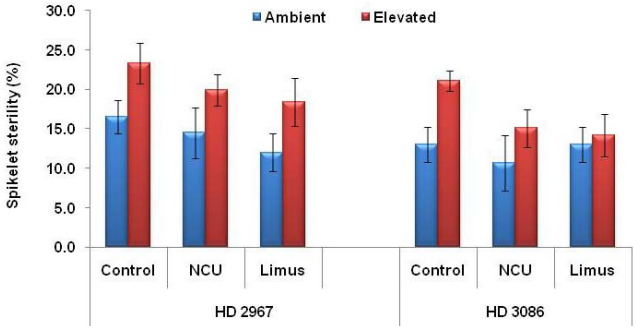
The effect of urease inhibitor on neem coated urea was evaluated for reducing nitrous oxide emissions inwheat. Limuswas used as the urease inhibitor for the study. Application of Limus coated NCU led to a 12.5% increase in yield and 19.8% decrease in nitrous oxide emissions (Fig).



Nitrous oxide emissions and grain yield under urease inhibitor coated neem coated urea

4.8.7 Effect of elevated carbon dioxide and temperature on wheat crop

An experiment was conducted growing wheat varieties HD 2936 and HD 3086 inside the Open Top Chamber (OTC) under ambient (400 ppm) and elevated CO_2 level (550 ± 25 ppm and two temperature levels; chamber control and elevated (+2°C). Results showed that straw weight increased under elevated CO_2 and high temperature treatment but grain yield was reduceddue to increased spikelet sterility under elevated CO_2 and high temperature. Spikelet sterility was more in control treatment as compared to NCU and Limus coated urea applied treatments. Total N of soil was reduced in elevated CO_2 and temperature treatment. Total soil N in Limus coated urea applied treatment was more than NCU applied treatment might be due to reduced N loss in Limus coated urea compared to NCU applied treatments.



Spikelet sterility in wheat varieties under elevated CO_2 and high temperature

4.8.8 Evaluation of manure potential of phycoremediated algal biomass on baby corn and spinach

In the present study, the microalgae *Chlorella minutissima* was selected for phycoremediation. *C. minutissima* reduced nitrate, ammonium, phosphate, and potassium content in sewage wastewater by 89, 48.2, 67.4 and 66.3 %, respectively. The reduction in BOD, COD and TDS was 93.2, 80.5and 94.3%, respectively within 15 days of inoculation. In a field study, the application of 100% N dose by algal biomass gave economic yield of spinach and baby corn higher or equivalent to yield obtained in urea treatment.

The soil supplied with 100% N by algae biomass (*C. minutissima*) significantly increased the dehydrogenase activity in spinach grown soil and the nitrate reductase in baby corn grown soil. Therefore, it can be that inferred phycoremediation coupled with manure production from algae biomass can be a sustainable practice for waste water treatment and to improve the soil quality.

4.8.9 Emission of air pollutants from crop residue burning

Based on remote sensing using satellite data 59668 and 9196 burning events were detected in states of Punjab and Haryana, respectively between Sept. 30, 2018 and Nov. 29, 2018. Based on satellite data in Punjab alone approximately 11.85 million tons of rice crop residue was burned on farms whereas in Haryana it was 1.67 million tons. Burning of rice residue resulted in emission of 18.40 million tons of GHG, 1.31 million tons of other gaseous air pollutants and 0.2 million tons of particulate matter in Punjab and 2.6 million tons of GHG, 0.18 million tons of other gaseous air pollutants and 0.03 million tons of particulate matter in Haryana.

4.4.10 Heavy metals contamination and risk assessment in marketable vegetables in Delhi region

Based on the study conducted in Delhi region at some selected site, the mean concentrations of the selected metals in soil varied over a wide range with decreasing order of Pb> Hg > Cr > Cd > As. The accumulation of heavy metals in vegetables was within the acceptable limits as given by WHO, except Cd, which showed greater contamination in all vegetables at most of the sites, including cultivated and marketed sites. The uptake of the selected metals in vegetables was found below the permissible limit except Cd**.** The maximum daily intake of metals (DIM) with vegetable consumption was higher for Pb and low for Hg. The results showed that the Hazard Quotient (HQ) for leafy and root vegetables was higher than the safe limits in the case of As at most of the sites. The hazard index (HI) and metal pollution index (MPI) were found higher for spinach compared to other vegetables. As and Pb were found to be potential metals having harmful health hazards in target hazard quotient (THQ) at all the sites.

4.8.11 Effect of NO_2 and SO_2 pollution on growth of vegetable crops

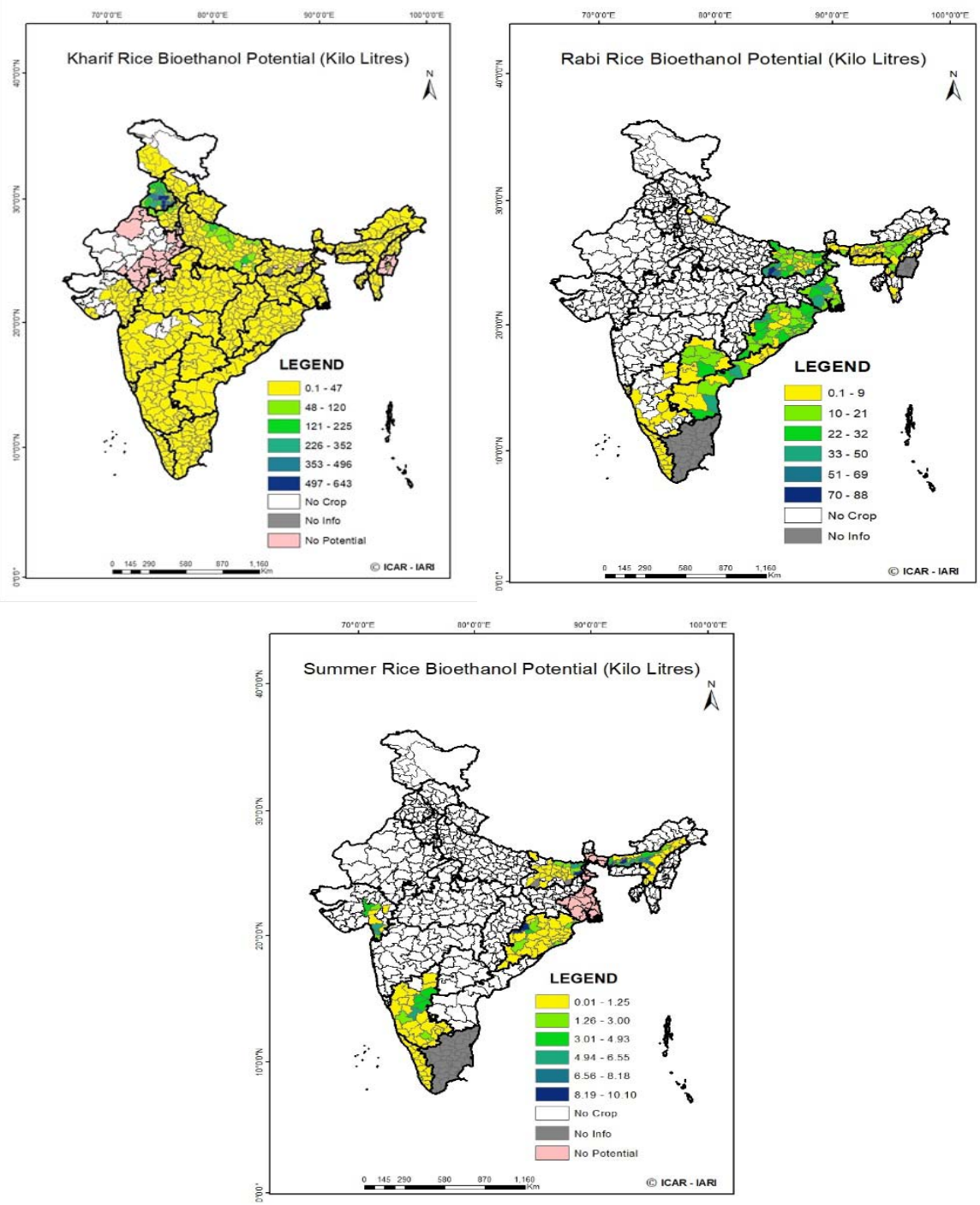
An experiment was conducted to study the effect of elevated level of NO_2 on plant growth attributes and nitrogen nutrition of the field grown carrot, spinach, tomato, mustard and wheat. The crops, at 30 day stage of growth were exposed to NO_2 in specially designed plastic enclosures at following levels viz., ambient (25-35 $\mu g\ m^{-3}$, C); ambient + 10-15 $\mu g\ m^{-3}$ (LN) and ambient + 40-50 $\mu g\ m^{-3}$ (HN) daily for 1 hour for 7 continuous days. Percent leaf necrosis on NO_2 exposure was highest for spinach followed by tomato and mustard. LN and HN exposure caused severe reduction in leaf chlorophyll for all crops. NO_2 exposure, in general, improved N nutrition except in tomato. The study revealed that spinach is highly susceptible to SO_2 and NO_2 pollution compared to other crops. Most of the selected crops exhibited capability to utilize SO_2 and NO_2 for sulphur and nitrogen nutrition, respectively.

In another experiment radio-labeled sulfur (^{35}S) was used to measure the contribution of SO_2 pollution towards S nutrition of crops showed significant variation in total and tissue S35 accumulation among the five varieties of carrot *viz.*, Pusa-Meghali; Pusa-Vrishti; Pusa- Rudhira; Pusa-Aashita and Pusa-Kulfi. Relatively higher 35S levels were recorded in shoot and root of the pink types *viz.*, Meghali and Vristi while least S35 were measured in the white carrot type *viz.*, Pusa-Kulfi. The data shows that the ability of the carrot type to utilize S from SO_2 is related to biosynthesis and presence of pigments in the root tissues.

4.8.12 Estimation of surplus rice residue and its bioethanol potential in India

A study was undertaken to quantify the amount of surplus rice crop residue 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. Of the total rice residue produced, 63% is produced in *kharif* season, 23% in *rabi* season and 7% in summer season. After

different usages of by farmers, 19% of the rice residue produced remains unused and is surplus.The season wise surplus biomass is 82% in kharif season and 16.6% inrabi season.The total annual bio-ethanol production potential from this surplus rice crop residue is 12.28 million liters. The maximum potential is in the state of Punjab (4.7 ML) followed by Uttar Pradesh (2.1 ML) accounting 52.2% of the total bioethanol production potential.



Bioethanol production potential of surplus rice residue in different districts of India

5. CROP PROTECTION

Crop Protection School develops and implement innovative diagnostic tools and management strategy for an early identification and counteracting the impact of diseases, insect-pest and weeds. Changing climate is affecting pest and pathogen dynamics every year, therefore, there is a need to reorient crop protection research strategies that include all options for providing effective and sustainable solution of management. 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 novel chemical/bio-control agents molecules and their efficacy against different pathogens and insect pests of field and horticultural crops alongwith weed management aspects were undertaken and the results are summarized herein.

5.1 PLANT PATHOLOGY

5.1.1 Pathogen diagnostics and genetic variability

***Characterization of false smut pathogen, Ustilaginoidea virens of rice*:** Twenty two isolates of *Ustilaginoidea virens* collected from 7 different states of India were characterized on the basis of morphology and at molecular level using Internal transcribed spacer (ITS) sequences. Isolates were found slow growing and 60% of the isolates showed less than 2 cm growth after 10 days of incubation in potato sucrose agar media.

***Population dynamics and genetic diversity within Colletotrichum gloeosporioides species complex*:** A total of 41 isolates of cryptic species belonging to *Colletotrichum gloeosporioides* aggregates associated with anthracnose disease of fruit crops were studied for the genetic diversity and population structure based on both ISSR and SSR markers. The genetic diversity was found high in north eastern population with a high polymorphism (78.75%). High gene flow within population reflected the high migration rate of the population over long distance. However, strict clustering of isolates based on region separation was not observed which indicated admixture between isolates from different geographical regions.

***Genetic diversity and physiological race characterization of Fusarium oxysporum isolates infecting tomato*:** In *F. oxysporum*, although three different races, *i.e.* race 1, race 2 and race 3 have been reported worldwide but no report on physiological races of the fungus is available from India. Development of resistant varieties is unsuccessfull by the lack of knowledge on the physiological races of the fungus. Hence, to characterize the pathogenic fungus, fungal isolates representing 18 locations were characterized based on their cultural, and morphological characteristics. Their identities were confirmed by sequencing of ITS region and translation elongation factor 1-alpha (EF-1α) gene. Pathogenicity was established in a susceptible cultivar, Pusa Rohini under artificial inoculation conditions in polyhouse. In assessing their genetic variability using Inter Simple Sequence Repeat, the fingerprints showed genetic variability among the isolates and were grouped into two major clusters.

***Development of non-structural protein-based recombinant polyclonal antibodies for specific detection of watermelon bud necrosis virus in plants and thrips vectors*:** Watermelon bud necrosis virus (WBNV) causing bud necrosis disease (BND), is an emerging threat for watermelon cultivation. The development of high throughput and species-specific methods are required for routine and accurate diagnosis of BND. The recombinant polyclonal antibodies (pAbs) were produced against a truncated (243 bp) region of Non-structural (NSs) protein unique to WBNV by cloning in a bacterial expression vector

pET-28a+. The resultant pAbs, were found working well at 1:1000 dilutions with the A_{405nm} values of > 3.0 with the purified protein and 1.1 to 2.3 with the WBNV infected samples within an hour of incubation. The pAbs also have the specific reactivity with only the WBNV infected (plant & thrips) samples, but not those infected with GBNV. This anti-WBNV NSs antiserum is the first of its kind in the world with regard to the pAbs specific to WBNV, that too against NSs protein. This antiserum will have a great significance in evaluating the watermelon genotypes for resistance to WBNV as well as in the virus-vector relationship studies.

***Identification of new illarvirus and viroid from mosaic infected apple cultivars*:** A survey of apple orchards in Jammu and Kashmir revealed the incidence of mosaic disease from 7.14 to 90% in different cultivars, *viz*., Oregon Spur, Fuji Aztec, Royal Delicious, Red Delicious, Golden Delicious, Red Gold and Gala Mast. In addition to mosaic symptoms of chlorosis, necrotic and ring spots were also observed on different cultivars of apple. Most of the collected samples were tested negative for apple mosaic virus (ApMV) in DAS-ELISA. Association of apple necrotic mosaic virus (ApNMV), a new illarvirus recently reported from China, Korea and Japan was determined in different cultivars showing both mosaic and necrotic symptoms by RT-PCR and sequencing of full coat protein gene. Out of 18 samples tested in RT-PCR, ten were positive for ApNMV and only two for ApMV. Sequence analysis of amplicons of 680 bp from five different cultivars showed 89-91% sequence identity ApNMV associated with apple mosaic disease. The phylogenetic analysis grouped Indian isolates into two sub-clusters under one major cluster (ApNMV group). The sub-cluster-I, included ApNMV isolates from cultivars, Oregon Spur, Red Delicious and Fuji Aztec along with Chinese and Korean isolates. Sub-cluster-II included ApNMV isolates associated with Golden Delicious and Royal Delicious. The comparison of coat protein gene based sequence identity matrix showed maximum and minimum similarity of 89% to 99% with ApNMV isolates from China and also with other illarviruses showed maximum identity with PNRSV (61.6%) and ApMV (52.8%).This is the first report of association of ApNMV with apple mosaic disease from India. It is evident from the results that the ApNMV is associated with AMD in India and is more common than ApMV and is a major cause of the mosaic disease in apple cultivars.

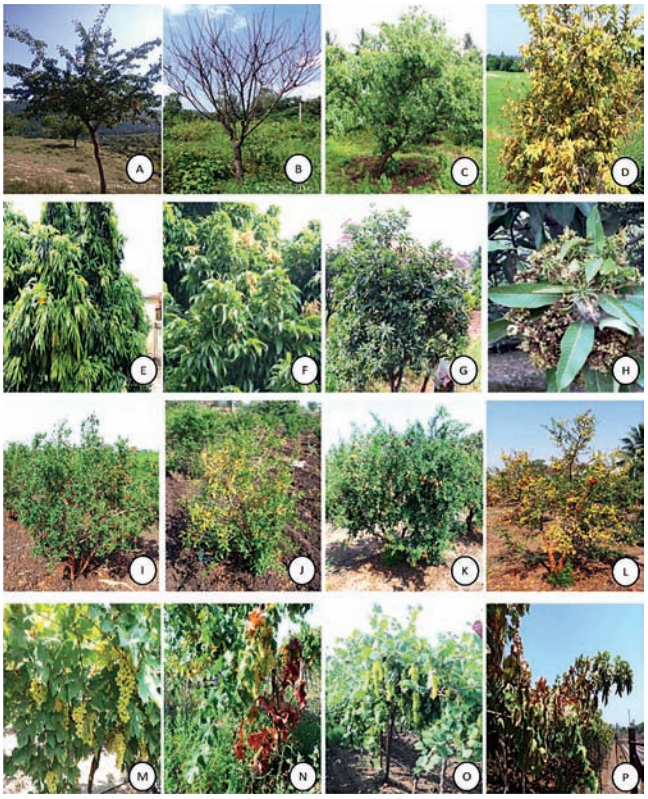
For identification of apple hammerhead viroid, six commercially grown cultivars (Oregon Spur, Red Delicious, Golden Delicious, Royal Delicious, Gala Mast and Red Gold) were screened using one-step RT-PCR. The amplicons of expected size 440 bp was obtained from 4 cultivars, whereas other two (Gala Mast and Red Gold) were tested negative. The amplicons from two cultivars Oregon Spur and Golden Delicious were cloned in pGEM-T Easy vector (Promega, Madison, WI) and sequenced. The sequence of both clones after BLASTn analysis showed 99% and 93% sequence similarity with AHVd isolates of MH649334 from New Zealand and MH643720 from China, respectively. The phylogenetic analysis grouped these two isolates with isolates from Italy, USA, New Zealand and China. This is the first report of AHVd association with apple from India.

***Identification of Zucchini yellow mosaic virus infecting bell pepper* (*Capsicum annum L.*):** Zucchini yellow mosaic virus causing symptoms of vein banding, chlorosis, mottling, puckering, and reduced fruit size with a rough surface was identified in bell pepper in Kolhapur, Satara, and Nashik districts of the western regions of Maharashtra. The virus was identified by ELISA, RT-PCR assay and sequence analysis.

***Detection and molecular characterization of orchid viruses*:** A survey was conducted at different orchid growing areas of Sikkim and Darjeeling hills of West Bengal and collected 44 virus infected samples of orchid species and hybrids with variable symptoms. Electron microscopy of negatively stained preparation of symptomatic leaves showed the presence of rigid rods (300 x 18 nm), flexuous rods (475 x 13 nm and 800 x 12 nm), bacilliform or bullets shaped particles (40 x 100-140 nm) and enveloped quasi-spherical particles (80-110 nm) from the collected samples. DAC – ELISA

results revealed that four viruses namely CymMV, ORSV, GBNV and CalMMV were found positive. Further, RT-PCR test was also performed using specific primers to detect ORSV, CymMV, GBNV, orchid fleck virus (OFV) and CalMMV and positive amplification was observed for CymMV, ORSV, GBNV and CalMMV. Cloning and sequencing of coat protein gene of ORSV in four species of orchids (*Phaiustan kervilleae* from NRCO Sikkim, Cymbidium hybrid (Baltic Glacier Mint Ice and SHOL-2 from CDC Rumtek, and *Epidendrum* sp. from Everest nursery Kalimpong showed 100% identity in nucleic acid sequences among themselves and more than 99% among the different ORSV isolates available on Gen Bank. Present study showed that coat protein sequences of ORSV in India and elsewhere are highly conserved and proved that ORSV would might have introduced in Sikkim and Darjeeling hills from other countries.

Identification of phytoplasma in fruit species in India: Symptoms of decline, leaf yellowing and reddening, little leaf and malformation were observed in apricot, guava, lychee, mango, pomegranate and grapevine in Delhi, Maharashtra and Jammu & Kashmir. Phytoplasmas belonging to three different groups were detected in symptomatic fruit tree samples in polymerase chain reaction assays with phytoplasma specific primer pairs amplifying 16S rRNA and *sec*A genes. A '*Candidatus* Phytoplasma asteris' - related strain was detected in apricot showing decline symptoms in Siot (Jammu & Kashmir). '*Ca*. P. australasia' - related strain was identified in guava, lychee, mango and pomegranate in Rajbag, Sunjwan (Jammu & Kashmir), Pusa (Delhi) and Baramati (Maharashtra), respectively, exhibiting little leaf, leaf yellows and malformation symptoms. Furthermore, a rice yellow dwarf group (16SrXI-B) - related strain was detected in pomegranate and grapevine that showed leaf yellowing and reddening at Pusa (Delhi) and Baramati (Maharashtra), respectively. Sub-group analysis using virtual RFLP of 16S rDNA sequences allowed enclosing these phytoplasma strains into 16SrI-B, 16SrII-D and 16SrXI-B sub-groups. In the present study, identification of phytoplasma sub-groups, 16SrI-B in apricot, 16SrII-D in guava, lychee, mango and pomegranate (Pusa) and 16SrXI-B in pomegranate (Baramati) and grapevine, are the first records globally.



Field view (A) Healthy apricot; (B) Decline symptom in apricot at Siot; (C) Healthy guava; (D) Guava leaf yellowing at Rajbag; (E) Healthy lychee; (F) Lychee little leaf symptoms at Sunjwan; (G) Healthy mango; (H) Mango malformation symptoms at Pusa; (I) Healthy pomegranate; (J) Pomegranate leaf yellowing symptoms at Pusa; (K) Healthy pomegranate; (L) Pomegranate leaf yellowing symptoms at Baramati; (M) Healthy grapevine (var. Fantassy); (N) Grapevine leaf reddening symptoms at Baramati; (O) Healthy grapevine (var. Krishna); (P) Grapevine leaf yellowing and reddening symptoms at Baramati.

Multilocus sequence analysis of a 'Candidatus Phytoplasma aurantifolia'-related strain associated with peanut little witches broom leaf disease: Severe little leaf and excessive shoot proliferation symptoms typical of the peanut little leaf disease were observed in different peanut (*Arachis hypogaea*) fields, variety K-6, at Kadiri and Gooty regions, of Andhra Pradesh, India, during the monsoon season of 2018-19. The phytoplasma etiology of the disease was confirmed by amplifying 1.25 kb DNA products of 16S rRNA gene from affected plants using nested

polymerase chain reaction with phytoplasma specific primers, P1/P7 and R16F2n/R16R2, respectively. A further confirmation of the phytoplasma etiology was obtained by amplification of 840, 1094 and 465 bp DNA fragments using phytoplasma specific primers targeting *sec*A,*tuf* and *SAP*11 genes, respectively. Sequence and phylogenetic analyses of the amplified 16S rRNA, *sec*A, *tuf* and *SAP*11 genes revealed that the detected phytoplasma is a member of the peanut witches'-broom phytoplasma group or 16SrII group ('*Candidatus* Phytoplasma aurantifolia').

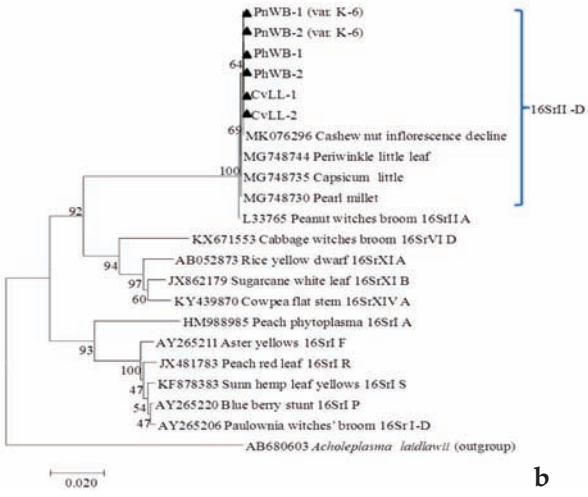
Characterization and genetic diversity of phytoplasma associated with elephant foot yam (Amorphophallus paeoniifolius) in three states of India: Leaf yellowing, stunting and declining symptoms were observed on elephant foot yam (EFY) at Gorakhpur and Kushinagar (Uttar Pradesh), Pantnagar (Uttarakhand) and Nagicherra, Agartala (Tripura). Witches' broom symptoms on *Datura stramonium* (DS) grown as weeds nearby EFY fields at Gorakhpur and Kushinagar districts of Uttar Pradesh state were also recorded. Pair wise sequence comparison, virtual RFLP and phylogenetic analysis of 16S rRNA sequence analysis confirmed association of *Ca*. P. trifoli related strains (16SrVI-D subgroup) with EFY leaf yellows. However, the phytoplasma isolates associated with the stunting, leaf yellowing and declining symptoms of EFY from Pantnagar and Tripura were identified as strains of *Ca*. *P. oryzae* (16SrXI-B subgroup). This is the first report of identification of *Ca*. P. trifoli and *Ca*. P. oryzae related strains associated with EFY in world. *D. stramonium* was reported as a natural putative weed host of *Ca*. P. trifoli in the study .

***First report of phytoplasma causing phyllody in Melia azedarach*:** A *Candidatus* Phytoplasma asteris belonging to 16SrI-B subgroup affecting *Melia azedarach* was reported for the first time in India associated with phyllody symptoms and virescent flowers from Pune district, Maharashtra in April, 2018. The presence of phytoplasma was confirmed by nested PCR assays using universal phytoplasma specific primers and virtual RFLP anlaysis.

5.1.2 Pathogenicity, host-pathogen interaction and genomics

Genome-based identification of simple sequence repeats markers in Tilletia indica population: A total of 5,772 simple sequence repeat loci were identified in *T. indica* genome (MBSW00000000). Maximum SSRs were tri-nucleotide (2,456) followed by di-nucleotides in the genome. *In silico* analysis, 40 microsatellite markers were used to genotype 20 *Tilletia indica* isolates belonged to north-western plain zone of India. In total, 130 alleles were identified. The highest number of alleles were 6 in TISSR1 and TISSR34 markers. The

a



b

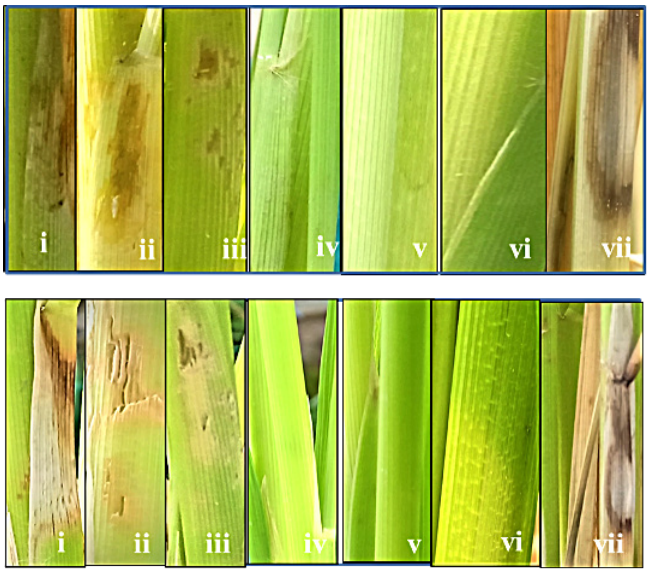
(a) Little leaf and witches' broom disease in peanut and (b) Phylogenetic tree constructed by the neighbor-joining method of 16S rRNA gene of the peanut

frequency of 2 loci was very high in *TI* population. The polymorphic information value content (PIC) values ranged from 0.20 to 0.81 with an average of 0.51. The highest PIC value was 0.81 in TISSR34 followed by TISSR1 (0.75).

Transcriptome analysis of resistant and susceptible genotypes infected with Bipolaris sorokiniana causing spot blotch of wheat: Whole transcriptome analysis was performed on *B. sorokiniana*-wheat interaction. Transcriptome of *B. sorokiniana* inoculated resistant (Chiriya 7) and susceptible (Agra Local) genotypes of wheat were analyzed. Approximately 33 million reads were generated using RNA sequencing by Illumina NextSeq500 platform. An average of 81.20% of the reads was aligned to the reference genome. Differential expression was performed to identify differentially regulated gene in two genotypes. Out of 2938 genes, 1408 were significantly up-regulated whereas 1530 genes were significantly down-regulated on the basis of *p*-values in Chiriya 7 inoculated with *B. sorokiniana*. Out of 2,293 genes, 1,005 were significantly up-regulated, whereas 1,288 genes were significantly down-regulated on basis of *p*-values in Agra local inoculated with *B. sorokiniana*. Transcripts of Chiriya 7 and Agra local inoculated with *B. sorokiniana* were also compared to *B. sorokiniana* transcripts. Out of 24 genes, 18 were significantly up-regulated whereas 6 genes were significantly down-regulated in Chiriya 7. Out of 32 genes, 16 were significantly up-regulated whereas 16 genes were significantly down-regulated in Agra local.

Transcriptomic analysis of bakanae disease resistant and susceptible rice genotypes in response to infection by Fusarium fujikuroi: Two contrasting genotypes of rice i.e. resistant (C101A51) and susceptible (Rasi) to bakanae disease were taken and transcriptome analysis was performed. Transcriptomic analysis was conducted between C101A51 control (CC) vs C101A51 inoculated (CI), Rasi control (RC) vs Rasi inoculated (RI) and C101A51 inoculated (CI) vs Rasi inoculated (RI). In CC vs CI, differentially expressed genes (DEGs) were 12,764 (79%). Out of them, 567 (4%) were significantly upregulated and 1399 (9%) genes were down regulated. For the RC vs RI 14, 333 (79%) genes were commonly expressed in both inoculated plants and control plants. When we compared CI vs RI ,13,662 (72%) genes were identified to be commonly expressed. Further, 280 (1%) genes were exclusive in CI and 532 (3%) genes were exclusive in RI. Cysteine proteinase inhibitor 10, disease resistance protein TAO1-like, oleosin 16 kDa-like, pathogenesis-related protein (PR1), pathogenesis-related protein (PR4), BTB/POZ and MATH domain-containing protein 5-like, alpha-amylase isozyme 3D-like (LOC4345814), were upregulated in resistant genotype C101A51. Whereas, GDSL esterase/lipase At5g33370, serine glyoxylate aminotransferase, CASP-like protein 2C1, WAT1-related protein At4g08290, cytoplasmic linker associated proteins, xyloglucan endotransglucosylase/ hydrolase protein and β-D xylosidase 7 were found to be upregulated in susceptible genotype Rasi. This study will be helpful for the development of bakanae resistant rice varieties.

Phytotoxin as a key component in pathogenicity and virulence of Rhizoctonia solani inciting sheath blight of rice: In the process of identifying interacting partners in rice for potential pathogenicity factors of *Rhizoctonia solani* inciting sheath blight, the role of host-selective toxins elaborated by the fungal pathogen in ShB development has been elucidated. The fungal isolates were collected from six locations and preserved as laboratory collections. These were characterized using their cultural and morphological characteristics and their identities were confirmed by PCR amplification of ITS region and sequencing. Pathogenicity assay was established in the polyhouse under artificial inoculation conditions. The phytotoxin was then extracted from the highly virulent isolate using ethyl acetate and tested for lesion development by both detached leaf and *in-planta* assays. The phytotoxin of the *R. solani* isolates was observed to reproduce symptoms of the disease independent of the pathogen itself, and induced maximum lesion development for a highly pathogenic isolate RIRS-K confirming its role as a key component in pathogenicity of the necrotrophic fungus.



Effect of crude RS-Toxin on ShB development on 60 days old rice cv PB-1 at various concentrations (A) in planta assay (i)10,000 ppm (Stock) (ii)1000 ppm (iii) 500 ppm (iv) aqueous fraction (v) acetone (vi) water (vii) RIRS-K

***Virulence analysis of powdery mildew (Blumeria graminis tritici) isolates*:** The powdery mildew infected wheat disease samples collected from different places *viz.,* 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 powdery mildew lines each carrying single *Pm*-gene along with two universal susceptible checks. Avirulence and virulence formulae of *Bgt* culture were also used to known the effective and ineffective genes. Virulence was observed on gene *Pm*3a, *Pm*3b, *Pm*3c, *Pm*5, *Pm*7 and *Pm*8. No virulence was detected on gene *Pm*1, *Pm*2, *Pm*4a and *Pm*6.

Identification and expression analysis of a virulence gene Tox A in Bipolaris sorokiniana causing spot blotch of wheat: *Tox A* gene has been identified and characterized in Indian isolates of *Bipolaris sorokiniana*. An amplicon of 600 bp (approx.) was sequenced. The analysis revealed 100% homology with *Tox A* gene in *Pyrenophora tritici repentis.* All these *BsToxA* sequences have been submitted in NCBI database (MN601358-MN601396). *In vitro* expression analysis of *ToxA* gene in *B. sorokiniana* isolate (BS112) using qPCR revealed maximum up-regulation (14.67) at 1st day after inoculation (DAI), followed by 2nd DAI (11.83 fold), then gradually expression level decreased at 3, 4 and 5 DAI. *In planta,* expression analysis was also performed using qPCR. The maximum expression (2.13-fold) was observed at 3rd DAI in susceptible cultivar (Agra local), while minimum expression (0.23-fold) was observed in resistant genotype (Chiriya 7) at 3rd DAI .

Comparative genomics of Magnaporthe species infecting rice and pearlmillet: Whole genomes of *Magnaporthe oryzae* strain RMg-Dl infecting rice and *M. grisea* strain PMg-Dl infecting pearl millet was sequenced using the Illumina and PacBio platforms. The high throughput hybrid assembly of short and long reads resulted to 341 and 996 scaffolds with the genome size of 47.89 Mb and 34.81 Mb of PMg-Dl and RMg-Dl strain, respectively. Comparative genome analysis revealed 83% average nucleotide identity (ANI) and gene calling confirmed a total of 10451 and 12,747 genes in both genomes with common and unique proteins/genes, protein family and superfamily between the genomes. A total of 5,589 and 5,032 genes were uniquely present in both genomes. Similarly, the Inter Pro Scan of predicted protein sequences of both genomes annotation revealed that 148 (4.3%) and 65 (1.9%) protein family (PFAM), 38 (7.7%) and 29 (5.9%) super family (PIRSF) were uniquely present in PMg-Dl and RMg-Dl genome. The prevalence of Virulence Factors (VF) determination revealed that majority (90.9%) of VFs were shared between both the genomes. However, two VFs were unique in PMg-Dl and three VFs were unique in case of RMg-Dl genome. Comparative annotation of whole genome of *M. grisea* and *M. oryzae* infecting pearl millet and rice revealed that genome size was larger in pearl millet infecting *M. grisea* than rice infecting *M. oryzae* indicating genome reduction in rice adapted *M. oryzae.* Comparative genome analysis also revealed specific virulence factors, CAZmes and unique pathways in pearl millet infected by *M. grisea*when compared to other *Magnaporthe* strains infecting rice.

***Comparative genome analysis of Tilletia indica reveals high genomic variation*:** The whole genome of *Tilletia indica* RAKB_UP_1 have been sequenced

(GCA_002220835.1). The genomes have variable size ranging from 26.7 Mb to 43.7 Mb. The genomes of seven isolates of *T. indica* were compared. For genome mapping, all the genome assemblies were aligned against *T. indica* RAKB_UP_1 genome using minimap2. Tik_1 was mapped 100% with the reference genome. Further, comparative genome analysis was done by identification of SNPs, In-Dels, segmental duplications, LTR and CNV. It revealed that variable number of SNPs were ranging from 1380 (Tik_1) to 160966 (Tik) and 82 (PSWKBGH_1) to 3309 (PSWKBGD_1_3) In-Dels. Copy number variations including duplications and deletions were also identified, while Tik had shown highest number of duplicate counts (100).

Agrobacterium-mediated in planta transformation of cotton with antisense βC1 gene construct (pCAMBIA-As-βC1): *Agrobacterium*-mediated *in planta* transformation with antisense βC1 gene construct (pCAMBIA-As-βC1) was carried out in 5 cotton vars. Coker 310, RST-9, F846, HS6 and PSS-2. The GUS assay and PCR analysis of T_1 cotton plants showed that two cotton vars. Coker 310 and RST-9 were transformed with pCAMBIA-As-βC1 gene construct. Stable segregation of As-βC1 transgene in both the cotton varieties was evaluated upto T_2 generation. RT-PCR of T_2 cotton plants confirmed βC1 and nptII gene expressing in T_2 transgenic line. T_3 cotton plants will be challenged with viruliferous whitefly to check the resistance capacity against CLCuD begomovirus.

Development of mutagenic construct of* avrBs1 *in suicide vector (pK18mobSacB): The mutagenic primers of *avr*Bs1 having restriction enzyme site. *i.e. EcoRI* and *XbaI* in fragment 1 (F1) and *XbaI* and *EcoRI* in fragment 2 (F2) of *avrBs1* gene were amplified by proof reading *Taq* polymerase. The amplified products of F1 and F2 fragments were digested with XbaI restriction enzyme and ligated by DNA ligase. The ligated product was cloned in pGEMT-Easy vector. The M13 forward and reverse primers were used to confirm the cloned product by Colony PCR. The clone of F1F2/pGEMT is using for the generation of mutagenic construct of *avr*Bs1 in pk18mobsacB, suicide vector. Additionally, the mutagenic construct of *avrBs1* gene of *Xcc* was developed and checked by colony PCR and restriction digestion analysis. The developed construct was confirmed by DNA sequencing.

***Role of suppressor proteins of begomovirus in viral pathogenicity*:** Three putative silencing suppressor proteins (V2, C2, and C4) of croton yellow vein mosaic virus (CYVMV) were amplified and cloned in pEarleyGate103 vector. Transient expression of each of V2, C2 and C4 proteins in *Nicotiana benthamiana* resulted in typical leaf curl symptom in systemic leaves. Further analysis through RT-PCR and confocal microscopy showed the expression of these proteins in systemic leaves, indicating that all of them act as pathogenicity determinants.

Development of hairpin-RNAi constructs against the suppressor genes of tomato leaf curl New Delhi virus and their evaluation through transient expression: Three suppressor genes (AV2, AC2 and AC4) of tomato leaf curl New Delhi (ToLCNDV) was amplified and hairpin RNAi constructs against them was developed using a high throughput golden gate based binary vector pRNAiGG. The efficiency of agro-constructs was evaluated through transient expression in *N. benthamiana* followed by challenged inoculation of ToLCNDV. qPCR analysis at 4 dpi indicated that the virus accumulation in the inoculated plant reduced significantly in all the hairpin RNA inoculated plants. Highest reduction was observed when the plants were treated with AC4 hairpin RNA.

Understanding the minimum size of begomovirus replication module to be used as vector: To understand the minimum viral replicon size of croton yellow vein mosaic virus (CYVMV), six constructs (gene deleted and point mutation) were developed. To understand the replication behavior of these constructs and the symptom phenotype produced by them, all the constructs were agroinfiltrated into *N. benthamiana* plants. None of the constructs developed any symptom phenotype even after 30 dpi. Further molecular analysis for understanding the replication of these molecules indicated that they are efficiently able to replicate in the inoculated area but could not move systemically.

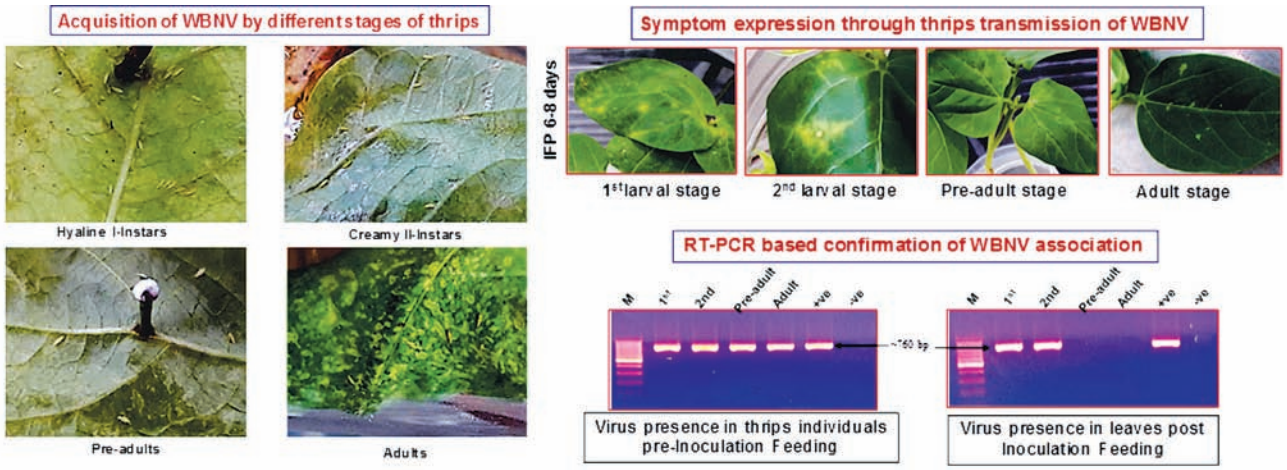
Result thus suggested that for replication C1-C3 portion are essentially required and V2-V1 portion are essentially required for cell-to-cell and long-distance movement of the virus. V2-V1 deleted minimum viral replicon module can effectively express GFP in the inoculated tissues.

5.1.3 Epidemiology

***Elucidated the stage-specific behavior of watermelon bud necrosis tospovirus (WBNV) transmission by Thrips palmi*:** The individuals of *Thrips palmi* at different growth stages viz., I & II instar (L_1 & L_2) larvae, pre-adults and adults were subjected to acquire the WBNV from the systemically infected cowpea leaves for 48hrs followed by inoculation feeding for 6-8 days on the cowpea plants grown on the soil-less media in the insect breeding jars. After incubating the plants at 28±2°C, post inoculation feeding, for 4-6 days, thrips individuals as well as the inoculated plants were tested by RT-PCR for the presence of virus and infection by WBNV. The virus was detected in the thrips individuals of all the stages. However, only the I & II instar (larvae L_1 and L_2 stages), but not the pre-adult and adults, could induce the symptoms on cowpea plants. Subsequently the WBNV was also detected only in the plants fed by the larvae of L_1 and L_2 stages. The results suggested that transmission occurred if the virus is acquired by 1st& early 2nd instar larval stages (Like-wise TSWV transmission by WFT). The pre-adult and adult individuals could acquire, however, failed to transmit the virus.

***Changing of population structure of CLCuD-begomo viruses associated with cotton leaf curl disease in Northwest India*:** Cotton leaf curl disease (CLCuD) is a major constraint in cultivation of cotton in entire northwest India. Variation in CLCuD incidence in cotton growing areas of NW India is common and 50-100% incidence was observed in some years but sporadic (0-30%) in other years. To explain the basis of these changes and the etiology of CLCuD begomo viruses, survey was carried out for the year 2018 and 2019 in the cotton growing states of NW India and samples were collected. The CP genes of 29 samples, 13 of the year 2018 and 16 of 2019, were amplified through PCR, sequenced and analysed. The cotton leaf curl Kokhran virus (CLCuKoV) and the cotton leaf curl Multan virus (CLCuMuV) were identified. It was observed that CLCuKoV was major in population in 2018 and CLCuMuV was major in 2019, indicating changes in etiology of the CLCuD-begomo viruses.

Simulation of leaf curl disease dynamics in chilli for evaluation of management strategies: Leaf curl epidemic in chilli is a dynamic tripartite interaction between the hosts, vector and virus transmission but largely unknown. Tripartite interactions of host-vector–virus over time taking into account on changes in the host population (*S*), transmission efficiency (*a*) and time delays underpinning viruliferous



Transmission of watermelon bud necrosis tospovirus by *Thrips palmi*

vector population (*V*) leads to epidemic progression. Infectious host (*I*) and viruliferous vector (*V*) were estimated from the field samples through *ChLCV* specific primers. Transmission efficiency (*a*) estimated under controlled experiment was 0.14-0.19. Parameters like contact rates (*b* and *v*) and immigration rate (*m*) for viruliferous vector were adjusted based on the changes in host and vector population observed in time. Pattern of population dynamics for healthy host ($dS/dt=-a*V*S$) and viruliferous vector ($dV/dt=b*v*[1-V]*I+m-u*V$) were simulated, through mathematical model having in-built tripartite interaction. Pattern of dynamic changes in population of *I* and *V* indicated high contact rates and immigration rate (*m*) of viruliferous vector in the field which caused high infection rate in chilli within a short period of time as within one month more than 97% of the plants was infected with the vir. PCR detection indicated 65% of the vector population was viruliferous at the time of chilli transplanting.

Developing yield loss assessment model for stripe rust and validation: Data on physiological parameters (NDVI & RBG indices) at different growth stages and agronomic parameters *viz.* grain number (m^{-2}), grain number ($spike^{-1}$), spike number (m^{-2}), TGW (gm), yield (kg/plot), harvest index (%), plant height (cm), heading date were also recorded for each conditions (protected & unprotected). Grain yield of protected and unprotected conditions were used to calculate the potential yield losses in each varieties with the aim of developing predictive model for grain yield and yield losses performing a Multivariate Regression analysis using the different epidemiological, physiological and agronomic parameters as independent variables. Epidemiological parameters found to be accurate predictors of grain yield and grain yield loss infected with stripe rust ($R^2 = 0.569$ and $R^2 = 0.527$, respectively). With regards to potential grain yield, presence of disease is found to be correlated with reductions in the grain number ($spike^{-1}$), Grain number (m^{-2}), Spike number (m^{-2}) and Harvest Index (HI).

5.1.4 Host resistance

Wheat: Among the PDSN wheat entries (589) evaluated for rusts and leaf blight resistance at different hot spot locations, 30 entries were found to be highly resistant against rusts and leaf blight at adult plant stage across the test locations. The CVT wheat genotypes (160) were evaluated against major pathotypes of three rusts at seedling stage (SRT). Seventeen lines were resistant to three rusts at seedling stage (SRT) across the test locations. Response of Race-specific Adult Plant Resistance (APR) in AVT wheat genotypes (97) against major races of stripe rust (46S119 & 110S119) revealed that some of the wheat genotypes, *viz.* 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 resistance to both the pathotypes of stripe rust.

Pre-breeding lines (PBLs) with resistance to stripe rust: Wheat pre-breeding lines (PBLs) derived from CIMMYT's Gene Bank were evaluated for yellow rust to identify new sources of resistance. Preliminary results provided encouraging information. Thirteen PBLs had yellowrust symptom score ≤5% (0 and 100% being completely resistant and susceptible, respectively), and six PBLs had powdery mildew symptom scores ≤ 2.5 on a 0–9 scale (0 and 9 being completely resistant and susceptible, respectively).

Genetic basis of leaf rust resistance in three bread wheat cultivars *viz*., MP 3288, HI 1418 and HI 784 which have been maintaining high levels of resistance to Indian pathotypes of leaf rust was studied at Indore. The genetic inheritance data of F_1, F_2 and F_3 populations indicated that resistance is governed by two dominant genes each. The gene *Lr34* is common among the three genotypes as revealed molecular markers, Lr34DINT9F and Lr34PLUSR. However, allelic relationship of the second seedling gene among the three genotypes is not known based on the available data and need to be studied. A total of 589 genotypes of preliminary disease screening nursery (PDSN) were evaluated for field resistance to stem and leaf rusts under artificial inoculations using mixtures of important pathotypes at Indore. Of these, 201 entries (~34% of the total) shown 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 identified were: HAS 2525, HAS 2528, HAS 2529 and HAS 2558.

Under AICWBIP on pathological nurseries, a total of 2304 lines were evaluated against leaf rust reactions at IARI, Wellington. Out of these, 38% lines of AVT, 21.5% of NIVT1, 17 of MDSN, 37% of IPPSN and 65.5% lines of EPPSN lines were completely free from leaf rust infection. Genomic DNA of 14 powdery mildew isolates was isolated amplified and short read of DNA sequences were deposited (Ac No. MK507502 to MK507515) in NCBI data base. Clonal/true-to the type collections of *Berberis* spp. (42 Nos) are established as biological resource materials for host pathogen interactions studies. Selected isolates of *P. triticina* and 170 of *B. graminis* f. sp. and *tritici* were maintained for virulence and genetic analysis.

A set of wheat genotypes (317) including popular released cultivars, advance lines and exotic material was inoculated with *Tilletia indica* at Zadok's stage 49 at IARI, New Delhi. Karnal Bunt (KB) incidence was recorded and coefficient of infection was also calculated. Out of 158 advance lines and popular cultivars screened for Karnal bunt, 47 lines were found free from disease. Fifty-seven lines showed resistance to KB (<5.00% incidence) while 36 lines were found moderately resistant (5-10% incidence). A set of 38 genotypes, which showed resistance to rusts during 2018-19 were evaluated for Karnal bunt at IARI, Delhi under artificially inoculated conditions. Among these, 15 lines were free from disease while 15 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 (158) was evaluated for head scab (Fusarium head blight) pathogen by inoculating the material at mid anthesis with cotton web technique in poly house at IARI, Delhi. Only three lines showed resistance to head scab pathogen, *Fusarium graminearum* (<10.00% spike infection). Disease score was more than 2 (0-5 scale) in 130 lines. A set of 38 lines which showed resistance to rusts during 2018-19 was also evaluated for head scab under artificially inoculated conditions. Only 13 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. Rest of lines were categorized as moderately susceptible, susceptible and highly susceptible. Genotypes, HPW 433, PBW 725, VL 3012 and MACS 5046 (Dicoccum) showed resistance to Karnal bunt and moderate resistance to head scab.

Rice: Out of 1301 rice genotypes evaluated against sheath blight disease as typha bit inoculation method under field conditions, 4 lines, *i.e.* IRG45, IRG54, IRG58 and IRG103 were found moderately resistant. Out of 380 rice genotypes evaluated against bakanae disease of rice under glass house and field conditions as a seed and seedling inoculation, respectively, genotypes IRG 84, IRG 90, IRG 148, NW42 and NW43 were found promising. 398 rice entries included in NSN 1-Screening for Leaf Blast Resistance (screening nursery) were evaluated under Uniform Blast Nursery (UBN) pattern using rice blast isolate (U77-i7-k177-z17-ta733) from Rothak (Haryana) region. Standard Evaluation System, *i.e.* 0-9 SES (IRRI, 1996) scale was used to record the data. Among the 353 rice genotypes, 30 entries were found resistant. In another trial, entries, Raminad STR-3, *O. minuta,* Zenith, Tetep and Rasi were found to be resistant.

Pearl millet: In 2019, under Pearl Millet Blast Variability Nursery (PMBVN) trial, 2 resistant entries (BRRL-2, ICMR 100845) were identified. Under Disease Screening of Advance Pearl Millet Hybrids and Varieties (PMPT II) trial, MH 2439 was found resistant while MH 2423 and MH 2549 were moderately resistant to blast under natural as well as artificial phenotyping.

Cauliflower: A total of 356 genotypes of cauliflower (*Brassica oleracea*) were screened against 3 Indian races of *Xcc, i.e.* race 1, 4 and 6 *Xanthomonas campestris* pv. *campestris* by bacterial inoculation at IARI, New Delhi.

Only 10 genotypes (EK, BR-207, PH-2-2, DC-42, xx-2-6-1, Alwari-1, Lawyana, DC-85, DC-73-7, DC-KT-2) showed moderate resistance towards Xcc race 1, 4 and 6.

Brinjal: One hundred fifty eight accessions comprising of brinjal germplasm lines and advance breeding materials were screened against brinjal mosaic mottle disease by visual observations followed by electron microscopy, of which 34 accessions showed field resistance while 17 accessions showed moderately susceptible reaction against the disease.

Apple: Total 312 entries of mother plants which performed best on the farmer's field were collected under the "Kinnaur Apple Contest" from 16 panchayts of Kinnaur district. These plants were marked and for 3 consecutive years, fruit samples were collected for laboratory study. Leaf samples from different panchayat's were indexed using ELISA and RT-PCR for 5 viruses, *i.e*. apple chlorotic leaf spot virus (ACLSV), apple stem grooving virus (ASGV), apple stem pitting virus (ASPV), apple mosaic virus (ApMV) and prunus necrotic ring spot virus (PNRSV). Plants were also indexed for apple scar skin viroid (ASSVd) through RT-PCR. On the basis of virus indexing through both the techniques only 5.73% plants were found virus free. ASPV was the most prevalent virus followed by ACLSV and ASGV where as incidence of ApMV was least among all the viruses.

5.1.5 Management

Characterization of phyllosphere niche adapted microbiome of rice and their exploitation for foliar disease management: The phyllopshere and spermosphere bacteriome of basmati and non basmati rice cultivars, namely PB1 and VLD85 were analysed using metagenomic and traditional cultivation based methods. While the culturable bacteriome was analysed on nutrient agar and M9 media, the total bacteriome was estimated by sequencing ribosomal V3-V4 conserved region using Illumina MiSeq Platform. Bacteriome of adaxial and abaxial surface of phyllosphere as well as bacteriome of blast lesion were also studied. Bacterial species like *Pseudomonas fulva* and *Pantoea agglomerans* were found dominating in cultured bacteriome of both the surfaces and *Methylobacterium platani* were found in high numbers in native bacteriome of phyllosphere of two cultivars. On blast lesion, two species were exclusively found, namely, *Paenibacillus lautus* and *Pantoea septica*. *Pseudomonas oryzihabitans* and *Flavobacterium acidificum* were found dominant in cultured and native spermosphere of basmati cultivar whereas *Pantoea ananatis* and *Flavobacterium acidificum* were found in non Basmati cultivar in high numbers. A total of 36 different species of phyllosphere bacteria were evaluated for their potential to suppress two important foliar pathogens of rice, *Magnaporthe oryzae* and *Xanthomonas oryzae* pv. *oryzae.* Nineteen isolates were found highly antagonistic against blast fungus by showing up more than 50 % inhibition. *Pantoea dispersa, Pantoea agglomerans, Pseudomonas parafulva, Pantoea ananatis, Acinetobacter baumannii, Enterobacter cloacae, Pantoea vagans* and *Pantoea deleyi*were were found effective against *Magnaporthe oryzae. Pseudomonas parafulva, Chryseobacterium cucilis, Pantoea anthophila, Enterobacter cloacae, Pantoea ananatis, Pseudomonas psychrotolerans, P. monteilii, Acinetobacter bayliyi, Pantoea vagans* and *Pseudomonas stutzeri* were found effective against *Xanthomonas oryzae* pv. *oryzae*. This study culminated in identification of potential bacterial communities for bacteriome transplantation on rice phyllosphere for mitigation of foliar diseases.

***Evaluation of rhizosphere bacterial antagonists for their potential to bio protect wheat against powdery mildew (Blumeria graminis tritici*):** The talcum based bioformulation of three different rhizosphere bacterial antagonists *viz.,P. fluorescens* strain DTPF-3, *B. amyloliquefaciens* strain DTBA-11 and *B. 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 the diseases severity (93.45%) was observed with *B. subtilis* DTBS-5 @ 10.0 gm/kg seed in comparison to other microbial antagonists tested in the study. Increased plant growth ability was observed

with *B. subtilis* DTBS-5 in comparison to other microbial antagonists tested.

***Management of bakanae disease of rice*:** Out of six fungicides evaluated against bakanae disease of rice as seed treatment and 12 fungicides evaluated as seedling treatment, Tebuconazole 6.7% + Captan 26.9% was found effective under field conditions. Results indicated that only seed treatment with fungicides can manage the disease up to 75-80%. Whereas, seed treatment along with hot water treatment at 60°C for 10 minutes can control the disease up to 95% and only seedling treatment with effective fungicide can manage disease up to 40% under field conditions.

***Potassium Phosphite: New biocidal molecules for blast disease management*:** Potassium phosphite has displayed dosage dependent inhibition of fungicidal and bactericidal activity to prevent major rice diseases causing fungal and bacterial infections. While 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. The bacterial pathogen *X. oryzae* pv. *oryzae* was suppressed at 35-40 mM. Open field trial on disease management on PB-1, the blast susceptible cultivar revealed that potassium phosphite could control rice blast upon spray at 200 mM that revealed its potential as fungicide and bactericide. Experiments on non-target effect of potassium phosphite revealed that the compound inhibited phyllosphere and rhizosphere microbiome of rice at 400mM. The fungicidal and bactericidal dose did not record substantial reduction in microbiome structure on epi and endogenous niches of roots and leaf. When compared to pathogen challenged check, 33% disease severity was observed in potassium phosphite at 200 ppm (a 45.71% disease severity reduction over control) and 24.5% disease severity was observed in potassium phosphite at 400 ppm (69.36% disease severity reduction over control). Tricyclazole at 0.1% showed 71.91% disease severity reduction over control. Over all, it is concluded that the potassium phosphite at 200mM showed disease control activity without any adverse effect on rice foliage.

***Bacterial volatiles as an elicitor of plant defense*:** The bacterial origin volatile compounds, 2-methylpyrazine and 2-ethyl-3,6-dimethylpyrazine were shown to inhibit all developmental stages of *M. oryzae* 1637 such as conidial germination, mycelial growth and sporulation. In order to validate the antifungal activity of 2-methylpyrazine and 2-ethyl-3, 6-dimethyl pyrazine on blast disease, *in planta* experiments were conducted on rice seeds and seedlings. The technique named as "Seed Volatilization" was adopted on rice during germination as well as early seedling growth. Blast disease incidence (40-60%) and disease severity (20-50%) on volatilized seedlings were significantly reduced as compared to unexposed seedlings. Analysis of transcripts of candidate defense genes, *Os*PAD4, *Os*EDS1, *Os*PDF2.2, *Os*PR3 and *Os*PR1.1 by quantitative real-time PCR (qPCR) with reference to house keeping gene, Actin, revealed differential expression of few genes in volatilized seedlings. Among them, *Os*EDS1, *Os*PDF2.2, *Os*PR3, and *Os*PR1.1 were found to be either non-responsive or slightly repressed at high concentration of volatile molecules but significant induction of *Os*PAD4 gene up to 26.0 and 7.0 folds were observed in 2-ethyl-3, 6-dimethylpyrazine and 2-methylpyrazine treated seedlings, respectively. To the best of our knowledge, this is the first report of salicylic acid-mediated defense activation by induction of *Os*PAD4 in rice plants by pyrazine group of volatiles. Volatilization mediated priming by pyrazine can be adopted as an alternative strategy for suppression of rice blast disease.

***Survivability of Bacillus subtilis in different liquid bioformulation for the management of foliar diseases of tomato*:** A liquid bio-formulation using different constituents and a suitable microorganism namely *Bacillus subtilis* has been developed to control fungal and bacterial diseases of tomato crops to replace pesticides. The liquid bio-formulation was tested and compared for viability as well as its inhibitory characteristics against *Alternaria solani, Phytophthora infestans* and *Xanthomonas euvesicatoria* which cause the foliar diseases of tomato. Using the liquid bio-formulation the bacterial cell viability tests were carried out by plate count method for every month.

The cell viability of *Bacillus subtilis* retains in the liquid formulation with better viability and bio-efficacy.

Assessment of the biocontrol potential of the cryptic species of Trichoderma harzianum complex against Rhizoctonia solani: Five different cryptic species of *Trichoderma harzianum* were assessed for their bio control potentiality against *R. solani* by dual culture method. The best bio-control potential was recorded in the *T. atrobrunneum* which showed nearly 100% growth inhibition of the pathogen followed by *T. afroharzianum* (85-100%). *T. afarasin* (26-78%), *T. inhamatum* (10-70%) were moderate whereas *T. rifaii* was recorded with only 20-26% inhibition of the *R. solani* which was least among the five species.

***Management of guava wilt through biocontrol agent Aspergillus niger*:** Eleven isolates of *A. niger* were collected from the Indian type culture collection (ITCC), ICAR- IARI, New Delhi. Isolates were evaluated under both *in-vitro* and *in-vivo* against guava wilt pathogen *F. oxysporum* f. sp. *psidii* (FOP). Dual culture, volatile and Non-volatile methods were performed under *in-vitro* studies. Isolates AN-1, AN-2, AN-3, AN-5, AN-6, AN-7 and AN-11 were found effective in controlling the pathogen.

5.2 ENTOMOLOGY

5.2.1 Integrated pest management

5.2.1.1 Cereals

Rice: ***Evaluation of rice germplasm against brown planthopper (BPH):*** Twenty rice germplasms, possessing different resistant genes were evaluated against brown planthopper (BPH) under greenhouse conditions on 0-9 damage scale in the presence of TN-1 as susceptible check using mass screening technique. Two germplasm lines were found to be resistant with 4.02 and 4.79 damage score, while four germplasm lines proved to be susceptible with 5-7 damage score.

Evaluation of biopesticides and insecticides against rice pests: Efficacy of biopesticides and insecticides either alone or in combination was evaluated against insect pests of rice variety, Pusa Basmati 1. The experiment had five treatments, with four replicates in randomized block design (RBD). The treatments were, T1: Botanicals-Insecticides (Neemazal 1% EC 25-30 DAT, eucalyptus oil 45-50 DAT, cartap hydrochloride 50% SC 60-65 DAT); T2- Botanicals-Insecticides (Neemazal 1% EC 25-30 DAT, neem oil 45-50DAT, triflumezopyrim 10% SC 60-60DAT); T3-All botanicals (Neemazal 1% EC 25-30 DAT, eucalyptus oil 45-50 DAT, neem oil 60-65 DAT); T4- All insecticides (chlorantraniliprole 0.4G 25-30 DAT, cartap hydrochloride 50% SC 50-55 DAT, triflumezopyrim 10% SC 65-70 DAT) and T5 with untreated control. Observations on pest incidence were commenced at 30 DAT and continued till crop maturity at 10 days intervals. Among insects, only brown planthopper (BPH) was observed to be economically important. The pest population remained very low during the experiment till 60 DAT (12.0-18.5 hoppers/10 hills). At 70 DAT, the pest population increased (38.5-87 hoppers/hill) but did not differ significantly among different treatments including untreated control. However, BPH population varied with the treatments at 80 DAT and was recorded to be 11.8-49 hoppers/10 hills compared to 72.8 hoppers/10 hills in untreated control. At 90 DAT also, pest population differed significantly among the treatments (30-124.3 hoppers/10 hills) compared to 129.3 hoppers/10 hills in untreated control. 'Botanicals-Insecticides' (Neemazal, Neemoil, triflumezopyrim) (T2) and 'All insecticides' (T4) treatment (chlorantraniliprole, cartap hydrochloride & triflumezopyrim) were found to be effective at 80 and 90 DAT as they harboured significantly less BPH population than untreated control. Both of these had triflumezopyrim, which has earlier been found effective against BPH. Between them, botanicals-insecticides (T2) comprised neem products, which also proved effective against planthoppers. On the other hand, 'all insecticides' (T4) treatment had chlorantraniliprole, cartap hydrochloride, which are basically effective against tissue consumers and may prove useful where both sucking pest as well as tissue consumers infest the crop. However, BPH population did not differ significantly again at 100 DAT in different treatments including untreated control due to natural decline in pest population. Crop yield did not vary

significantly among different treatments. However, all insecticides (T4) treatment had maximum yield followed by botanicals-insecticides (T2) and it was in accordance with lower BPH infestation in them among all treatments.

Effect of crop phenology on rice insect pests: Effect of three sowing dates, *viz.*, 5th July, 25th July and 14th August was evaluated against brown planthopper (BPH) on Pusa Basmati 1121. The BPH population at its peak was found to be significantly higher in II (13.4 hoppers/ hill) followed in decreasing order by III (6.8 hoppers/ hill) and I transplanting (4.7 hoppers/ hill). The II transplanting thus had higher BPH population than I and III transplanting. The BPH population exceeded economic threshold level in II transplanting. The whorl maggot damage at its peak was significantly lower in I (7.2%) and II (10.0%) transplanting compared to III transplanting (24.4%). The early transplanting thus had least incidence of BPH and whorl maggot. On the other hand, maximum incidence of rice leaf folder during the season was observed to be 2.6, 2.5 and 1.5 % damaged leaves in I, II and III transplanting but did not differ significantly.

Development of economic injury levels of wheat aphids: The effect of aphid complex on wheat yield was studied through field experiments. Yield-infestation relationship was investigated on two widely cultivated wheat varieties HD-3059 and HD-3086 utilizing five regression models *viz.*, linear, semi-$\log_e$ (X), semi-loge (Y), $\log_e$-linear and quadratic. Optimum number of sprays to get higher yield was computed to be two sprays between 60 to 80 days after sowing (DAS) for both the varieties. Further, economic injury levels (EIL) were determined to be 6.3 aphids/tiller at 60 and 14.4 at 70 DAS for HD-3059 and 34.6 at 60 and 29.3 aphids/ tiller at 70 DAS for HD-3086.These EILs will facilitate timely management practices against the pest.

5.2.1.2 Vegetables and fruits

Evaluation of cabbage breeding lines against DBM under field condition at IARI RS, Katrain: Twenty cabbage germplasms were evaluated against diamond back moth during *kharif* season of 2019 under natural field infestation. Two moderately resistant lines *viz.* Green Emperor and 9A were identified with DBM population bellow ETL (2 DBM larvae/plant) up to marketable curd formation stage. Remaining 18 lines were either susceptible or highly susceptible and failed to form marketable curd.

Evaluation of cauliflower breeding lines against DBM under field condition: Twenty two cauliflower germplasms were evaluated against diamond back moth during *kharif* season of 2019 under natural field infestation. Italian Giant was found to be moderately tolerant and hence can be used as a source of tolerance for DBM in cauliflower breeding programme.

Technology recommended for eco-friendly management of cabbage aphid in mid hills conditions of Himachal Pradesh: Application of neem seed powder extract @ 40 g/L and Diafenthuron @ 1 g/L resulted significant reduction of aphid population over control and provided significantly higher yield in field trials conducted over last three years. Hence, these two treatments were recommended for eco-friendly management of cabbage pests, especially cabbage aphids during *rabi* season cultivation of cabbage in mid hills conditions of Himachal Pradesh.

Tomato: Seasonal incidence of whitefly, leafhoppers, serpentine leaf miner, *Tuta absoluta*, *Tetranynchid* mites and aphids are being recorded since 2017. Whitefly, *T. absoluta*, serpentine leaf miner and aphid population was very less and below the Economic injury level. Leaf hoppers peak was noticed during first week of November. Heavy incidence of Tetranynchid mites (both two spotted and red spider mites) was noticed from March, and the population increased with increasing temperature and for the first time out break/ ballooning of mites was noticed during winter.

5.2.1.3 Pulses

Chickpea: ***Species composition of pod borers in chickpea*:** Continuous monitoring was done to study the species composition of pod borers in chickpea. A total of 462 larvae were collected from chickpea fields of IARI, New Delhi during reproductive stage of crop.

Among collected larvae, semiloopers, beet armyworm (*Spodoptera exigua*) and gram pod borer, *Helicoverpa armigera* were recorded and they accounted for 5.6, 4.5 and 89.9 per cent, respectively. Three different species of semiloopers *viz*., *Autographa nigrisigna*, *Thysanoplusia orichalcea* and *Chyrsodeixis chalcites* were found feeding on the pods of chickpea. This seems to be the first report of semiloopers and beet armyworm feeding on chickpea from Delhi. Ragged and irregular pod damage is the characteristic damaging symptom of semiloopers in contrast to the neat and round hole damage of gram pod borer.

***Appraisal of Helicoverpa armigera adult population in chickpea using weather based indices*:** Adult population of *Helicoverpa armigera*at different chickpea phenological stages was assessed using the weather based indices *viz*., growing degree days (GDD) and heliothermic units (HTU) during *rabi* 2016-17, 2017-18 and 2018-19. At different chickpea phenological stages *viz*., from emergence to maturity stage, the pest population varied from 0 to 66.3, 0 to 256 and 0 to 124 with respective cumulative population of 148, 555 and 167 male moth catches during three consecutive seasons. Among different phenological stages, highest population was recorded during pod formation and crop maturity stage. Among the three seasons, the GDD and cumulative male moth trap catches was found to be highest during 2016-17. The relationship of GDD and HTU with *H. armigera* was analyzed through linear regression and inferred that GDD and HTU accounted for 64 and 71 per cent variation, respectively in pest population across the seasons. The weather based indices *viz*., GDD and HTU may thus be useful for predicting *H. armigera* adult population at different chickpea phenological stages.

5.2.2 Biological control

Per cent colonization of *Beauveria bassiana* in leaf, stem and roots of tomato was assessed at 15 and 30 days after inoculation (DAC) through surface sterilization and isolation technique for all the inoculation methods. In roots, colonization was high in seed treatment (44 and 38%) followed by soil drench (10 and 12%) and foliar spray (10 and 8%) at 15 and 30 DAI, respectively. In stem, colonization was high in foliar spray (30 and 27 %) followed by seed treatment (26 and 20%) and soil drench (6 and 0%) at 15 and 30 DAI, respectively. In leaf, colonization was high in foliar spray (44 and 40 %) followed by seed treatment (12 and 22 %) and soil drench (4 and 0%) at 15 and 30 DAI, respectively. Percent mortality of *Tetranychus urticae* bioassay on leaf detached from endophytes established plants showed that, mortality was high in was high in foliar sprayed plants followed by seed treatment and soil drench. Survey, seasonal incidence and predator and prey synchrony of heteropteran predator was conducted during 2017 to 2019 revealed presence of five heteropteran predators, *viz*., *Geocoris* sp., *Orius* sp., *Nesidiocoris tenuis*, *Rhynocoris fuscipes*, and *Coranus* sp. Incidence of *Geocoris* sp. Started from March, peaked during May and reduced with the onset of winter; occurrence of *N. tenuis* coincided with the occurrence of whiteflies from July to September.

Foraging behavior of six spotted ladybird beetle, Cheilomenes sexmaculata F. on mustard aphid, Lipaphis erysimi Kaltenbach: Functional response of a predator is a function of available prey density which describes two key parameters like attack rate and handling time. When the number of prey eaten by a predator is plotted against the prey density it

Damage by semilooper

Autographa nigrisigna

Thysanoplusia orichalcea

Chyrsodeixis chalcites

reveals two types of functional response *viz*., Type II (a decelerating curve) or Type III (a sigmoid curve). To assess functional response parameters earlier workers have used Holling's or Rogers's model for Type-II and Hassell's model for Type-III response. However, we have used both models *viz*., Hollings and Rogers for Type II and Hassels and Flexpnr for Type III response. A comprehensive functional response method for predator-prey system of coccinellid beetle, *Cheilomenes sexmaculata* F. and mustard aphid, *Lipaphis erysimi* Kaltenbach using R software was used to determine type of functional response (polynomial logistic regression) *viz*.,

Eg.>firstinstar_LRA<-glm(cbind(Eaten, Remained)~ Density+I(Density^2),family='binomial',data=firstinstar_data)

Positive logistic regression coefficient for first order (P1) with a negative second order coefficient (P2) confirmed the type-III functional response for first and second instar predator. Whereas, the negative coefficient for first order (P1) confirmed the type-II functional response for third instar grub, fourth instar grub and male and female beetles. Commands used to estimate functional response parameters (attack rate and handling time) for first and second instar predator fitted to Hassell's and a flexpnr model are given as under.

Eg.>firstinstar_hassell<-frair_fit(formula=Eaten~Density,data=firstinstar_data,response="hassIIInr",start=list(b=0.05,c=0.1,h=0.1),fixed=list(T=1))

Commands used to estimate parameters for type-II functional response of third, fourthinstar grubs and adults fitted to both Holling's and Roger's equation are given as under.

Eg.>thirdinstar_hollings<-frair_fit(formula=Eaten~Density, data=thirdinstar_data, response="hollingsII", start=list(a=0.1,h=0.01), fixed=list(T=1))

The best fit and preference between the two models for each type was determined by an Akaike'sInformation Criterion (AICs). For first and second instars Hassell's (type-III) model exhibited best fit whereas, for remaining stages Roger's (Type-II) showed best fit with lower AIC values.

Estimates of coefficient of attack rate (*a*) and handling time (T_h) for different stages of *C. sexmaculata* on *L.erysimi* (T = 1 day).

5.2.3 Insect physiology

Virus vector interactions in whitefly, Bemisia tabaci: Studies on virus vector relations in whitefly revealed that transmission efficiency of tomato leaf curl New Delhi virus was influenced by genetic groups, sex of

Estimates of coefficient of attack rate and hanlding time for *C. sexmaculata* on *L. erysimi*

Growth stage	Equation/ Model	Estimated parameter		Max. predation per day (T/Th)	AICs
		Attack rate (a)	Handling time (T_h) in days		
First instar	hasselsIIInr		0.0531	18.8	214.5*
	flexpnr	$a = 0.91N0^{-0.42}$	1.8 e -8	-	236.8
Second instar	hasselsIIInr		0.0252	39.7	237.4*
	flexpnr	$a = 0.113N0^{0.162}$	0.00035	-	251.3
Third instar	HollingsII	0.817	0.01155	-	244.6
	RogersII	1.420	0.01449	69.0	240.5*
Fourth instar	HollingsII	0.832	0.00536	-	248.1
	RogersII	1.576	0.00777	128.7	246.3*
Male	HollingsII	1.050	0.00994	-	239.9
	RogersII	2.564	0.01385	72.2	231.4*
Female	HollingsII	1.0563	0.00706	-	234.7
	RogersII	2.8058	0.01081	92.5	230.7*
				*Indicates best fit	

the whiteflies, host plants and insecticide susceptibility status of the genetic groups. Serial transmission study indicated that whitefly, *B. tabaci* AsiaII-1 had higher transmission rate whereas Asia – I population was found to be a more persistent vector which were able to retain virus for longer duration. However, current studies revealed that populations reared on tomato showed relatively higher virus transmission rate and enzyme activity which indicated that vector and host both play a role in virus transmission and tomato can serve as a good host for *B. tabaci* in terms of induction of metabolic and xenobiotic detoxification enzyme thereby imparting insecticide tolerance.

Characterization of gut bacterial isolates in key insect pests: Significant differences were observed in nitrate reductase activity in aerobic and anaerobic gut bacterial isolates of white grub, *Lepidiota manseuta*. Under aerobic conditions, nitrate reductase activity showed significant differences among bacterial strains ranging from 1.09 to 4.57 (U/ml) in *Chryseobacterium* spp. and *Dysgonomonas termitidis* bacteria while at anaerobic condition, the enzyme activity ranged from 1.64 to 5.65 (U/ml) in *Chryseobacterium* spp. and *D. termitidis*. The present study indicated that midgut bacteria of *L. mansueta* had the ability to produce nitrate reductase enzyme that hydrolyze nitrate (NO_3^-) to nitrite (NO_2^-) which may then be degraded to various nitrogen products like nitrogen oxide, nitrous oxide and ammonia (NH_3).

Field evolved resistance to Bt cotton BGII expressing Cry1Ac and Cry2Ab in the pink bollworm, Pectinophora gossypiella: Transgenic Bt cotton in India revolutionized cotton production and bollworm complex control in India since its commercialization. However, the success of Bt cotton was reduced due to development of resistance in pink bollworm (PBW) at field level to BGI cotton expressing Cry1Ac in India during 2009. Subsequently progressive increase in survival rate on dual toxin Bt cotton (Bollgard II) since 2015 was observed. 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} values 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 *Cry1A* cagainst most of the PBW populations. 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). In our earlier reports two year survey data indicated high incidence of PBW 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.

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 was 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 leucine aminopeptidase 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 indicated association of these two enzymes in imparting resistance in *P. gossypiella* against BG II.

Quantification of Juvenile hormone (JH-III) in diapausing and non-diapausing larvae of C. partellus using the HPLC-PDA method: A total volume of 100 µl of haemolymph was collected from diapausing and non-diapausing *C. partellus* larvae in plastic centrifuge tubes, and blown into a mixture of Iso-octane and methanol in 1:10 (v/v) ratio and vortexed for 20 seconds. This mixture of Iso-octane and methanol was concentrated to 100 µl and stored at -20°C till further use. To detect juvenile hormone, HPLC-PDA system of Waters was optimized/standardized. Sixty percent acetonitrile was used as mobile phase and a Sunfire C-18 column was used as the stationary phase. The flow rate was kept at 0.6 ml/min and the PDA was set at 215 nm. The sample along with a known amount of juvenile hormone III standard (procured from Sigma Aldrich, USA) was kept in maximum recovery vials. A 20 µl mixture of juvenile hormone III standard and sample was injected through auto sampler. Chromatogram of JH-III using the HPLC-PDA method revealed a considerable variation among aestivating hibernating and non-diapausing larvae of *C. partellus.* Statistical analysis of JH-III titers present in aestivating, hibernating and non-diapause larvae of *C. partellus* clearly showed a considerable variation ($P<0.05$). Titer of JH III was significantly higher in aestivating ($F = 133.70$; $df = 2,2$; $P = 0.00$) (40.90 ng/100 µg of hemolymph) as compared to hibernating (17.95 ng/100µg of hemolymph) and non-diapause larvae (15.67 ng/100 µg of hemolymph). However, hibernating and non-diapausing larvae showed no significant variation in titer of JH III . The higher amount of JH-III titer in diapause as compared to non-diapause larvae indicated that titer of JH-III further increased when *C. partellus* larvae entered diapause (aestivation and hibernation).

Activation of certain biochemical constituents through enzymatic and nonenzymatic antioxidants for resistance against Sesamia inferens in maize: The biochemical defense through activation of enzymatic and non-enzymatic antioxidants in response to damage by *Sesamia inferens*in diverse maize genotypes was studied. The level of anti-nutritional compounds such as phenol, total antioxidants and total tannins were significantly higher in *S. inferens* resistant compared to susceptible maize genotypes. The levels of these anti-nutritional compounds were also found to increase in the test maize plants in response to damage by *S. inferens* larvae, which could be due to generation of high free radicals and production of oxidative molecules. Further, the non-enzymatic anti-oxygen scavenging activity of ferric ion anti reducing power (FRAP) was also significantly higher in yellow stem borer-resistant maize genotypes, which in response to damage by *S. inferens* larvae further increased compared to healthy plants. The activity of plant enzymes *viz.*, ascorbate oxidase, ascorbate peroxidase, phenyl ammonia lyase and tyrosine ammonia lyase was significantly higher in test maize genotypes CPM 2, CPM 8, CPM 9, CPM 18, CPM 15, CPM 19, CPM 4 and CPM 13 in comparison to susceptible genotype, Basi Local. The activity of these enzymes also significantly increased in response to damage by *S. inferens* across test maize genotypes. These studies thus indicated that increase in activity of these enzymes in the test maize plants due to *S. inferens* feeding possibly result in physiological and chemical changes in the form of accumulation of plant defense compounds. Further, several biochemical compounds and their regulating enzymes play an important role in plant defense against *S. inferens* in CPM 2, CPM 8, CPM 9, CPM 18, CPM 15, CPM 19, CPM 4 and CPM 13, and therefore can be utilized in breeding to derive yellow stem borer resistant maize.

5.2.4 Insect toxicology

Molecular mechanisms for neonicotinoid résistance were analyzed for Sri Ganganagar and Bathinda populations of whitefly, *Bemisia tabaci*. These two populations were reported to be relatively resistant to the neonicotinoid insecticide, imidacloprid. Gene expression studies were carried out for three genes *cyp6cm1, cyp4c64* and *cyp6cx1* keeping *Elongtaion factor α1* as the reference gene. In the study, it was revealed that expression of *cyp6cm1* after three hours exposure to neonicotinoid insecticides with discriminating dose, was high in Sri Ganganagar population compared to that of Bathinda, whereas the expression of *cyp4c64* was higher in Bathinda population.

Solvent extracts and essential oil of *Murraya paniculata* leaves, a hedge plant, were evaluated and found to possess contact toxicity against *Cadra cautella*, antifeedant and growth regulatory properties against *Spodoptera litura*. Hexane extract was most effective against *C. cautella* adults (LC_{50}=1.49 %) and larvae (LC_{50}= 3.40%). The highest antifeedant activity against *S. litura* was also observed for hexane extract (AI_{50}= 1.820%) after 24 hrs of exposure. GC-MS analysis of essential oil of *M. paniculata* leaves revealed presence of 32 chemical compounds of which germacrene-D (23.9%), α-zingiberene (23.3%), β-caryophyllene (17.2%) and trans-nerolidol (13.2%) were dominant compounds. Essential oil was found to possess fumigant toxicity. Acetone, methanol extract and essential oil possessed insect growth regulatory activity.

The first report of Aleurothrixus trachoides (Back) as vector of begomovirus: Solanum whitefly, *Aleurothrixus trachoides* (Back). (Hemiptera: Aleyrodidae) was considered as a non-virus vector by European and Mediterranean Plant Protection Organization (EPPO). We have demonstrated for the first time that it can transmit Duranta leaf curl virus to tomato, bell pepper and potato. The results suggest *A. trachoides* as vector of begomovirus. This will have great impact on solanaceous vegetable cultivation in India and other parts of the world.

5.3 NEMATOLOGY

5.3.1 Nematode genomics and transcriptomics

Anguina tritici is a plant-parasitic nematode (PPN) from clade IV of phylum Nematoda, causing Earcockle and Tundu disease of wheat. It is distinct from other PPNs due to its ability to parasitize wheat seeds and having long-term survival ability under anhydrobiosis condition within seeds. Genome of *A. tritici* thus, provides an opportunity to understand genomic basis for adaptation to parasitize aerial part of the plant and may also provide information on life longevity. The nematode has a small genome of 164 MB with 39,965 protein coding genes at 60-fold coverage deciphered using Illumina MiSeq platform. BUSCO provided quantitative assessment for completeness of assembly with C: 36.6% [S: 35.5%, D: 1.1%], F: 14.8%, M: 48.6%, n: 982. Repeat analysis using repeat masker revealed 1.28 % repeat covers of total *A. tritici* genome. Comparative genomic analysis was also performed with other available PPN genomes. We were able to predict the annotation of about 62% of the protein coding genes while remaining 38% were uncharacterized. Ortho finder inferred rooted species phylogenetic tree showed that *A. tritici* and *Ditylenchus destructor* share a common recent ancestor (monophyletic group) with each other as *Globodera* spp., *Meloidogyne* spp., *Caenorhabditis elegans* and *Bursaphelenchus xylophilus* during different speciation event in the lineage. Key genes involved in various biological process including effectors, peptidase, CAZymes *etc.* RNAi and anhydrobiosis have been predicted for *A. tritici*. The Genome sequence data of *A. tritici* will serve as an important model for understanding seed parasitism and anhydrobiosis in future.

Similarly, the rice root-knot nematode *Meloidogyne graminicola* is a major biotic stress for the rice crop under upland, rain-fed lowland and irrigated rice cultivation conditions. The long-read sequencing approach (PacBio Sequel platform) was used to improve the draft genome of *M. graminicola*. A total of 7 Gb of raw reads were generated, and the preliminary Falcon assembly size was 55 Mb with 1388 contigs and N50 value of 61.9 kb. Further improvement in the assembly by using Falcon Unzip, purging haplotigs, and two rounds of polishing by using short, and short and long reads, respectively, resulted in the new genome assembly of 36.86 Mb size including 514 contigs, with N50 of 105 kb. The genome completeness (BUSCO) showed complete presence of 82% genes, 6.6% genes as partial and 10.5% as missing. Gene prediction using GenMark ES predicted ~10,500 genes, and 50% of predicted genes could be annotated using *C. elegans* database including 2,675 unique full length homologues of *C. elegans* proteins.

5.3.2 Understanding the changes in transcriptome of pre-parasitic *Meloidogyne incognita* juveniles after silencing of effectors *msp-1* and *msp-20*

Plant-parasitic root-knot nematodes use a wide array of effector proteins to establish successful plant infections. *M. incognita msp-1* and *msp-20* are

expressed in sub-ventral esophageal gland cell. *msp-1* is a putative secretory venom allergen AG5-like protein, whereas *msp-20* is a pioneer gene with a coiled-coil motif. It was shown that host induced gene silencing of both genes significantly reduced nematode parasitism on transgenic egg plants. Here, we used RNA-Seq to investigate the pleiotropic effects of silencing *msp-1* and *msp-20*. A total of 25.1 to 51.9 million HQ reads were generated from *msp-1*, *msp-20* silenced and freshly hatched second stage juveniles, and mapped to an already annotated *M. incognita* proteome to understand the significant biology. As compared to control, silencing of *msp-1* caused differential expression of 29 transcripts, while *msp-20* silencing resulted in differential expression of a larger set of 409 transcripts Limited crosstalk between these two effectors was also observed as 5.9% percent of the up-regulated transcripts were common between *msp-1* and *msp-20* silenced nematodes. Our results suggest that in addition to the direct knock down caused by silencing of *msp-1* and *msp-20*, the cascading effect on other genes might also be contributing to reduction in nematode's parasitic abilities.

5.3.3 Nematode profiling in Nilgiris

Nematode population dynamics study was undertaken in seven different cropping sequences for two years. Among the seven sequences, three sequences represent undisturbed land (tea, eucalyptus, lantana), two sequences represent wheat based sequence and other two sequences represent vegetable based sequences (farmer based). The Crop Rotation Intensity of the sequences ranges from 50 to 250. From each experimental plot, monthly soil sampling was done, where the nematodes were extracted and quantified based on their feeding habit. Results showed that the total nematode population was high in vegetable based sequence (1182-2167 nematodes/100cc soil) than in wheat based sequence (557-614 nematodes/100cc soil) and undisturbed land (361-305 nematodes/100cc soil). However, the trophic group diversity (Shannon index) based on Bacterivore, Fungivore, Herbivore and Omnivore-Predator grouping was higher in undisturbed land (1.16-1.33) and wheat based sequence (1.31-1.38) than in high input intensive vegetable based sequence (0.57-0.75). Among the cultivated crops, the wheat crop showed highest trophic group diversity

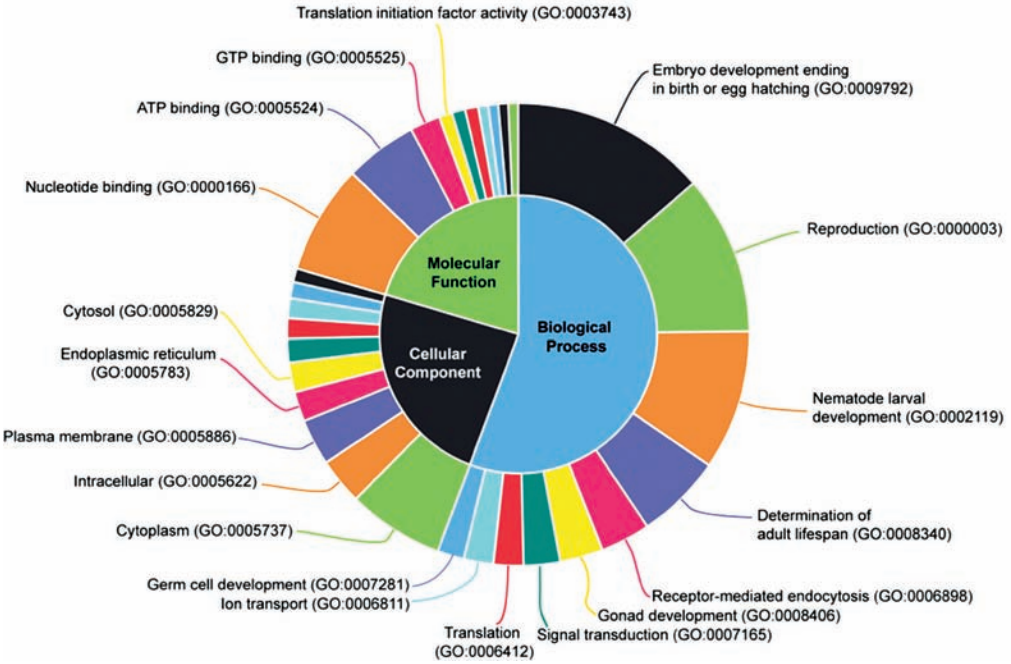


Diagram representing the top 10 enriched gene ontologies in each of the three gene ontology types of biological processes, cellular component and molecular function in 409 transcripts differentially regulated in *msp-20* silenced *M. incognita* J2s.

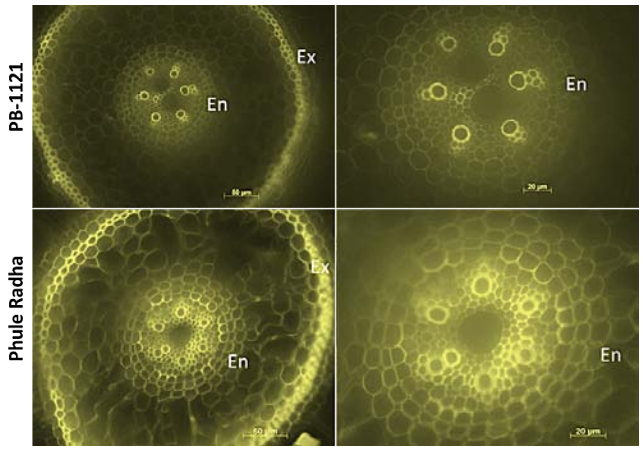
of 1.38 than others, possibly due to addition of crop residues. The herbivore nematode population was higher (913–1834 nematode per 100 cc soil) in fields with carrot - carrot rotation. Overall results confirmed the reduction in nematode Trophic Group Diversity at high intensive cultivation. Continuous survey was done to catalog total biodiversity associated with fields (43.5 acres) of ICAR-IARI, RS, Wellington in which a list of 30 nematode species, 203 plant species, 25 animal species, 42 insect species and 46 bird species were so far documented.

5.3.4 Nematode management

Management through transgenic approach: A synthetic peptide expressed in eggplant provides resistance against Meloidogyne incognita: Transgenic eggplants were developed with a construct containing disulfide-constrained peptide gene (nAChRbp) binding to nematode acetylcholine (ACh) receptors under the control of CaMV35S promoter (Fig.). Six primary and secondary transformants were selected *via* PCR, qPCR and Southern hybridization analysis. Transformed lines exhibited marked reduction in nematode chemotaxis and infection in the host plant compared to control. Nematodes treated with transgenic root exudates showed reduction in the expression of acetylcholine esterase genes, *Mi-ace-1* and *Mi-ace-2*.

5.3.5 Suberin, a complex biopolymer in the rice root, forms a protective barrier against *M. graminicola*

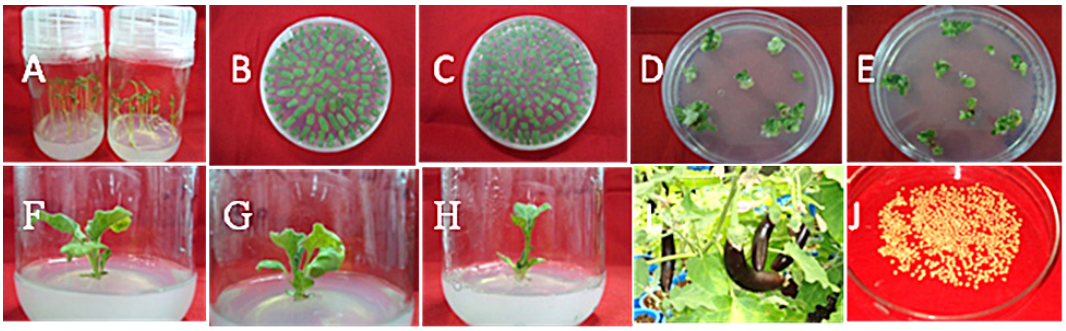
Nematode penetration was severely affected in a rice cultivar Phule Radha compared to PB 1121 in an agar-pluronic gel based assay indicating the presence of a physical barrier in the former. Fluorol Yellow 088 staining of root sections exhibited the deposition of high suberin content in the exodermis of Phule Radha compared to negligible deposition in PB 1121. This was further confirmed by GC-MS analysis of suberic acid residues and qRT-PCR-based suberin gene expression analysis in Phula Radha and PB 1121. This demonstrates that hindered nematode development in Phule Radha than PB 1121 may be because of the higher suberization in the former variety.



Comparative suberin deposition in the exo- and endodermis of Phule Radha and PB 1121

5.3.6 Biocontrol agents

Talc based formulation developed for a nematicidal isolate of *Trichoderma asperellum* resulted in significant reduction in reproduction factor of root knot nematode, *M. incognita* .The reproduction factor was 1.48 and 2.04 in treated soil, compared to 9.4 and 8.5 in sterilized and unsterilized soil, respectively. The experimental trials



Transformation of eggplant (cv. Pusa Purple Long) with 35S-LEV construct and generation of transgenic lines

confirmed the endophytic nature of the selected isolate in plants belonging to Cucurbitaceae, Malvaceae and Solanceae but not in Fabaceae. Visible enhancement in plant growth parameters were confirmed on soil application of the formulation at 3 & 6% w/w inoculum levels. The selected *Trichoderma* isolate was found compatible with systemic and nonsystemic fungicides like carbendazim, mancozeb and ridomil and insecticide spinosad at the recommended doses. Blitox however caused inhibition in radial growth of the bioagent. The shelf life of the formulation is under study.

Understanding the effect of temperature on resistance to Meloidogyne graminicola in rice: Rice (*Oryza sativa* L.) is an important cereal and a staple food of more than a half of the world's population.The rice root-knot nematode, *Meloidogyne graminicola*, is a major threat in rice-wheat cropping system in most Asian countries. This nematode has been reported under different cultivation practices adopted by the Indian farmers'. The survival and reproduction of this nematode varies with the fluctuating abiotic factors, thus making the rice crop more vulnerable to *M. graminicola*. Temperature is known to influence nematode activities such as hatching, migration, penetration, development and reproduction. The present work is carried out to examine the host response of the *M. graminicola* to most and least resistant cultivars/landraces/wild relatives of rice genotypes under four day/night temperature regimes. At the 34/31°C regime, second-stage juvenile population densities and post penetration development in roots of the susceptible rice genotypes increased significantly compared to those of plants grown at the 29/26°C regime, suggesting that the resistance to *M. graminicola* became ineffective at the later temperature regime. An increase in temperature also resulted in breaking of resistance in most of the reported resistant rice genotypes. High variability was recorded in terms of penetration, hatching, development and reproduction among the genotypes examined at the 34/31°C, compared to the 29/26°C regime. The study would be of great help in future to overcome the menace of the rice root-knot nematode under RWCS.

5.3.7 Entomopathogenic nematodes

Entomopathogenic nematodes (EPNs) exhibit a complex host-seeking behavior, and use universal host cue CO_2, as well as host- and insect-damaged plant-derived odorants to locate their hosts. The odorant response (*odr*) genes, expressed in the olfactory epithelium are expected to play an important role in insect-host recognition. Here we investigated *odr* genes in the EPN *Heterorhabditis bacteriophora.* Seven *odr* genes could be identified by *in-silico* analysis in *H. bacteriophora* out of which six were successfully amplified and cloned. Four genes (*Hb-odr-2*, *Hb-odr-3*, *Hb-odr-4* and *Hb-odr-10*) could be validated by re-sequencing. Further bioinformatic analysis confirmed presence of various protein domains respective to *C. elegans odr* orthologs. The phylogenetic analysis of these genes revealed that *Hb-odr* genes have evolved according to their taxonomic clades. The developmental stage-specific expression profile showed that *odr-2*, *odr-3* and *odr-10* were highly up regulated at the IJ stage, whereas *odr-10* was significantly up regulated in J4 and adult stages as well. Kinetic expression profile of the *odr* genes showed significant down regulation at 60 m after exposure to *Galleria* hemolymph. Only *odr-3* was found as up regulated at earlier time points as well. The *in-situ* expression analysis showed that *odr-2* and *odr-3* genes express at nerve ring and anterior esophageal region of the IJs, respectively. To the best of our knowledge, this study is the first comprehensive investigation of odorant response genes in EPNs.

Photorhabdus akhurstii produces a variety of toxins that aid this bacterium and its mutualistic nematode vector, *Heterorhabditis indica* to kill the insect host. A toxin complex protein, TcaB (63 kDa) was molecularly characterized from different *P. akhurstii* strains. The LD_{50} value of the toxin was 52.08-67.25 ng/g (at 12 h) and 598.44-709.55 ng/g diet/larva (at 7 days post feeding) when intra-hemocoel injected and orally administered to*Galleria mellonella* larvae, respectively. Injection of purified TcaB caused loss of viability of fourth instar *G. mellonella* hemocytes at 6 h post incubation; cells

displayed morphological changes typical of apoptosis, including cell shrinkage, membrane blebbing, nuclear condensation and disintegration. Injection of TcaB also elevated the phenoloxidase activity in insect hemolymph, which triggers an extensive immune response that potentially leads to larval death. TcaB can be used as an efficient agent for future pest management strategies.

5.4 AGRICULTURAL CHEMICALS

5.4.1. Development of active molecules for crop protection

5.4.1.1. Bioefficacy evaluation of ferrocenyl chalcones

The efficacy of ten most effective compounds (based *in vitro* study) and the commercial formulations of carbofuran 3G were evaluated active against root knot nematode (*Meloidogyne incognita*) in pot cultured tomato cv. Pusa Ruby under net house conditions. All compounds positively influenced plant growth parameters. Four of the tested compounds showed highest activity @ 80 ppm at 30 DAI and 60 DAI. The activity was higher in soil drenching compared to root dipping. The efficacy of three effective compounds, based on *in vitro* results, and the commercial formulations of Tebuconazole 25.9% EC and Mancozeb 75% WP were evaluated against *Sclerotium rolfsii* and *Alternaria solani* in pot cultured tomato cv. Pusa Ruby under nethouse conditions. The study revealed that shoot length was significantly increased as compared to control. The shoot length was found highest (24.50 cm) in plants treated with one of the compounds followed by other two @ 1000 ppm at 60 DAI. The percent disease incidence was significantly decreased as compared to control and was found minimum in plants treated with DS-2 @ 1000 ppm. The disease incidence was minimum in soil drenching compared to root dipping.

5.4.1.2. Insecticidal activity of *Eucalyptus* globulus oil

The leaves of *E. globulus* was found to contain about 1.9% oil containing 1,8-cineole (60.0%), limonene (14.0%), p-cymene (8.41%), β-pinene (3.83%), α-terpineol (3.29%), 4-terpineol (3.34%) and β-fenchol (2.31%) as major compounds in the oil. The volatile oil and its major compound, 1,8-cineole were evaluated for their insecticidal activity against *Bemisia tabaci* (whitefly) under lab conditions. Result showed that mortality of whitefly due *Eucalyptus* oil varied from 21.56 to 84.90% and 23.42 to 86.21% after 24 and 48h at concentrations of at 0.07 to 0.9%, respectively. Similarly, 1,8-Cineole showed 31.36 to 76.81% and 34.86 to 78.78% mortality at 0.07 to 0.9% concentrations at 24 and 48 h. 1,8-cineole in oil was identified as active compound responsible for the mortality of whitefly.

5.4.1.3 Nematicidal activity of *Pelargonium graveolens* oil

Pelargonium graveolens aerial parts were found to contain 0.12% volatile oil which contained citronellol (40.9%), geraniol (21.9%), citronellyl formate (12.86%), menthone (5.14%) and geranyl formate (3.87%) as major compounds. The oil was evaluated against *Meloidogyne graminicola* and *M. incognita.* The mortality of J_2s of *M. graminicola* in geranium oil was recorded to be 28.25 - 82.75%, 34.75-90.5%, 40.75-93.25% and 51.25-98.5 at 31.25 and that of *M. incognita* was 48.5-77.5%, 55-83.75%, 61.5-88.55% and 66.0-97.5 at 31.25 to 1000 ppm concentrations in 24 to 96 h of treatments. Activity was comparable to synthetic nematicides carbofuran and velum prime.

5.4.1.4. Synthesis and antifungal evaluation of series of substituted-1H-pyrazoles

Synthesis of series of disubstituted and trisubstituted-1H-pyrazoles were carried out and these pyrazole derivatives were evaluated for their antifungal activity against *Rhizoctonia solani*. The test compounds demonstrated 36 to 96 per cent inhibition of fungal growth at 25-250 ppm concentration.

5.4.1.5. Antifungal evaluation of mercapto nicotinic acid hydrazones and amides against *Sclerotinia sclerotiorum*

Sixteen nicotic acid hydrazones and amides were synthesized, characterized and evaluated as potential

succinate dehydrogenase inhibitors (SDHI). In the molecular docking simulation model two derivatives appeared as most active based on their binding energy and number of hydrogen bonding. The most active compound N-methyl benzylidene-pyridine-6-mercapto-3-carbohydrazide scored highest and showed possible H- bonding with the amino acid residues of HIS207, TRP164, TYR83 and SER27 of the homology model of the protein. Furthermore, nicotinic and mercapto nicotinic acid was esterified, followed by preparation of hydrazides and finally hydrazones were synthesized. The synthesized compounds were characterized by 1HNMR spectroscopy which exhibited characteristic amide peaks at δ 8.62-8.85 ppm.

5.4.1.6. Characterization of secondary metabolites from *Chaetomium globosum*

Screening of antagonistic potential of three different strains of *C. globosum* (5157, 2523 and 2034) against four phytopathogens namely, *S. sclerotiorum* 4042, *M. phaseolina, S. rolfsii* and *F. oxysporum* resulted highest fungal growth inhibitory action of *C. globosum* 5157 against *S. sclerotiorum*. Mass production (20 L) of *C. globosum* 5157 followed by sequential extraction with hexane, ethyl acetate and methanol gave mass of 5.14, 8.24 and 2.82 g, respectively. GC-MS analysis of hexane concentrate revealed at least twenty six compounds, representing 65.5 per cent of hexane extract. Among these, 3-octanone (21.4%) was found to be most abundant followed by 2-pentanone (5.4%) and 1-hexanol (5.3%). UPLC-QTOF-MS analysis of ethyl acetate and methanolic concentrates resulted several peaks corresponding to chaetomin, chaetocin, parietin, chaetoviridins A, C, E, chaetoquadrin, globosumone, chaetomugilin I and chaetomugilin J, chaetochalasin A, chaetocochin F, chaetoglobin A, chaetoglobin B, cochliodinol, chaetoglocin A and chaetoglobosins A, chaetoglobosins C, chaetoglobosins J chaetoglobosin N, chaetoglobosin Q, chaetoglobosin W, Prochaetoglobosin I, Prochaetoglobosin II, prenisatin, globosuxanthone, chaetominine.

5.4.2. Development of formulations for smart delivery of crop protection inputs

5.4.2.1. Entomopathogenic nematodes based bioinsecticidal water dispersible granules and water dispersible powder formulations and coated cadavers

Novel prototype for WDG and WDP formulations of EPNs (*S. thermophillum* and *H. indica*) was developed employing green adjuvants. The formulations exhibited 100% survival of encased biocontrol agent (*S. thermophillum*) at 35°C for 3 months of ongoing evaluation. A novel cadaver-based granule composition prepared exhibited 85-90% survival of EPNs till 30th day of storage. Optimization of compositions is being fine tuned.

5.4.2.2. Novel pre-mix micro and nano suspension concentrate premix formulations

PGR formulations of tebuconazole and CCC has been developed based on recommendation of AICRP, wheat and barley. The micro formulation under in vivo evaluation exhibited ~ 40-50% reduction in the plant height of lodging prone C-306 variety of wheat, ~ 10-20% more as compared to that expressed by the tank mix. The product is being validated under field conditions.

5.4.2.3. Preparation of coacervate hybrid polymer composite for encapsulation of acetamiprid

Standardization of the work on encapsulation of acetamiprid in complex polymeric composite by a W/O/W double emulsion technique was continued. To improve the slow release property of the formulation experiment was carried out with addition of palmitic acid in the oil phase. Release study revealed that with the subsequent addition of palmitic acid, the pattern of release of acetamiprid changed in a conspicuous manner. Though the cumulative release was same with or without palmitic acid, but the rate of release was controlled. 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.

5.4.3. Standardization and validation of methods for detection/quantification of contaminants

5.4.3.1. LC-MS/MS method for trace level analysis of 146 pesticides in soil

A method involving sample processing using modified QuEChERS technique and analysis using LC-MS/MS for simultaneous identification and quantification of 146 pesticides (74 insecticides, 30 fungicides, 41 herbicides and 1 plant growth regulators) under Electrospray Ionization (ESI) in +/- ve mode in 20 min run was achieved using LCMS/MS. QuEChERS method optimization results suggested that equal amount of C-18 (50 mg) and PSA (50 mg) in both dry and hydrated soil were not able to offer requisite cleanup for the pesticide where only 22.60 and 45.89 % of pesticides were recovered in acceptable range of 70-120% at 0.01 µg/g fortification level. On the contrary PSA (100 mg) alone was capable to achieve satisfactory cleanup where 77.39% (113 out of 146) pesticides were recovered in acceptable range with 90.41% pesticides showing acceptable repeatability (RSD ≤20%) when compared against solvent standard. The developed method with mass confirmation technique is effective in detecting and quantifying the trace level residues of 146 presently used pesticides in soil.

5.4.3.2. Method for estimation of hydrogel monomers by LC-MS/MS

Water absorbing cross-linked hydrogel and hydrogel composite has been developed for use in dry land agriculture requiring water retention over long periods. Usually the hydrogel which are used in agriculture are made up of monomers like acrylamide, methylene-bis-acrylamide and acrylic acid. Polyacrylamide (PMA) has been shown to be non-toxic to humans, animals, fishes and plants; the only concern has been the toxicity of its residual monomers, which is a known neurotoxin to humans. Thus it has become essential to find out whether the monomers or cross linkers are generated during degradation of these polymers to ensure human and environmental safety. Till date highly sensitive validated method for estimation of the free and residual acrylamide, acrylic acid and methylene-bis-acrylamide have not been developed to determine degradation kinetics of these key components in Indian soil. A LC-MS/MS [LC-MS/MS-8030, Shimadzu Corp, Japan] method has been developed after MRM optimization, where in a 5 min. run acrylamide, acrylic acid and methylene-bis-acrylamide eluted through C-18 column after 2.32, 2.302 and 2.388 min. using methanol-water (ammonium formate buffer) solvents system.

5.4.4 Management and assessment of contaminants in agricultural commodities and environment

5.4.4.1.Sugarcane trash ash: A low cost adsorbent for atrazine and fipronil removal from water

The sugarcane trash ash (STA) was explored as low cost adsorbent for atrazine and fipronil removal from water. Kinetics study suggested that the pseudo second order model best explained the adsorption of both pesticides. The STA showed higher adsorption of fipronil (K_d - 1267.5-3321.1) than atrazine (K_d - 137.0-1445.3), while desorption followed reverse trend with 0-2.27 and 4.83-9.32% fipronil and atrazine desorption, respectively. Isotherm model optimization suggested that the Freundlich isotherm best predicted the adsorption-desorption behavior of pesticides. Adsorption was highly nonlinear as 1/n values were 0.23 and 0.407 for atrazine and fipronil respectively. Adsorption decreased with increase in initial concentration of pesticide in solution. The sugarcane trash, a waste, can be used as energy source in boilers and the ash obtained can be utilized as low-cost adsorbent for pesticide removal from contaminated water.

5.4.4.2. Evaluation of biomixtures for removal of atrazine and fipronil

Biomixtures are integral components of on-farm biopurification systems for pesticide rinsate detoxification. Biomixture composition plays an important role in pesticide removal and degradation. A soil:compost:rice straw in 1:1:2 (weight basis)

biomixture (BM) and improvised biomixture, mixing 5 and 10% rice husk ash (RHA), 5 and 10% sugarcane bagasse ash (SBA) and 1, 5 and 10% wheat straw biochar (5% RHABM, 10% RHABM, 5% SBABM, 10% SBABM, 1% BCBM, 5% BCBM and 10% BCBM) were evaluated for adsorption of atrazine and fipronil. Adsorption results suggested that biomixtures varied in their capacity to adsorb atrazine while not much variation was observed for fipronil adsorption. Fipronil was more sorbed than the atrazine on all biomixture. Biochar was the best adsorbent in increasing atrazine adsorption in the biomixtures. Rice husk was more effective than the bagasse ash in increasing atrazine adsorption and adsorption increased with increasing ash content. These results suggested that mixing ash or biochar increased atrazine adsorption capacity of biomixture while not much effect was observed on fipronil adsorption.

5.4.4.3. Persistence and degradation of cyantraniliprole in soil

Persistence and degradation of cyantraniliprole, in inceptisol soil has been studied. Effect of different abiotic factors like light source (UV-light, sunlight and dark), temperature (5, 25 and 37°C), moisture regime (dry, field capacity and flooded) and carbon dioxide levels (415 and 625 µL L^{-1}) on its dissipation were also evaluated. Formation of IN-J9Z38, a major metabolite of cyantraniliprole, was monitored and the residues quantified. Cyantraniliprole residues dissipated with time and on 90th day 47.7- 98.8% dissipation was recorded in different treatments. Minimum half-life of cyantraniliprole, *i.e.* 8.6 days was recorded at elevated CO_2 level (625±5 µL L^{-1}) and maximum of 86.6 days at 5°C. Metabolite IN-J9Z38 starts forming from 0-day and reached maximum on 15th to 60th days under different treatments. The dissipation pattern of cyantraniliprole followed first-order kinetics. Study revealed cyantraniliprole to be a moderately persistent molecule with half-life values of 8.6-86.6 days. Metabolite IN-J9Z38 was identified as the major degradation product and it was found to persist longer in soil under different treatments. Microbial biomass carbon, as an index of microbial activity of soil correlated well with the degradation of cyantraniliprole.

5.4.4.4. Preparation of molecularly imprinted and non-imprinted polymers of tricyclazole and screening for their sorption efficiency

Detection of pesticides in environmental and food matrices with high selectivity and sensitivity has always been a challenging task. Demand for rapid, accurate and cost effective analytical methods to guarantee food safety, molecular imprinting technology is being explored as an attractive tool. Twenty one molecularly imprinted and non imprinted polymers (MIPs and NIPs), including magnetic MIPs and NIPs, were prepared for tricyclazole using different combinations of monomers like acrylic acid, acrylamide, methacrylic acid, styrene, 4-vinyl pyridine, methayl acrylate, methyl methacrylate; cross linkers like EGDMA, TRIM; porogens like MeOH, ACN, $CHCl_3$, DCM, toluene, MeOH:ACN (1.1). Screening of the prepared MIPs and NIPs showed 75.75 to 93.78% and 23.24 to 57.71% sorption efficiency for MIPs and NIPs, respectively; with imprinting factor ranging in between 1.38 to 4.03. The MIPs with high sorption efficiency and good imprinting factor can be used for selective extraction of tricyclazole from complex matrices.

5.4.4.5. Evaluation of modified agricultural waste-based sorbents for enhanced cationic dye removal from simulated aqueous solutions

Batch adsorption experiments were carried out for the mixture of cationic dyes (Methylene blue, Crystal violet and Rhodamine B) on citric acid (CA) modified cob husk to evaluate the potential of the adsorbent to remove the mixture of dyes from simulated aqueous solutions. The results showed that the adsorbent was much more effective in the removal of dyes' mixture at low initial concentrations while at higher concentrations the removal capacity of the adsorbent was found to be low. The maximum dyes uptake was 22 mgg^{-1} by CA modified cob husk. Crystal Violet and Rhodamine B adsorption on cationic and anionic surfactant modified cob husk was standardized and effect of contact time, concentration of the adsorbate, pH and adsorbent dosage studied. Enhanced removal of Crystal Violet (55 mg g^{-1}) and Rhodamine B (25 mg

g^{-1}) dye from by anionic surfactant modified maize cob as compared to the unmodified one (CV = 30 mg g^{-1}, RB=19 mg g^{-1}) was observed.

5.4.4.6. Study on the persistence of antibiotics in water

The persistence of amoxicillin (Penicillin group), sulfamethazine and sulfamethoxazole (Sulphonamide group) antibiotics in water was studied in distilled water at 25°C. The DT_{50} value for amoxicillin was found to be 4 days. However, the sulphonamide antibiotics persisted longer in water with DT_{50} values of 13 days for sulfamethazine and 9 days for sulfamethoxazole.

5.4.4.7. Study on the asorption of sulphonamide antibiotics in sandy loam soil

Sorption behaviour of two antibiotics namely sulfamethazine and sulfamethoxazole was investigated in sandy loam soil of Delhi. Antibiotics exhibited weak sorption in the sandy loam soil and higher adsorption was exhibited by sulfamethoxazole as compared to sulfamethazine. This could be related to the water solubility of these antibiotics (sulfamethazine: 1500 mg/L and sulfamethoxazole: 500 mg/L). The effect of pH on sorption of these antibiotics suggested that acidic pH favoured higher sorption. The pH dependence of sorption was due to the different ionization states of sulphonamides. At pH less than 7.4, sulfamethazine exists as non-ionized form and at pH less than 6.16, sulfamethoxazole exists as non-ionized form. So the decrease in sorption above pH 7 may be due to the predominance of the anionic forms of sulphonamides which is less absorbed on the negative soil surface.

5.5 WEED MANAGEMENT

5.5.1 Effective weed management in CA-based maize under maize-wheat-green gram cropping system

In a long-term tillage, conservation agriculture (CA)-based maize–wheat–green gram cropping system, residue and N, and weed management options significantly influenced weed density and maize yield. The ZT-based systems resulted in lower weed density than the CT. Among the ZT-based systems, ZT+R+100%N was more effective than others in controlling of weeds. This ZT+R+100%N treatment provided highest maize yield. The tank-mix application of atrazine @ 0.75 kg/ha + pendimethalin 0.75 kg/ha as pre-emergence led to considerable reduction in weed density than the sequential applications of atrazine @ 1.0 kg/ha as pre-emergence *fb* tembotrione 100 g/ha at 25 DAS and atrazine 1.0 kg/ha as pre-emergence *fb* hand pulling at 25 DAS and recorded higher weed control efficiency and maize yield.

5.5.2 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. The density of narrow leaved weeds was higher over broad-leaved weeds at 45 DAS in rainy and winter seasons. 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 30DAS in mustard over no-herbicide.

5.5.3 CA-based weed management options for pigeonpea–wheat cropping system

A minimum weed density, highest weed control efficiency (42.5%), organic carbon, bulk density,

resource use efficiency (water, nutrient and energy), system productivity and monetary benefit were recorded with ZT + crop residue 3 ton/ha in pigeonpea. The maximum system productivity in terms of wheat equivalent yield and net returns increased by 18.7% and 27.3%, respectively with ZT + crop residue at 3 t/ha over CT. Among weed management practices, two hand weeding recorded highest weed control efficiency (82.6%) followed by (fb) pendimethalin 1.0 kg/ha+ one hand weeding (HW) at 30 DAS (79.1%).

5.5.4 Weed management in CA-based direct-seeded rice

Weed management was studied in direct-seeded rice under a nine-year old conservation agriculture (CA) based rice-wheat cropping system. The treatments comprised of six tillage and crop establishment methods in main plot and four weed control treatments in sub-plot. Direct-seeded rice was infested with 14 weed species comprising of six grassy weeds, four broad-leaved weeds, and four sedges. It was observed that two most dominant grassy weeds, *Echinochloa colona* and *E. crusgalli* were heavily infested with rice root knot nematode. A triple zero-till system with three crops (rice, wheat, mungbean) residue, which involved ZT DSR with summer mung bean residue - ZT wheat with rice residue–ZT summer mung bean with wheat residue resulted in significant reduction in numbers of nematodes galls than other treatments and remained comparable with the transplanted puddled rice – CT wheat system. Mung bean residue could reduce rice root knot nematodes considerably than other used crop residues. The application of pyrazosulfuron-ethyl 0.025 at 1 DAS *fb* cyhalofop-butyl 0.100 kg/ha at 20 DAS *fb* bispyribac-Na 0.025 kg/ha at 25 DAS gave more effective weed control, which, in turn, led to better nematodes management in DSR.

6. BASIC AND STRATEGIC RESEARCH

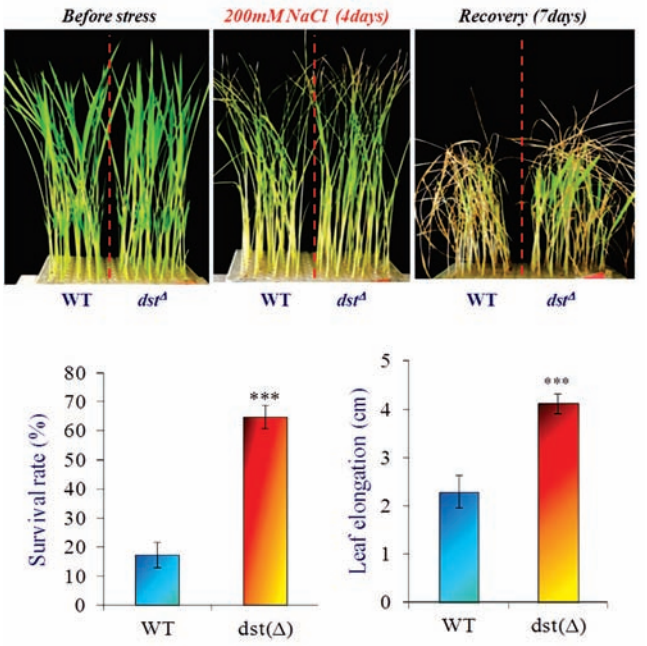
The basic and strategic research at IARI was focused on phenomics and high throughput phenotyping for identification of superior donors and breeding lines, development of CRISPR-Cas9 genome editing platform in rice and soybean, functional validation of genes and mapping QTLs for biotic and abiotic stress 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 Genetic engineering and genome editing

6.1.1.1 Genome editing of rice for abiotic stress tolerance

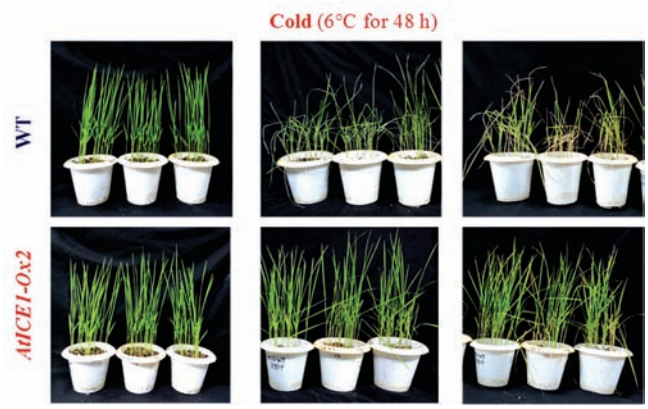
For enhancing abiotic stress tolerance, *DROUGHT AND SALT TOLERANCE* (*DST*) gene was mutagenized in mega rice cv. MTU1010 by using CRISPR-Cas9. A homozygous deletion mutant with loss of function was identified. This 366 bp deletion mutation resulted in the deletion of amino acid residues from 184 to 305, and hence the mutant was named as $dst^{\Delta 184\text{-}305}$. The $dst^{\Delta 184\text{-}305}$ mutant produced broader leaves with reduced stomatal density, and thus enhanced leaf water retention under dehydration stress. Our study showed that the reduction in stomatal density in loss of function mutants of *dst* is, at least, in part due to down regulation of stomatal developmental genes *SPCH1*, *MUTE* and *ICE1*. The Cas9-free $dst^{\Delta 184\text{-}305}$ mutant exhibited tolerance to salt stress in seedling stage.



Genome edited mutant of $dst^{D184\text{-}305}$ showed enhanced salt (200 mM NaCl) tolerance. Top panel shows photograph of seedlings before and after stress, and after recovery. Bottom panel shows survival rate and expanded leaf length after recovery in 200 mM salt stress. (*P ≤ 0.05 and ** P ≤ 0.01 and *** P ≤ 0.001)

6.1.1.2 Over expression of *AtICE1* enhances yield and stress tolerance in rice

Arabidopsis ICE1 (Inducer of CBF Expression 1), a MYC-type bHLH transcription factor, is a master regulator of cold tolerance in *Arabidopsis*. Since *indica* rice is highly sensitive to cold stress, *AtICE1* gene was overexpressed using stress inducible *AtRD29A* promoter in mega rice cv. MTU1010. *AtICE1* transgenic rice plants produced significantly higher grain yield as compared with WT plants under control conditions. Of the three *AtICE1* overexpression lines, two lines produced significantly higher grain yield as compared with WT plants under cold, salt and drought stresses. The components of water use *viz.*, stomatal conductance, photosynthesis and instantaneous WUE were higher in transgenics as compared with WT plants. The results showed that *AtICE1* confers multiple stress tolerance to *indica* rice.

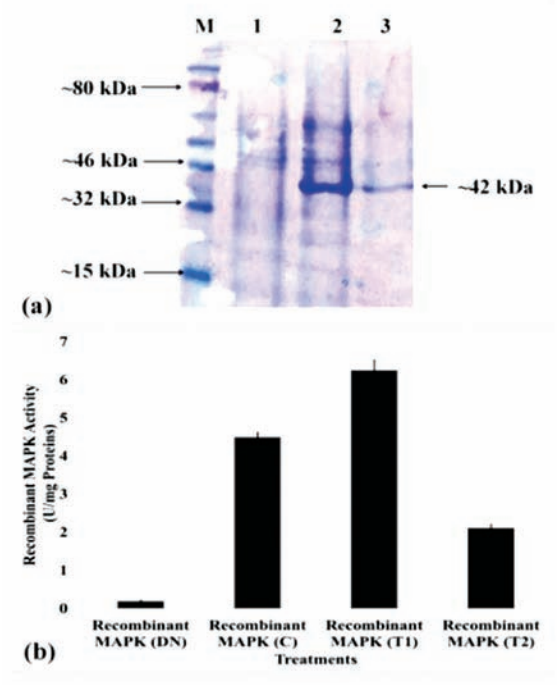


Cold stress tolerance of *AtICE1* overexpressing transgenic rice (T2) lines

6.1.2 Genomics and gene discovery

6.1.2.1 Cloning and characterization of recombinant MAPK protein from wheat

MAPK is one of the most important signaling cascades that regulates biotic and abiotic stress responses of plants. The coding sequence of *MAPK1* (1.1 kb) was cloned in pET28a(+) vector in BL-21 (DE3) strain of *E. coli*. The MAPK1 protein was expressed by inducing with 0.9 mM of IPTG at standardized temperature and duration of growth. The expressed protein was purified and checked by polyacrylamide gel electrophoresis. The protein showed a band of ~40.2 kDa, and the highest activity of 6.2 U/mg at 32ºC.



Expression and activity assay of recombinant MAPK protein from wheat

6.1.2.2 Genome-wide analysis of NIN-LIKE PROTEIN (NLP) transcription factor family genes in rice

The nitrogen use efficiency (NUE) of cereal crops including rice is approximately 40%, resulting in economic loss and environmental degradation. The NIN-LIKE PROTEIN (NLP) family of transcription factors were identified as nitrate-responsive *cis*-element (NRE)-binding proteins, which function as transcriptional activators of nitrate-regulated genes. Based on physiological analysis of rice germplasm under N sufficient (N+) and N deficient (N-) conditions, genotypes with high NUE under sufficient N (APO), High NUE at low N (IR-3-1-1 and NL-42), and N responsive and low NUE (Pusa Basmati 1) were identified. Based on *in silico* analysis, 6 NLP genes (including alternative splice forms 11 NLPs) were identified from rice genome. Expression of NLPs was promoted by nitrate supply as well as N deficiency (*NLP1, NLP4, NLP5*). The high NUE genotype IR3-1-1 showed a general upregulation of *NLP* expression which correlated with high assimilation and uptake gene transcript abundance, indicating that *NLPs* could be a potential target for improving NUE in rice.

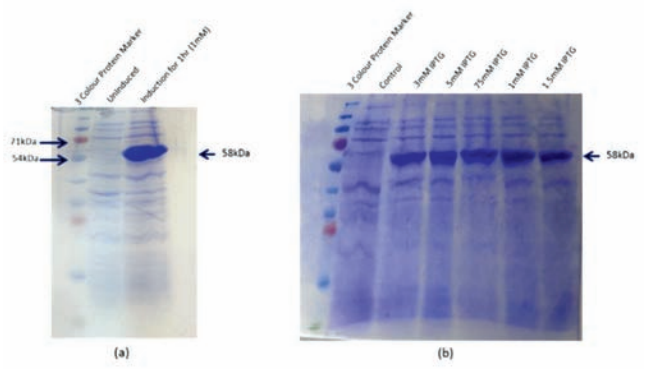
6.1.2.3 Identification of candidate genes associated with starch biosynthesis in wheat

The glumes/awns and developing grains of wheat cvs. Raj 3765 and BT-Schomburgk grown under control (22±3°C) and heat stress (HS) (38±2°C) conditions were used for whole transcriptome analysis. About 60,000 stress associated genes and 154 starch biosynthesis pathway-associated transcripts were observed in both the cultivars. About 100 hypothetical proteins associated with the process of stem reserve mobilization and 125 "predicted proteins" associated with carbon assimilatory pathway were also identified. Although most of the genes associated with starch biosynthesis pathway were down-regulated, up-regulation of genes coding for starch degrading enzymes was observed

under HS. The maximum fold expression was observed in thermosensitive cultivar, compared to that in the thermotolerant cultivar.

6.1.2.4 Cloning and expression of β-Glucosidase gene from soybean

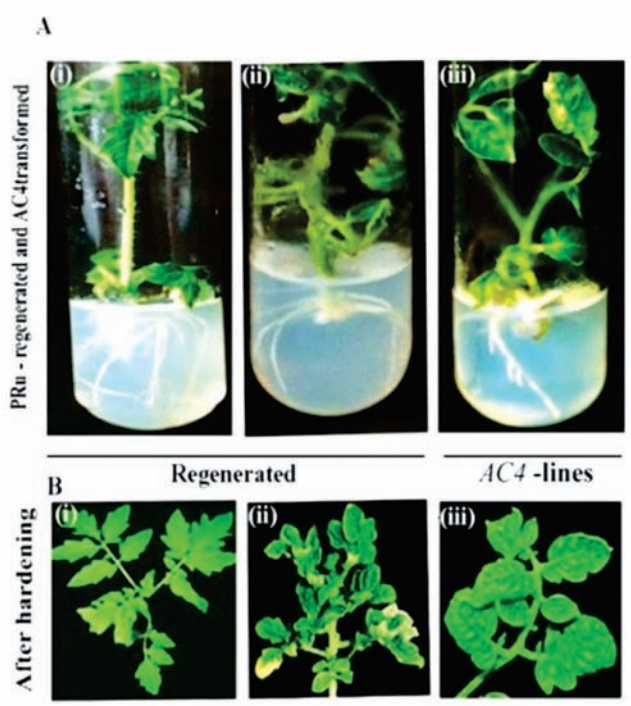
β-glucosidase-mediated bioconversion of glycosidic soy-isoflavones into their aglycones forms by human gut microbiota is an essential pre-requisite for their bioavailability. Previous screening of probiotic bacterial strains resulted in identification of *Lactobacillus acidophillus* to be a competent strain for enhancing the bioavailability of soy-isoflavones as it is having the maximum activity of Isoflavone-Conjugate Hydrolysing β-glucosidase (ICHG). The strain can either be used directly in soy-products or it can serve as a good source for obtaining ICHG which can be used in free or the immobilized form. Therefore, 1383 bp of the gene (LBA0885) encoding putative β-glucosidase was amplified and cloned in pGEMT easy vector, and expressed in pET28a+ using BL21 strain of *E. coli*. The 0.5 mM IPTG concentration for induction was found to be optimum for high level of expression of protein. The β-Glucosidase enzyme was purified and characterized for immobilization and utilization in soymilk for enhanced bioavailability of isoflavones.



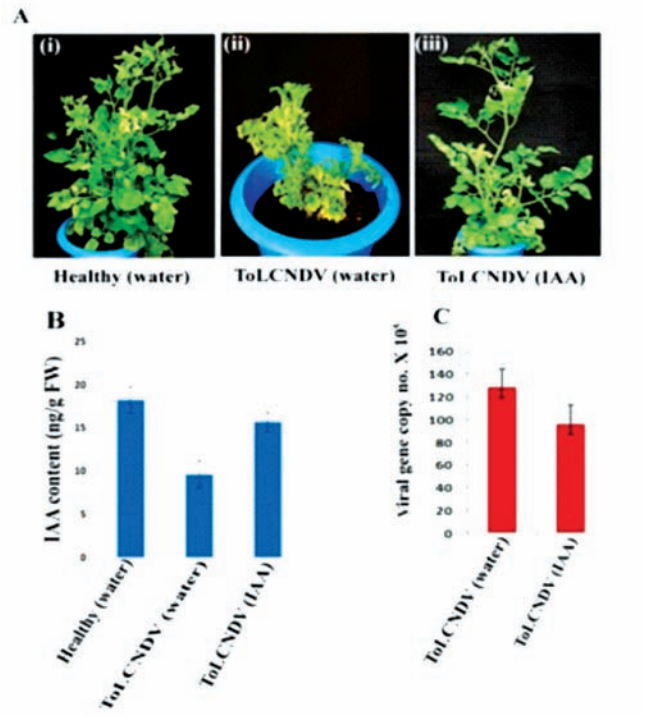
β-Glucosidase protein induction and optimization of induction conditions

6.1.2.5 Geminivirus AC4 protein induce pathogenicity through reprogramming of auxin biosynthesis/ signaling pathway in tomato

Plant virus infections cause characteristic disease symptoms similar to hormone-deficient mutants. *tomato leaf curl New Delhi virus* (ToLCNDV) encoded *AC4* protein is a micro protein that attenuates the host transcriptional gene silencing. Previously, we reported the interaction of ToLCNDV-AC4 with tomato host factors and found that proteins involved in auxin/IAA signaling are the crucial components of this interactome. In this study, to prove the role of *AC4* protein of ToLCNDV as symptom determinant, *AC4* overexpressing tomato lines were evaluated. These lines showed severe morphological abnormalities such as stunted and aberrant growth, reduced leaf lamina, typical leaf curl symptoms and abnormal root characteristics. Endogenous auxin levels were significantly low in *AC4* overexpressing lines (7.8 ng/g FW) and ToLCNDV infected plants (9.6 ng/g FW) as compared to healthy plants (18.2 ng/g FW). Exogenous foliar application of auxin analogue IAA (5 mg/ L) resulted in remission of ToLCNDV symptoms, recovery of healthy phenotype and reduction of viral load in tomato.



Root and leaf morphological changes due to *AC4* expression in tomato cv. Pusa Ruby. (A) Regenerated healthy, ToLCNDV infected plants and *AC4* overexpressing lines. (i) Healthy tomato leaf explants inoculated with empty vector showing normal leaf and root growth (ii) ToLCNDV infected tomato leaf explants showing lesser root growth and curling of leaves (iii) 35S:ToLCNDV-*AC4* overexpressing tomato plants showing poor root growth, stunting and curling of leaves. (B) *AC4* overexpressing plants two months after hardening (i) regeneration from healthy tomato leaf, showing normal leaf growth, and (ii) regeneration from ToLCNDV infected leaf showing leaf curling symptoms (iii).



Exogenous application of IAA (50 mg/L) restorates growth phenotype of ToLCNDV infected tomato plants. Plant images were taken after 40 days of exogenous application of IAA (50 mg/L) A) (i) Healthy tomato plants after exogenous water application; (ii) ToLCNDV infected tomato plants after exogenous water application (iii) Restored phenotype of ToLCNDV infected tomato plants after IAA application. B) IAA content in healthy, ToLCNDV infected and ToLCNDV infected plants after 40 days of exogenous IAA application. C) Virus titre in infected and IAA treated plants. Error bars represent standard deviation of mean data in three replications.

6.2 BIOCHEMISTRY

6.2.1 Biochemical responses of rice under phosphorus-deficiency

Acid phosphatases produced by plants are involved in mobilization of inorganic phosphorus (Pi) from soil. A considerable increase in acid phosphatase activity was observed in root of 7-week-old plants grown under P-deficiency. Phosphorus use efficiency of high yielding rice varieties (Pusa-44 and IR 64) and their near isogenic lines (NILs) for phosphorus uptake 1 (*Pup*1) QTL from Kasalath were assessed in hydroponics medium containing varying concentration (0, 25 and 100%) of Pi. Results showed that NIL 23 is the most tolerant NIL, which will be used for further molecular studies.

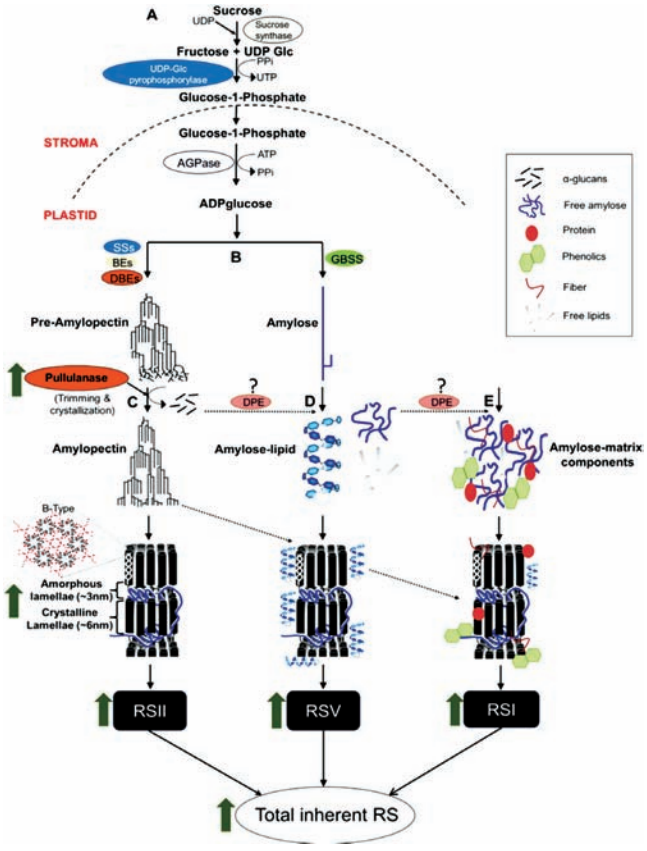
6.2.2 Amylases in developing endosperm in wheat under heat stress

The amylolytic activity of the developing endosperm and mature seeds of wheat cvs. HD 3086 and BT-Schomburgk grown under control and heat stress (HS) conditions were analyzed. In HD 3086, the amylolytic activity was observed maximum (3.6 U/mg proteins) in HS-treated sample of developing endosperm. Similar pattern of amylolytic activity was observed in developing and mature grains of BT-Schomburgk under control and HS conditions. In case of BT-Schomburgk, the maximum amylolytic activity (3.9 U/mg proteins) was observed in HS-treated tissue of developing grains, whereas minimum (3.0 U/mg proteins) was observed in mature grains under control condition. *In gel* assay showed prominent isoforms of amylases in developing grains of HD 3086 under HS with non-significant differences from control seeds. In BT-Schomburgk, gradual increase in many bands of amylases in response to HS treatments was found. In mature seeds, the intensity of bands showing amylases activity was observed maximum in wheat *cv*. HD 3086, as compared to BT-Schomburgk under differential HS. The appearance of bands in response to HS treatments was similar in both the cultivars.

6.2.3 Pullulanase activity: a novel indicator of inherent resistant starch in rice

Starch quality studies over the decades highlighted the immense health benefits of resistant starch (RS), but the mechanisms of RS formation is poorly understood. We observed RS has medium dependency on amylose and low dependency on amylopectin content. The discrete differences in microstructure, unimodal distribution and tight packing of starch granules observed in higher RS genotype indicated the higher possibility of compact cluster structure of amylopectin, modulated by pullulanase (PUL). Qualitative and quantitative assays performed validated the relevant role of PUL towards inherent RS content with very high dependency score (R^2 = 0.98). High PUL activity contributing to higher inherent RS content

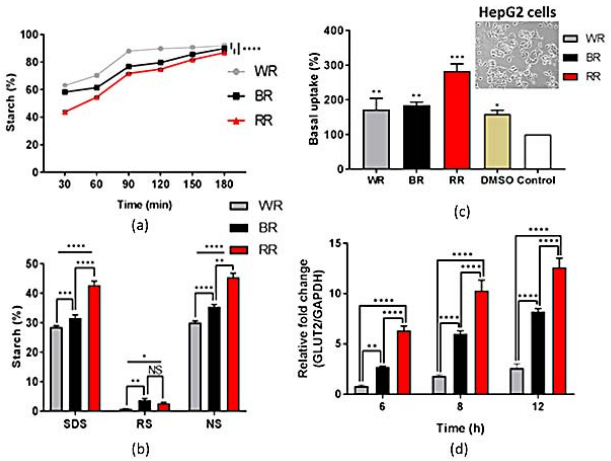
thus depicted using novel proposed 'Pullulanase-Amylopectin Trimming Model'. PUL convert pre-amylopectin to amylopectin, get crystallize to form double helices as well as high order alignment into crystalline lamellae. The crystalline lamellae (~6 nm) alternates with amorphous lamellae (~3 nm) form, such highly compact architecture contributed by amylopectin cluster render less dense hexagonal B type polymorph, which is less digestible and known as Type II RS. Linear α-glucans generated during PUL trimming possibly get extended by disproportionating enzyme (DPE) into linear amylose chains and bind with intrinsic lipids in the matrix, generating V type polymorph which is less digestible, known as Type V RS (E) Linear α-glucans can also form ordered multi scale structures with other matrix macro components (like fiber, protein, lipids, phenolics), generating less digestible Type I RS.



Pullulanase-Amylopectin trimming model on the possible role of pullulanase (PUL) activity in inherent resistant starch (RS) formation in rice endosperm.

6.2.4 Role of resistant starch and proanthocyanidins in modulating glycaemic response

Variation in the inherent glycemic potential due to complex food matrix in pigmented rice [black (*Chakhao*) and red (*Njavara*)] was validated using *in vitro* simulation and cell line screening models. Phenolic profiling of differentially pigmented varieties revealed a variation of 70.2 to 82.5 mg/g in pro-anthocyanidin content, which was negligible in white rice (Pusa Basmati 1509). Starch hydrolyzation kinetics profiled slowly digestible starch (SDS), resistant starch (RS) and nutraceutical starch (NS) fractions in black and red rice and was found to have 3-5% higher as compare to white rice. The possible role of these in anti-hyperglycaemic activity was further validated by inhibitory effects on α-amylase and β-glucosidase activity as well as their anti-glycation potential. We also examined the role of rice phenolics to stimulate C^{14} glucose uptake into HepG2 hepatocytes, a key function in glucose homeostasis. 40% increased basal glucose uptake was observed on exposure to red rice phenolic extracts. To unravel the nutrigenomic potential, expression kinetics



Characterization of inherent glycaemic potential of differentially pigmented rice – White rice (WR), Black rice (BR) and Red rice (RR) (a) Starch hydrolyzation kinetics of WR, BR and RR (d) Fractions of SDS, RS and NS in pigmented rice (c) C^{14} glucose uptake by HepG2 (hepatocytes) cells on exposure to phenolic rice extracts; Dimethyl sulfoxide (DMSO) – vehicle control and control-negative control (d) Time kinetic expression of glucose transporter (GLUT)-2 receptor (6-12hrs) after exposure to phenolic rice extracts. Relative expression was normalized using internal control GAPDH (Bars indicate ± SE and symbol**** denotes p<0.001, *** p<0.001, ** p<0.05, NS – non significant).

of Glucose transporter 2 (*GLUT2*) was also studied. These findings indicate that RS and proanthocyanidins rich red rice could be better candidate in glucose homeostasis through inhibiting carbolytic enzymes or through intracellular glucose uptake.

6.2.5 Optimization of efficient extraction method for natural vitamin E for fortification:

Global natural vitamin-E (vit-E) market is valued at 820.18 million US in 2016, with an expected compound annual growth rate of 5.2% during 2018-23. The huge demand for natural vit-E is due to lower (<50%) biological activity of synthetic vit-E. A lab scale prototype was developed for efficient and cost effective extraction of natural vit-E from soy products. Our results showed significantly highest amount of natural vit-E yield of 2000 µg/ml from soy oil and 634.8 µg/g from soymeal using ethanol as against the reported value from 900 to 1400 µg/ml and 248.8 µg/g, respectively.

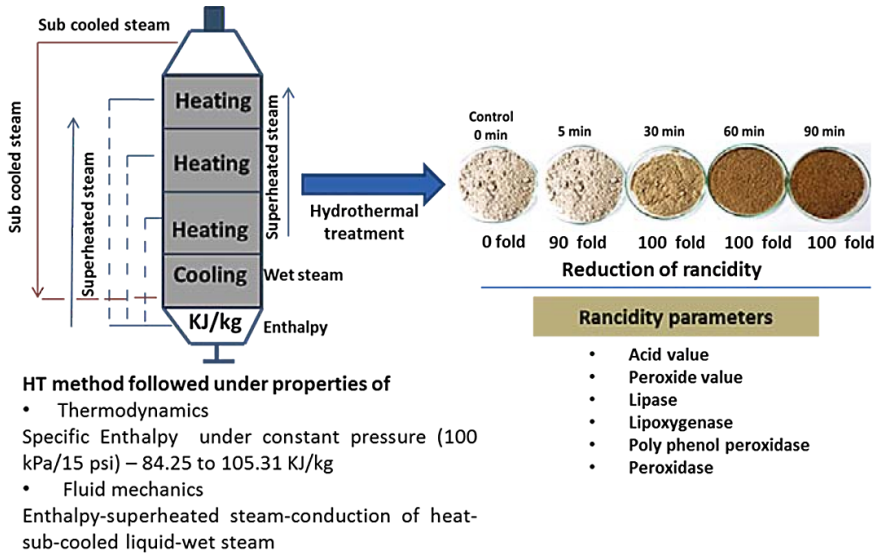
6.2.6 Optimization of hydrothermal (HT) and infrared (IR) processing method to reduce rancidity in pearl millet

Despite being nutrient dense, use of pearl millet is limited due to rancidity and off-odour development during storage. Higher lipid content (5 to 6%) with highly active lipases cause hydrolysis of lipids to free fatty acids and its peroxide derivatives leading to bitter and mousy odour, which hinders the commercialization of pearl millet and its products. To address this problem, we have standardized the processing method by keeping retention and steaming condition at 100ºC for 5-90 min. Based on the significant reduction in rancidity and retention of original colour/texture of the flour, we have optimized a short time hydrothermal and infrared rays (IR) treatment, *i.e.* 5 min HT followed by 5 min IR. The optimized processing method was applied to 12 important zonal varieties of pearl millet growing across India and the processed flour was stored upto 90 days at room temperature. Based on the results of hydroperoxides and free fatty acids levels, rancidity matrix was developed. The optimized processing method is highly efficient in shifting rancidity matrix of the varieties from the highest rancidity value to lowest rancidity values.

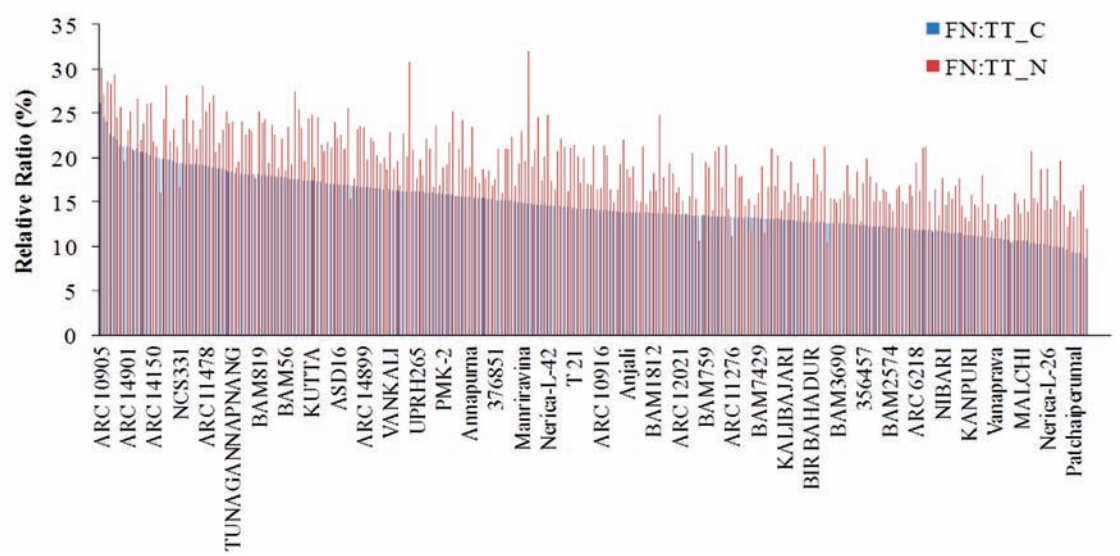
6.3 PLANT PHYSIOLOGY

6.3.1 Phenomics of WUE in rice

Since fresh water scarcity is emerging as a major problem for sustainability of rice production, development of varieties that uses less water is



Schematic overview of optimization of hydrothermal processing method to limit rancidity in pearl millet flour.

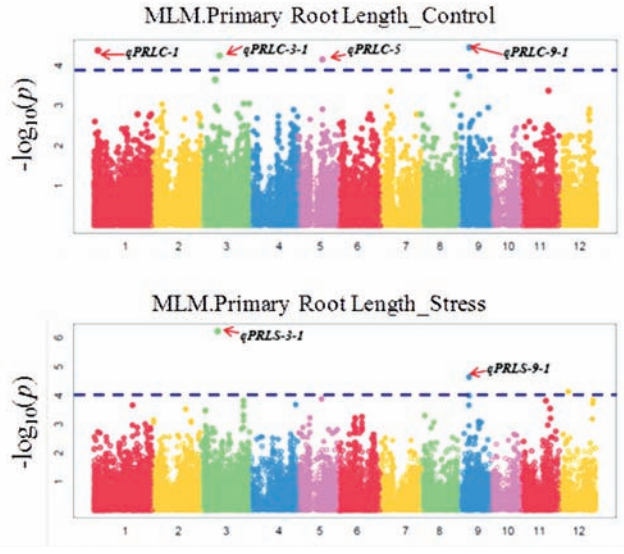


Relative night time transpiration to total transpiration in rice germplasm lines

important. Towards identification of donors for component traits of water use, in *kharif* 2018, a RIL population (170) of BVD109 (drought tolerant) x IR 20 (drought susceptible) were phenotyped for diurnal and nocturnal water use in phenomics facility. RILs C-822-103, C-822-105, C-822-123, C-822-130, C-822-99, C-822-124 and C-822-129 showed high transpiration efficiency (used less water per unit biomass) as compared with both the parents BVD109 and IR20. The parents and RIL population were genotyped with 50K SNP chip and QTL for transpiration and WUE were mapped. In addition, 300 rice germplasm lines were phenotyped for water use in *kharif* 2019 under normal and nitrogen deficiency conditions. Nocturnal transpiration was found to vary from 10-25% of under normal conditions, while N-deficiency significantly increased the nocturnal transpiration. Germplasm lines identified will be useful for enhancing NUE and WUE in rice.

6.3.2 Donors and QTLs for root traits in rice

Towards understanding genetic factors governing root system architecture, 162 rice genotypes were phenotyped for root traits under non-stress and osmotic stress (-0.15 MPa) in hydroponics conditions. Root traits such as primary root length, total root length, root surface area and average root diameter were measured. Over 50,000 SNP genotyping data of these genotypes were used for Genome-wide association study (GWAS) to identify genes/QTLs for root traits under non-stress and osmotic stress conditions. Thirty-six most significant QTLs for constitutive and stress inductive root traits of which 10 were novel QTLs (*qPRLC9-1, qPRLC1, qPRLS9-1, qPRLS9-2, qTRLC6-1, qARSC9, qARSS2-1, qARSS2-2, qARSS1-3, qARDC4-1*) in addition to several suggestive loci governing root traits were identified. The constitutive and stress inductive novel QTLs identified in this study for root traits can be utilized in introgression and development



GWAS derived Manhattan plots for primary root length. Top panel, PRL_C: primary root length in control; Bottom panel, PRL_S: primary root length in osmotic stress conditions

of rice varieties that can perform well both under irrigated and stress environments.

6.3.3 Phenotyping of rice accessions for reproductive stage high temperature tolerance

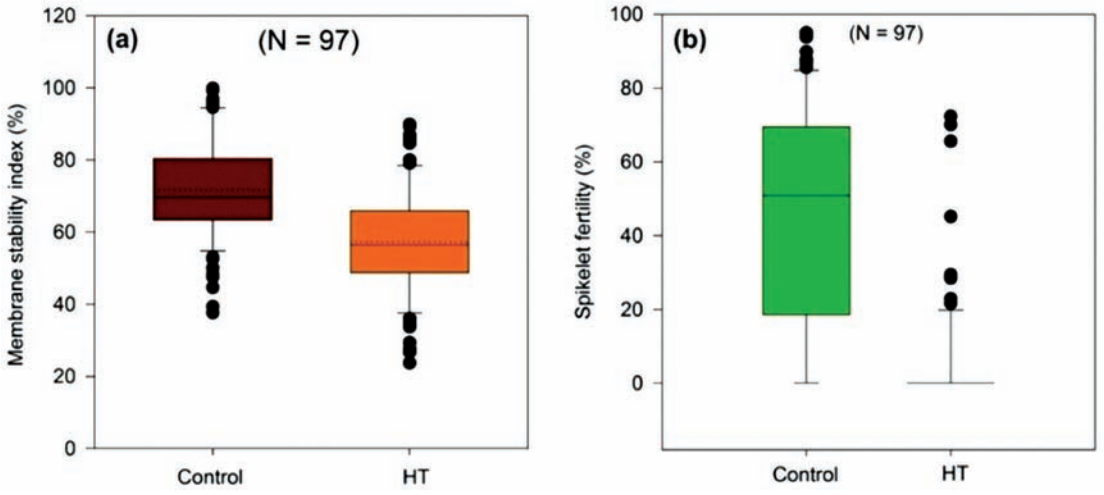
A set of 110 rice accessions (indica type) representing different flowering duration was selected for screening under high temperature stress at reproductive stage. All the accessions were raised in pots under ambient environment, till booting stage, and thereafter transferred to controlled environment green houses for exposing to high temperature (38.7±1.2°C). The main tiller and two primary tillers of each accession were tagged before high temperature treatment. Membrane stability and canopy temperature were recorded in control and high temperature exposed plants. Harvested plant samples were dried and analyzed for spikelet fertility, dry biomass and grain weight per plant. There was large variability among the rice accessions for flowering duration and flowering behavior. There was large variability in spikelet fertility among the accessions and it ranged from 0 to 90%. Similar response was observed for membrane stability index. On the basis of changes in spikelet fertility and heat susceptibility index, three accessions were identified as tolerant to high temperature stress.

6.3.4 Stem reserve mobilization and fructan metabolism in wheat

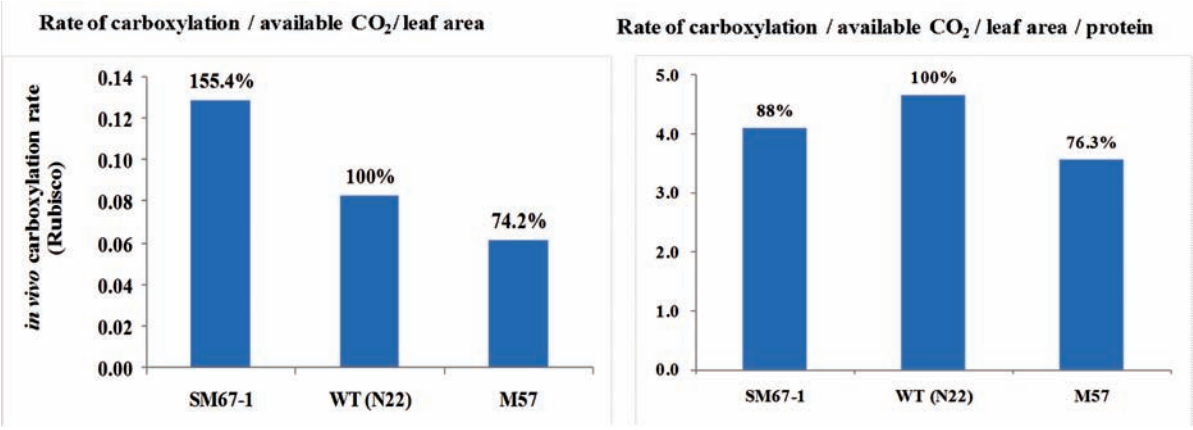
Stem reserve mobilization (SRM) is an important trait that contributes to grain weight and grain yield, especially under drought conditions. This study revealed that stem reserve mobilization plays an important role in grain filling under combined heat and drought stress. The results revealed that grain weight was highly associated with stem specific weight at 12 DAA. The study validated that the genotypes with higher mobilization of stem reserves under different stress conditions maintained their grain yield. Expression analysis of genes involved in the metabolism of fructan revealed that high level of fructan biosynthetic and hydrolytic gene expression at 10 days after anthesis (DAA) and 20 DAA, respectively. The high stem reserve mobilizing genotype accumulates more water-soluble carbohydrates at 10 DAA and same mobilizes towards the grain development at 20 DAA. The genotypes with higher stem reserve mobilization can be used in breeding programmes.

6.3.5 Identification 'high photosynthesis' mutants of rice nagina 22

Increasing single-leaf photosynthesis is necessary to substantially enhance yield potential of rice. A more efficient Rubisco could be the key to enhance



Membrane stability index (a) and spikelet fertility (b) of rice accessions under high temperature stress during flowering stage. Control= Ambient temperature (31.5±0.7°C), HT= High temperature (38.7±1.2°C)



***In vivo* carboxylation rate of Rubisco in rice N22 mutants and WT N22**

single-leaf photosynthesis. Evaluation of growth and photosynthesis related traits in a set of 230 rice Nagina 22 mutants revealed higher single leaf photosynthesis in the rice N22 mutants M-24-1A, 16-AKS-2, 2208-A, 108-2 and SM-67-1. However, the higher photosynthesis rates were not associated with increase in the *in vivo* rate of carboxylation of Rubisco on per unit leaf protein basis, but with the leaf thickness related traits such as higher specific leaf weight and higher leaf soluble protein content. Increase in leaf protein content was the real cause of higher *in vivo* carboxylation rate of Rubisco in the mutant SM67-1 rather than the true Rubisco efficiency on per unit leaf protein basis.

6.3.6 Salt tolerance of sugar beet

Two genotypes, LKC-2006 and LKC-HB were identified as less tolerant and highly tolerant to 150 mM NaCl salinity, respectively. Short term response to salinity using ^{14}C pulse chase experiments showed that LKC-HB preferentially invested ^{14}C translocates for the development of new leaves and production of more photosynthate for subsequent storage in roots. Equal compartmentation of Na^+/K^+ ratios between roots and leaves in LKC-HB suggested the ion homeostasis in the plant contributing towards tolerance. Under long term response, significantly high levels of raffinose in leaves was responsible for maintaining osmoticum under salinity in the more tolerant genotype. An increase in the activity of sucrose phosphate synthase and sucrose synthase during the sucrose accumulating phase of roots implicated the role of both the enzymes in synthesis of sucrose under salinity.

6.3.7 Protective role of carotenoids and xanthophylls cycle in developing seeds of wheat under heat stress

Plant carotenoids protect photosynthetic apparatus and xanthophyll cycle reversible inter-conversion of violaxanthin to zeaxanthin plays important role in photo-protection under heat stress. An experiment was conducted to scrutinize the photosynthetic and yield response of wheat variety HD 3086 to xanthophyll cycle activators for heat tolerance. High temperature stress was imposed by delaying sowing dates i.e. Normal (30th Nov) and late sowing (15th Jan). Plants were treated before anthesis with foliar application of xanthophyll cycle activators, namely, Ascorbic acid (ASC) (10 mM), BA (40 µM), Ca $(NO_3)_2$ (CaN) (60 mM), putrescine (Put) (10 mM) dithiothreitol (DTT) (3mM) (xanthophyll cycle inhibitor) and water spray (control). In general, all xanthophyll cycle activators modulated xanthophylls activity and enhanced the grain yield by improving rate of photosynthesis, Fv/Fm, level of photosynthetic pigments and induced heat tolerance by inducing non-photochemical quenching (NPQ). Under heat stress, maximum NPQ was recorded with the application of Ca $(NO_3)_2$ followed by Ascorbic acid.

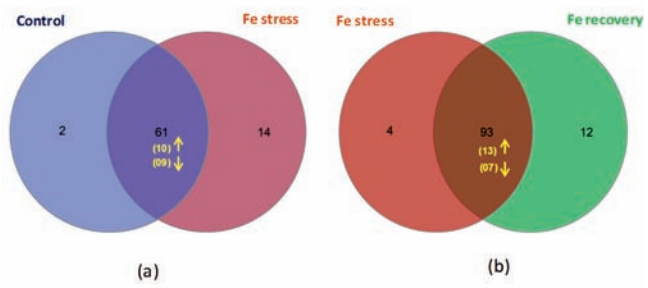
6.3.8 Root traits for improved nitrogen uptake in wheat

Bread wheat genotypes of India (128 genotypes) and UK (144 selected from the RILs derived from

Nested Association Mapping population) lines were phenotyped for root traits under low and sufficient N levels. Two N levels were maintained in solution, 8.5 mM (control) and 10 µM (low N). After appearance of visual symptoms of N deficiency, *i.e.* 15-days-old plants, observations were recorded on biomass of root and shoot and root trait using root scanner. The common good performing genotypes between low and sufficient N were 16, while poor performers were 7. Similarly, cluster analysis of the UK lines (for low N) revealed four clusters with highest group mean in cluster 4 (20 lines) for root traits, while the lowest values were recorded in cluster 1 (37 lines). The principal component analysis showed that the component traits for root studies which contributed to >80% variability under low N were root volume, surface ara and total root length, while traits contributing to variability between 60 to 80% were average diameter and number of tips in both India and UK lines. Thus, some of the good performers identified among Indian genotypes on the basis of their performance under low and sufficient N were K 53, WH 147, RAJ 4248, PBW 550, HD 3090, UAS 323, NI 917, BWL 6156, HW 1021, BWL4431, DBW 17, NP 825, KENPHAD 25, HUW 12 and PBW 677.

6.3.9 Identification of iron deficiency induced genes and genes involved in foliage fe absorption in soybean

Experiments were conducted to identify and characterize the channel/transport proteins involved in absorption of iron (Fe) when applied as foliar spray. For this, soybean (var. DS-2614) plants were grown for 15 days in hydroponics followed by Fe starvation till the appearance of first visible symptom. The treatments included Fe deficient (-Fe), Fe recovery and control. Leaf samples collected at 24 h after foliar application were used for protein profiling by 2D-PAGE, spot identification (PDQuest), MALDI-LC-MS/MS for peptide identification and protein annotation by Blas2Go. Results revealed a total 126, 134 and 130 spots in control, Fe stress and Fe-recovery conditions, respectively. In Fe-stress vs. control, 36 proteins showed >2-fold change in expression at Fe-stress. All 36 proteins were predicted from soybean genome. A total of 13 proteins were up-regulated at Fe-stress, and seven uncharacterized proteins also showed >2-fold up-regulation under Fe-stress, while nine proteins showed down-regulation under Fe-stress as compared to control. In Fe-recovery, 37 proteins showed >2-fold change in expression as compared to Fe-stress. Out of which 25 proteins were up-regulated, while 12 were down-regulated under Fe-recovery. Out of 12 down-regulated proteins, eight proteins were uncharacterized but all peptide sequences possessed significant MASCOT scores and were predicted from soybean genomes. Out of 35 differentially abundant proteins obtained in Fe stress vs. control, 10 were validated at transcript level. Nine genes and their product exhibited similar trends at both gene and protein level. Similarly, out of 37 differentially expressed proteins in Fe-recovery vs. Fe stress, 12 transcripts were validated and transcripts of eight genes showed similar trend at both gene and protein level under Fe recovery. All genes encoded hypothetical or predicted proteins. The functional characterization of hypothetical/uncharacterized proteins which are probably expressed at membrane, might reveal novel genes involved in absorption of foliage applied Fe.



Differentially expressed proteins in soybean leaves in response to foliar application of Fe (as Fe-citrate)

6.4 GENETICS

6.4.1 Wheat

6.4.1.1 Understanding of the molecular mechanism of leaf rust resistance in wheat

MicroRNA of wheat that suppressed important genes of wheat host and its pathogen (*Puccinia triticina*)

were identified to understand the role of miRNA in host pathogen interaction for leaf rust disease. Differentially expressed miRNA were identified in wheat NILs carrying leaf rust resistant gene *Lr28*.

6.4.1.2 Exploration of heat stress-responsive markers in wheat

A total of 243 novel SSRs, developed from heat stress-associated genes identified through RNA-seq, were used for marker-trait associations. Out of 37 SSRs which exhibited polymorphism, 27 SSR loci were significantly associated with component traits of heat stress (HS) tolerance. Expression analysis revealed that six out of seven selected genes were induced under HS in the wheat cultivars WH 1021 and Raj 3765 (thermotolerant) and repressed in HD 2009 (thermosusceptible). The information on candidate genes based SSR markers will help the breeders in precise development of heat tolerant genotypes through MAS.

6.4.2 Maize

6.4.2.1 Validation of candidate genes for retention of carotenoids during storage

Expression level of the *CCD1* gene in two genotypes *viz*, V335PV (low retention) and HKI161PV (high retention) showed an increasing trend in the *CCD1* experession first three months of storage, followed by a decreasing trend in the subsequent two months. The correlation between the expression level of *CCD1* gene and retention potential for pro-vitamin A was significant, with higher expression of *CCD1* associated with the loss of proA. Lipoxygenase activity did not correlate with loss of pro-vitamin A. Transcript expression level of *LOX3* and putative *Orange* gene though varied between V335PV and HKI161PV, the expression level did not show association with retention of pro-vitamin A.

6.4.2.2 Development of breeder-friendly gene-based marker for *sugary1* gene

Sugary1 (*su1*) based sweet corn cultivars are popular worldwide. The entire *su1* gene was sequenced among six sugary type and five wild type inbreds using 27 overlapping primers. A 36-bp InDel (at position 1247) in the promoter region and a 6-bp InDel (at position 6456) in intron-10 were predicted to have SRp40 exon-splicing enhancer. Nucleotide substitution in exon-2 at position 2703 (SNP-2703) was involved in C to G mutation leading to conversion of phenylalanine to leucine. The 6-bp and 36-bp InDels and SNP-2703 were used to develop three breeder-friendly codominant markers, (i) SuDel6-FR, (ii) SuDel36-FR and (iii) SNP2703-CG-85/89. All three markers were validated in five F_2 populations, and SuDel36-FR and SNP2703-CG-85/89 were validated in a set of 230 diverse inbreds. This is the first report of development and validation of universal functional markers for *su1*. These markers assume great significance in marker-assisted breeding programme.

6.4.2.3 Screening and identification of inbred lines for nutrient use efficiency

Forty-eight maize inbred lines were exposed nitrogen and phosphorous starvation in hydrophobic condition. The inbreds LM 13 and MG 13 showed contrasting morpho physiological responses for nitrogen starvations. Whereas, the inbred lines LM 14 and PML 47 showed contrasting responses under phosphorus starvation. Further, MG 13 and PML 47 showed higher nitrate accumulation and increased root acid phosphatase activity, respectively.

6.4.3 Diversity analysis and allele mining of *DHN* gene from chickpea

Candidate gene based mapping was used to comprehend the genes governing drought tolerance. Seven candidate genes *viz., ASR, ERECTA, SPS, MYB, AMADH, AKIN* and *DHN* were sequenced across forty chickpea genotypes using the BigDye terminator v3.1 kit. Sequencing data was analysed in Sequencing Analysis v5.4. The sequence similarities were confirmed using NCBI-BLAST (BLASTN) and aligned using CLUSTALW (http://www.ebi.ac.uk/Tools/clustalw2/index.html). nSequence variants were analyzed using Sequencer 5.4.6 software and 1079 SNPs

were identified in total. Highest numbers of SNPs (517) were identified in *SPS* gene while the lowest numbers of SNPs (14) were identified in DHN gene.

6.4.4 Development of novel EST-SSR markers in lentil

Lentil is nutritionally important crop for human diet and enriched with quality protein, complex carbohydrates, fibres, essential minerals and vitamins. However, genetic improvement of lentil is hampered largely due to limited use of genetic and genomic resources. To administer genomic resources in lentil, we identified 9949 EST-SSR loci from lentil RNASeq data and validated 50 of them using 234 genotypes representing various Lens species and 34 accessions of 12 different legumes. Out of 50 EST-SSRs, 46 were polymorphic with polymorphic information content (PIC) ranging from 0.16-0.74. The transferability of these markers exhibited varied levels from 45.1 to 71.3% across the cultivated/wild species of lentil and from 10.8 to 54.3% across the twelve legume genera. On the basis of total identified EST-SSRs, mononucleotide (51%) repeat proportion was high followed by trinucleotide (30%) and dinucleotide (14%) repeat. Population structure and cluster analysis classified all the studied genotypes into 4 groups. Principal component analysis (PCA) grouped the genotypes based on their area of collection. Annotation of all the 46 polymorphic marker sequences revealed that most of the markers linked to genes involved in metabolism of plants. Further, polymorphic markers were also used for linkage mapping in F_3 population where 4 markers were found to be linked with a map distance of 72.5 cM. The newly developed markers will be useful for characterization of germplasm, genetic linkage mapping, phylogenetic studies, as well as to determine disparity in taxonomic status of subspecies of the genus Lens.

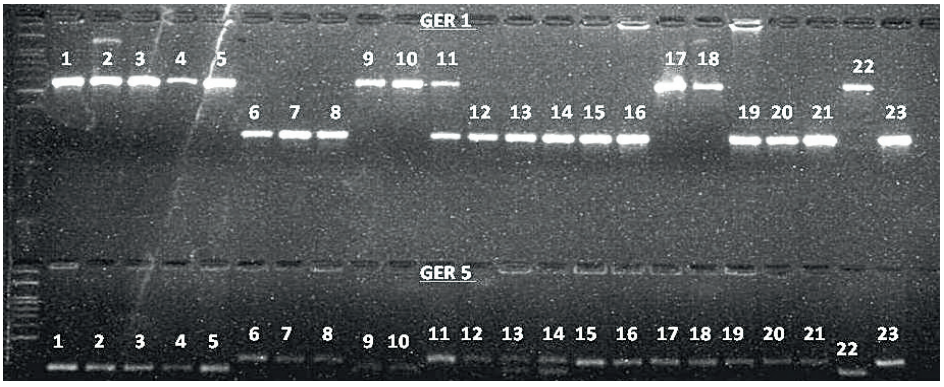
6.4.5 Mustard

6.4.5.1 Trait improvement and creating genetic variability through re-synthesis of *Brassica juncea*

To infuse genetic variability from related species *B. juncea* derived *B. carinata* introgression lines were developed. These fixed ILs were again crossed with improved *B. juncea* genotypes and a total of 191 progenies from F_6 generations were raised under both irrigated and rainfed conditions for characterization. Multiple/ three way interspecific crosses involving *D. erucoides*/ *B. rapa*//*B. juncea* derived introgression lines were used to improve *B. juncea* genotypes and F_3/ BC1F1 generation were raised. For re-synthesis of *B. juncea* six crosses were attempted involving *B. rapa acc.* NRCPB rapa8 and six different accessions of *B. nigra* and a total of 53 progenies were raised.

6.4.5.2 Development of STS marker for glucosinolates

Markers associated with phenotypic variation in total glucosinolate were GER1, GER5, At5g101, At5gAJ30, At5g41, At5g67, Myb28A9, Myb28B1 and CYP79F1 were reported. Out of these markers *viz.*,



Marker GER1 and GER5 showing polymorphism between low and high glucosinolates content genotypes (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)

GER1, GER5 Myb28A9, Myb28B1 and CYP79F1 were found to be controlling maximum phenotypic variance of total glucosinolates trait. The primers for these markers were developed using the orthologs from *Arabidopsis*. These primers either amplified multiple alleles or at times failed to amplify the desired allele in the individuals. To overcome this limitation, we developed STS markers for GER1 and GER5 by *in-silico* analysis and re-sequencing the genes from RLC3 and Pusa Jagannath. These STS markers were validated with the previous reported markers and no recombination frequency was observed.

6.4.5.3 Introgression of Genes/QTLs governing stress tolerance, yield and quality traits into elite cultivars

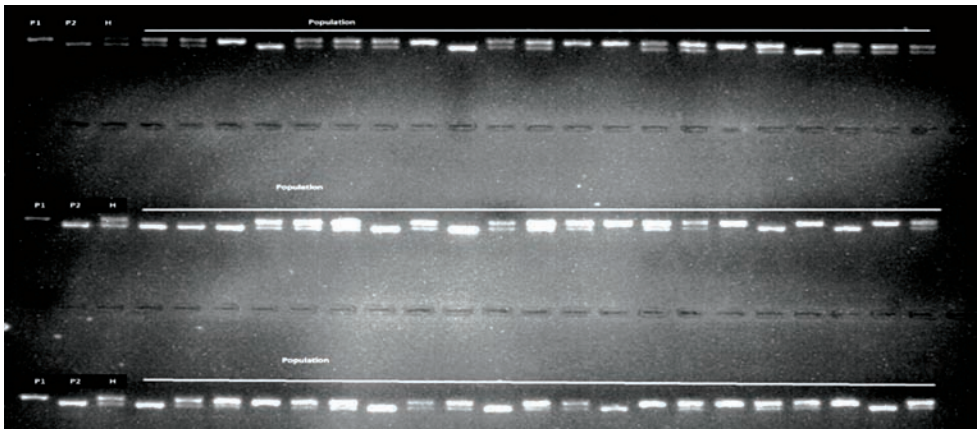
Several molecular markers linked with total glucosinolates, low erucic acid and white rust resistance in *Brassica* have been reported. To introgress white rust resistance using Donskaja as a donor, marker WR360360 was used for foreground screening, while *FAE1.1P* and *FAE1.2P* markers were used to track the genes for low erucic acid trait. Markers contributing major phenotypic variation for glucosinolates content were GER1, GER5 Myb28A9, Myb28B1 and CYP79F1. These markers were found to be polymorphic between high glucosinolate containing recipient parents and low glucosinolate donors and used for foreground selection in back cross progenies to introgress low glucosinolates in elite nuclear backgrounds.

The BC_3F_2 population generated from cross PDZ1 X Pusa Jagannath was genotyped for glucosinolates and erucic acid linked molecular markers. Total 150 plants with all the desirable markers were then phenotyped for glucosinolates and erucic acid content in the seeds. Total glucosinolates in the selected progenies ranged from 22 to 125 µmol/g of defatted seed meal cake. Plants with double low quality traits, *viz.*, less than 30 µmol/g glucosinolates and less than 2% erucic acids in oil were grown in plant to progeny rows to select desirable progenies for further yield trials.

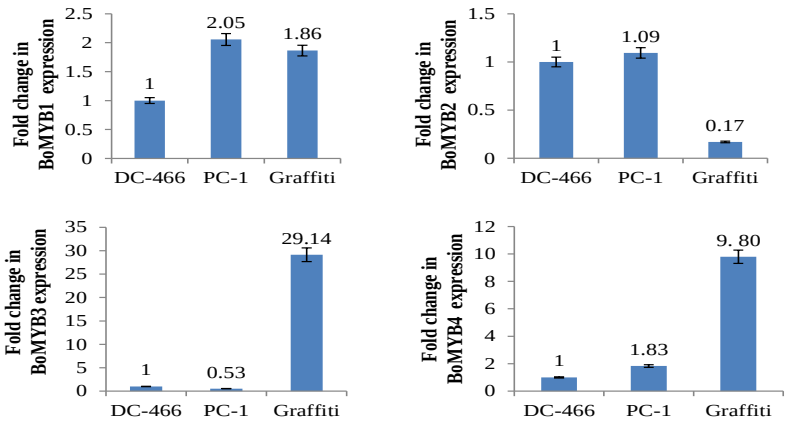
6.4.7 Cauliflower

6.4.7.1 Expression analysis of anthocyanin genes in purple cauliflower 'PC-1'

The expression of *BoMYB1* gene was upregulated in both the lines with purple cauliflower, *viz*. PC-1 and 'Graffiti' as compared to DC-466, the white curded line. The expression of *BoMYB2* gene was however, found to be slightly upregulated in PC-1' but was downregulated in Graffiti. Both *BoMYB3* and *BoMYB4* genes were found to be substantially upregulated (29.14 and 9.80 fold, respectively) in Graffiti, while the former was down regulated in PC-1 by 0.47 fold *BoMYB4* however, showed only 0.83 fold higher expression in PC-1 as compared to the white curded line DC-466. These observations indicate that different modes of regulations of anthocyanin pathway in PC-1 and Graffiti.



Screening of BC_2F_2 population derived from cross Pusa Jagannath (P_2) X Donskaja (P_1) for white rust resistant using markers WR360360.



Expression of different *BoMYB* genes in DC-466' (white curd), 'PC-1' (intense purple curd) and Graffiti (bright purple curd)

6.4.7.2 Development of mapping population for *Xcc* black rot resistance in alien Brassicas

The F_1 crosses in Brassica napus, *viz*., GSL-1 × Bn-2, GSL-15 × Bn-2, Zhang Suang × Bn-2 were raised and artificially challenged with *Xcc* race 1, 4 and 6. The all F_1 s were found 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 A and B genome specific R gene(s) in alien Brassicas.

6.4.7.3 Marker-assisted backcross breeding

Through marker assisted breeding, black rot resistance gene (*Xca1bo*) and downy mildew resistance gene (*Ppa*^{3}) were successfully transferred to Pusa Meghna background and five double gene homozygous backcross derived NILs were identified. The genome recovery of five selected lines ranged from 74.3% to 92.3%. Among these lines, BC2F2:3-7-33 (*Xca1boXca1bo/Ppa3Ppa3)* had the highest yield with highest vitamin C content.

6.4.7.4 Development of haploids through isolated microspore culture

A large number of (>100) plants were developed through isolated microspore culture in Indian cauliflower. 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. Among the different developmental stages, 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 ^{0}C for 48 hours.

6.4.8. Cucumber

6.4.8.1 Development of haploids through gynogenesis

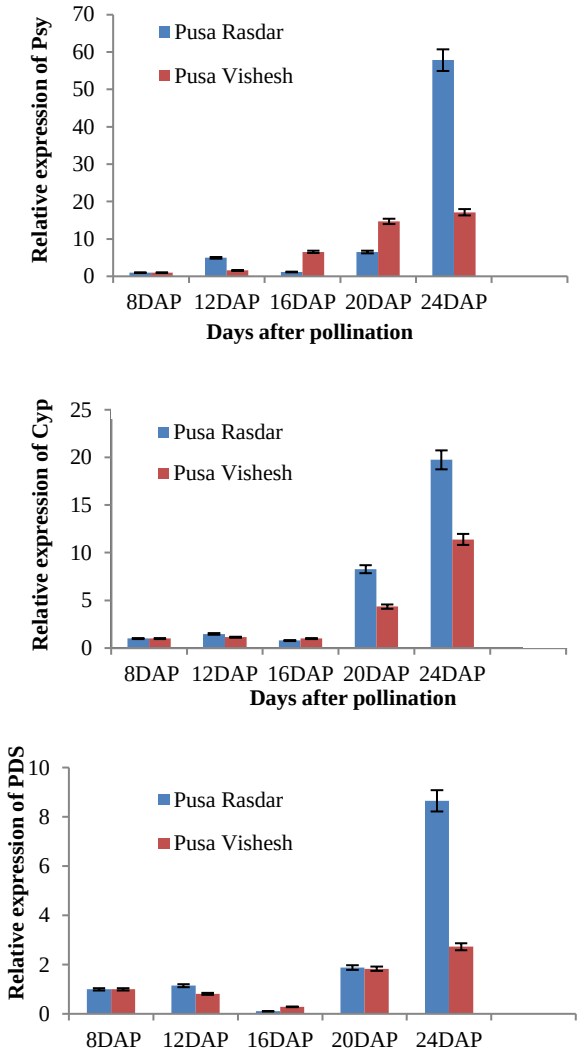
A tissue culture-based protocol for development of haploids through gynogenesis has been standardized in cucumber. Two gynoecious x gynoecious and three gynoecious x monoecious F_1 hybrids were used as donor parent for gynogenesis. Using the earlier developed nutrient media composition and unopened female flower buds on the day of anthesis or one day after anthesis, we were able develop a large number of embryo like structures (ELS). We have also optimized a temperature shock treatment (2-4 days of cold at 4^{o}C and 4-6 days of heat at 32.5^{o}C) for generating large number of ELS.

6.4.8.2 Mapping population for extended shelf-life and high β-carotene content

Four F_2 and Back-cross progenies were developed by utilizing novel genotypes, DC-48 (staygreen trait with extended shelf life) and AZMC-1 (high *carotene* content with orange flesh).

6.4.9 Carotenoid biosynthesis in bitter gourd

The expression of three different carotenoid biosynthetic genes viz. *McPSY, McPDS* and *McCYP* was studied in two the bitter gourd varieties (Pusa Rasdar and Pusa Vishesh) at 8, 12, 16, 20 and 24 DAP. The expression of *PSY* gene was after 24DAP 57.9 fold higher in Pusa Rasdar at 24 days after pollination (DAP) in comparison to only 17.1 fold in Pusa Vishesh. Similarly *PDS* gene expression also showed a sharp increase (8.6 fold) at 24 DAP in Pusa Raasdar as against only 2.7-fold in Pusa Vishesh. *CYP* gene expression was increased to 8.3 and 19.7-folds after 20 and 24 DAP respectively in Pusa Rasdar and 4.3 and 11.4-fold increase at these time points respectively in Pusa Vishesh.



Expression of carotenoid biosynthetic genes in Pusa Rasdar and Pusa Vishesh at different DAP

6.4.10 Heat tolerance in chilli

Biochemical as well as gene expression analysis of heat tolerant genotypes (DLS-152-1, DLS-161-1, DLS-10-2 and DLS-20-11) and susceptible genotypes (Chilli Kashmir Long, Jwalamukhi, Anugraha and Pusa Jwala) was carried out. Five biochemical characters like protein content, lipid peroxidation (malonaldehyde content), activities of enzymes like superoxide dismutase (SOD) and guaiacol peroxidase and proline accumulation as well as expression of seven different Heat shock protein genes, *viz. CaHSP832, CaHSP703, CaHSP90, CaHSP3, CaHSP2272, CaHSP2271* and *CaHSP* was studied. Protein content and proline accumulation was higher in heat tolerant genotypes along with higher SOD and GPX activities as compared to heat susceptible genotypes. Significant difference between heat tolerant and susceptible group was found for the expression of *HSP832, HSP703* and *HSP2272.* Expression of these genes was significantly upregulated in the highly heat tolerant lines under heat stress.

6.4.11 Molecular diversity in onion

A total of 96 onion accessions from 17 countries were genotyped with 145 microsatellite markers. Seven SSR markers (46.7%) showed PIC values higher than 0.5 and eight markers (53.4%) had PIC values less than 0.5. The microsatellite marker (ACM091) had the highest PIC value (0.715) and ACM463 had lowest PIC value (0.203). Ninety-six accessions were clustered into three main groups based on cluster analysis. Structure analysis also clustered the onion accessions into three groups. Group I was made up of thirty six (75%) exotic accessions and 25% mixtures of Indian genotypes. In group II, 32 accessions were grouped together out of which 21 (65.6%) accessions were of Indian origin and eleven (34.3%) were exotic accessions. Twenty-eight accessions formed group III out of which 20 accessions

(71.4%) were Indian genotypes and eight accessions (28.5%) belong to exotic origin. It was observed that grouping of genotypes was irrespective of the any morpho-agronomic traits.

6.4.12 Molecular diversity in carrot

Molecular diversity analysis of twenty four carrot genotypes (4 CMS lines and 20 inbreds) was carried out using 34 SSR markers. Maximum number of alleles were amplified by the primer GSSR101 (11) followed by GSSR130 (10) and BSSR43 (9). The average number of alleles obtained was 5.82. The mean value of observed heterozygosity and expected heterozygosity was 0.05 and 0.74, respectively. Highest observed heterozygosity (0.50) was noted in the primers GSSR 130 and BSSR 43 and highest expected heterozygosity (0.87) was observed in the primer BSSR 43, GSSR 35 and GSSR 51. Polymorphic information content (PIC) with a population mean of 0.83 was recorded highest in the primer BSSR 43, followed by GSSR 35 and GSSR 51.

6.4.13 Molecular diversity in okra

To study the genetic diversity among 96 okra genotypes, 65 pairs of microsatellite markers (SSRs) were used. Polymorphism among 96 okra genotypes was revealed by 50 primers and all these primer pairs were considered for this study. Analysis of allelic frequency revealed that overall 168 alleles were amplified through these 50 SSR primer pairs with a mean value of 3.36 alleles per locus. Number of alleles per locus varied from 2 to 7 (for primers AVRDC okra 21 and AVRDC okra 64). PIC value ranged from 0.05 (okra 105) to 0.71(AVRDC okra 64). Further, neighbor joining (NJ) cluster analysis revealed the formation of three major clusters and two outgroups (only IC-218893 of *A. esculentus* in one group and IC- 265268 and EC- 762130 of *A. esculentus*in another group. Among the three major clusters, cluster-I comprising of 22 okra genotypes out of which all were cultivated types. However, three genotypes EGR, DOV- 37 and Pusa Makhmali were clearly distinct from the rest of the genotypes. Two red fruited types (IC-1610753 and IC-685583) of *A. esculentus* species were grouped together in a single clade.

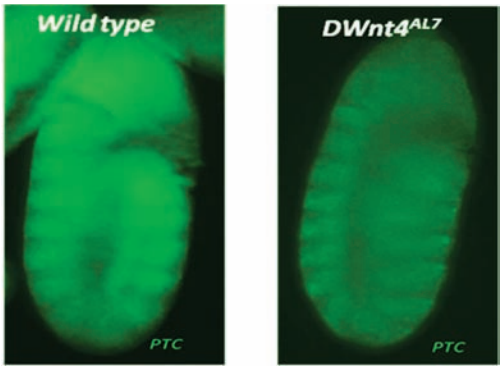
6.4.14 Drosophila

6.4.14.1 Characterization of *DWnt4* mutant alleles

To detect mutant lesions causing DWnt4 embryonic lethality, Next Generation Reseqencing of all seven mutations has been done. Putative SNPs were categorized as synonymous and non synonymous SNPs, which are further classified into Missense mutations, located in coding region or regulatory regions of the gene through bioinformatics analysis.

6.4.14.2 Expression of *Patched* protein in *DWnt4^{AL7}* embryos

Drosophila embryos is made up of para segments (PS) Patterning of PS borders in two adjacent cell rows is a function of interaction between *wingless* and *hedgehog* signalling pathways. Expression of other segment polarity genes depends upon crosstalk between these two signalling pathways. Disruption of any one of the gene results in change in expression of *wingless* in embryonic ectoderm. We checked expression *patched* protein in DWnt4AL7 homozygous null embryos. Patched protein acts upstream of *wingless* pathway and after hedgehog reception *patched* act negatively on *hedgehog* expressing cells and causes activation of *wingless* expression. We previously reported expansion of *wingless domain* upon loss of DWnt4, but *DWnt4^{AL7}* mutation did not show change in expression pattern of *patched*, indicating that *Patched* is acting upstream of *DWnt4* and hence no change in expression of patched is seen upon loss of *DWnt4*.



Expression pattern of *DWnt4^{AL7}* embryos in Drosophila

6.5 AGRICULTURAL PHYSICS, REMOTE SENSING GIS AND METEOROLOGY

6.5.1 Soil physics

6.5.1.1 Simulation of grain yield and water productivity of wheat under different tillage, residue and nitrogen management using Aqua Crop model

The evaluation of the FAO AquaCrop model with response to grain yield (GY) (under 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) showed that the observed grain yield could account for 83.4% variation in the simulated GY. The RMSE between the observed and simulated GY of wheat was 0.255 t/ha, which account for 7.2% of the mean observed GY, which indicates excellent predictions of GY by the model. RMSEs and RMSEu were 0.193 and 0.197 t/ha, respectively. Higher RMSEu indicates that the error in the model predictions was less than the experimental error. The Wilmott d-index and CRM were 0.99 and 0.026, respectively. Higher d-index support better simulation of GY by the model. A positive value of CRM indicates the model under-predicted the GY of wheat. The evaluation of the Aqua Crop model with respect to final biomass yield (BY) of wheat indicate that the observed above ground biomass yield of wheat accounted for 82.9% variation in the simulated biomass yield. The RMSE between the observed and simulated biomass yield of wheat was 1.40 t/ha, which accounted for 14.14% of mean observed biomass yield. This indicates good prediction of biomass yield by the model. The RMSEs and RMSEu were 1.335 and 0.423 t/ha, respectively. Higher RMSEs indicate that the error in model prediction of biomass was higher than that of experimental error. The Wilmott d-index and CRM were 0.97 and 0.120, respectively. The positive value of CRM indicates under-prediction of the biomass yield of wheat by the model. Evaluation of the model with respective to water productivity (WP) of wheat showed that the model could account 71.5% variation in the observed WP of wheat. The RMSE between observed and simulated WP of wheat was 0.118 kg/m^3, which accounted for 8.45% of the mean observed WP of wheat. The nRMSE value indicates excellent agreement between the observed and simulated WP of wheat. RMSEs and RMSEn were 0.0114 and 0.031 kg/m^3, respectively. The higher RMSEs indicate the error in the model prediction was more than the experimental error. The d-index and CRM were 0.97 and -0.006, respectively. The negative value of CRM indicates that the model over predicts the WP of wheat. Therefore, AquaCrop model ver 6.1, which requires relatively less input parameters, can be used satisfactorily for optimizing different management practices like tillage, residue and nitrogen management practices under different soil and weather condition for improving yield of wheat.

6.5.1.2 Prediction of soil hydraulic conductivity through ML and AI

Saturated hydraulic conductivity (SHC) is an important soil hydraulic parameter that determines the rate of water flow systems through soil. As direct measurements of SHC in field conditions is very difficult, laboor-intensive, time-consuming, and expensive, artificial intelligence (AI) based on artificial neural network (ANN) and support vector machine (SVM) models and multi-linear regression (MLR) model were used to obtain soil hydraulic conductivity from easily measurable soil parameters *viz.*,particle size distribution, bulk density (BD) and organic carbon (OC). MLR model showed that SHC is negatively correlated with clay and silt while it is positively correlated with sand (%). Results indicated that ANN with 2 number of hidden layer performed best both for training and testing dataset. In prediction of SHC, for training datasets, the root mean square error (RMSE) value of SVM model was found to be lowered by 17 and 6.4% as compared to MLR and ANN, respectively. SVM resulted similar trend in testing dataset, where RMSE value was lowered by 9.11 and 5.7% as compared to MLR and ANN. Correlation value (r) was found to be greater for SVM (0.77) in training data sets while

for testing data sets, r was highest in case of MLR (r = 0.80). Results indicated that SVM could account the more complex nature of inputs and output variables.

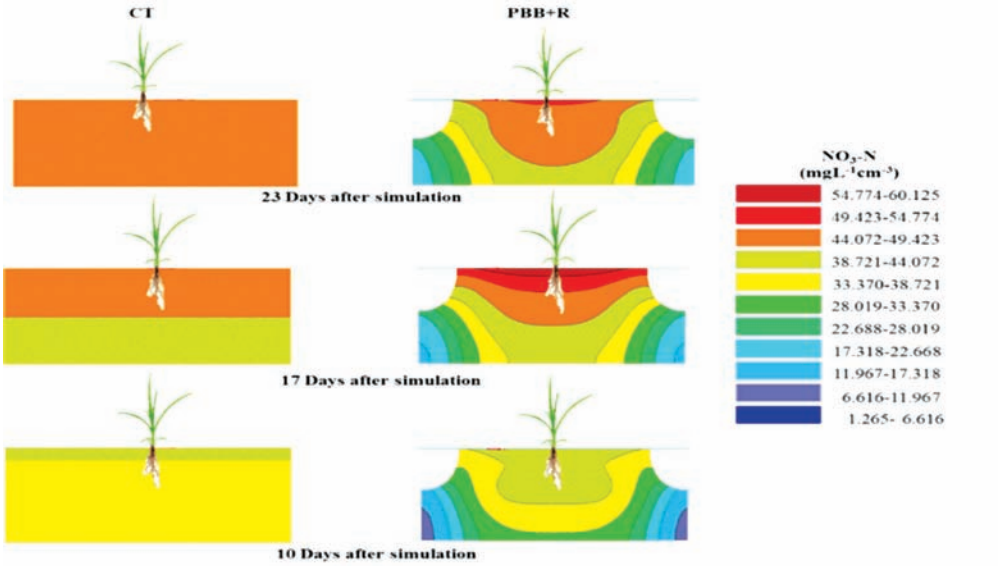
Comparative performance evaluation of MLR and ANN in prediction of SWC_{FC}

Models	Datasets	Performance criteria			
		MAE	r	RMSE	MAPE
MLR	Training	2.46	0.64	2.97	40.29
	Testing	3.11	0.80	3.84	43.47
ANN	Training	2.09	0.73	2.62	38.7
	Testing	2.90	0.78	3.89	57.2
SVM	Training	1.85	0.77	2.45	31.2
	Testing	2.92	0.73	3.49	41.6

6.5.2 Bio-Physics

6.5.2.1 Modeling the temporal distribution of water, ammonium-N, and nitrate-N in the root zone of wheat using HYDRUS-2D under conservation agriculture

The temporal distribution of both soil water and soil NO_3-N under different conservation agriculture (CA) practices during the wheat crop growth were characterized by HYDRUS-2D model. Treatments comprised of conventional tillage (CT), permanent broad beds (PBB), zero tillage (ZT), PBB with residue (PBB+R) and ZT with residue (ZT+R). Hydraulic inputs of the model, comprising the measured value of K_{fs} and α and n, obtained as the output of Rosetta Lite model were optimized through inverse modeling. Model predicted the daily change in soil water content (SWC) of the profile during the simulated period (62-91 DAS) with good accuracy (R^2 = 0.75; RMSE= 0.038). In general, soil water balance simulated from the model showed 50% lower cumulative drainage, 50% higher cumulative transpiration along with higher soil water retention, in PBB+R than CT. Reported values of the first-order rate constants, signifying nitrification of urea to NH_4(μ_a) (d^{-1}), nitrification of NH_4-N to NO_3-N (μ_n) (d^{-1}) and the distribution coefficient of urea (K_d - in $cm^3 mg^{-1}$) were optimized through inverse modeling and were used as solute transport and reaction input parameters of the model, which predicted the daily change in NO_3-N of the profile with better accuracy (R^2 = 0.83; RMSE = 4.62). Since NH_4-N disappears fast, it could not be measured frequently. Therefore, not enough data could be generated for their use in the calibration and validation of the model. Results of simulation of daily NO_3-N concentration indicated a higher concentration of NO_3-N in the surface layer and its leaching losses beyond the root zone were relatively lesser in PBB+R, than CT, which resulted in



Pictorial presentation of NO_3–N under CT and PBB+R on different days during the simulation period

less contamination of the below ground water. Thus the study clearly, recommended PBB+R to be adopted for wheat cultivation in maize-wheat cropping system, as it enhances the water and nitrogen availability in the root zone and reduce their losses beyond the root zone.

6.5.3 Remote sensing and GIS

6.5.3.1 A prototype for spatial wheat yield forecasting system

A reliable crop yield forecast system is an imperative for stabilized food security. The study attempted to develop a novel regional wheat yield forecasting system by assimilating remote sensing derived LAI and weather forecast into crop simulation model, *i.e.* InfoCrop-wheat, using minimum observations as model inputs. The CSM model was calibrated and validated using experiments at research farm of IARI, as well as the model was validated for 42 farmers' fields selected in Pataudi block of Haryana during *rabi* season 2015-16 and 2016-17 and showed good performance of the model at both the scales. The developed forecasting framework consisted of four components, *viz.*, (i) retrieve LAI from multi-spectral remote sensing images, (ii) assimilate LAI into modified InfoCrop model, (iii) incorporate bias corrected WRF modelled weather forecast and (iv) computer coded prototype system for spatial implementation. LAI was retrieved through inversion of PROSAIL RTM from Sentinel 2A MSI and Landsat-8 OLI imageries and validated using *in-situ* LAI measurements of farmers' fields and also assessed the effect of atmospheric correction algorithms, inversion approaches and image resolutions on LAI retrieval. Among the two atmospheric correction algorithms, MODTRAN outperformed libRadtran, while among the inversion approaches, Look-Up-Table outperformed ANN. The inclusion of additional two red-edge bands as available in MSI significantly reduced the uncertainly in LAI retrievals over that obtained by using six bands, while inclusion of only additional VNIR band did not show any significant effect on LAI retrievals. MODTRAN and LUT based inversion reduces average error in LAI retrieval to 0.44 from 1.19. Then, we developed the novel modified InfoCrop-LAI assimilation framework through successful implementation of Ensemble Kalman filter and Forcing algorithm of multiple LAI assimilations with crop phenology adjustment. This study demonstrated that assimilation of LAI through EnkF improved not only crop yield prediction performance but also phenology and growth of wheat using standard management inputs and minimum actual observations. Finally, we demonstrated the wheat growth and yield forecasting system assimilating LAI through ensemble kalman filter and bias corrected weather forecast from dynamical WRF model into InfoCrop-wheat model for a region. The workable system has shown the acceptable accuracy in forecasting phenology, total dry matter and yield of spring wheat at fine scale and minimized the large management input data requirements. It has potential to be adopted for actual applications in many national projects like FASAL and PMFBY of Govt. of India.

6.5.4 Agricultural meteorology

6.5.4.1 Multi stage wheat yield estimation using weather-based models

Wheat yield data and weather variable during crop growing period (46th to 15th SMW) for last 35 years data were collected from Hisar, Ludhiana, Amritsar, Patiala and IARI, New Delhi. Stepwise multiple linear regression (SMLR), Principal component analysis in combination with SMLR, Artificial Neural Network (ANN) alone and in combination with principal components analysis (PCA), Least absolute shrinkage and selection operator (LASSO) and elastic net (ENET) analysis are carried out by fixing 70% of the data for calibration and remaining dataset for validation. Results showed that out of six multivariate models lasso and elastic net are excellent for four out of five station and good for one station, because of prevention in over fitting and reducing regression coefficient by penalisation. nRMSEv range between 5.0 to 15.9% for Elastic Net, 4.2 to 16.9 for LASSO, 3.7 to 20.0% for SMLR, 6.2 to 15.9% for PCA-SMLR, 7.8 to 22.3% ANN and 11 to 16.1% PCA-ANN, respectively.

Multistage wheat yield prediction was done at tillering, flowering and grain filling of crop by considering 46th to 4th, 46th to 8th and 46th to 11th SMW for model development. On examining these multivariate models for stage-wise prediction of wheat yield, percentage deviation was found between -0.1 to 25.6, 0.9 to 22.8, -0.7 to 22.5% during tillering, flowering, and grain filling stage respectively. On the basis of percentage deviation of estimated yield by observed yield, prediction accuracy at different growth stage was found better by Elastic net and LASSO model followed by SMLR model. PCA-SMLR, ANN and PCA-ANN model were giving least prediction accuracy in all phenological stage. From this study it may be concluded that LASSO, Elastic Net and SMLR model based on weather parameters can be used for district level yield forecast at different crop growth stage of the crop.

6.5.4.2 Simulation of biomass and seed yield mustard cultivars using AquaCrop model

AquaCrop model (v 6.1) was calibrated for above ground biomass accumulation and seed yield using 4 types parametric values, namely, conservative and non-conservative crop parameters, soil parameters and management parameters. Conservative crop parameters were obtained from the published literature, non-conservative crop, soil and management parameters were generated using the field experiment data of earlier years of the same field for three mustard cultivars namely Pusa Vijay, Pusa Mustard 21 and Pusa Bold in the model data files. AquaCrop Model (v 6.1) was then run with the daily weather data of *rabi* season of 2013-14 for aboveground biomass calibration of three mustard cultivars: Pusa Vijay, Pusa Mustard-21 and Pusa Bold. The calibrated final biomass was 12.70, 11.05 and 9.81 t/ha, respectively. The difference in observed and simulated final biomass was +1.35, +1.80 and -1.6%, respectively. So, the final biomass calibration was within ± 10 % difference. After running the calibrated AquaCrop Model with the weather data of *rabi* season 2013-14, the simulated seed yield was obtained for mustard cultivars, Pusa Vijay, Pusa Mustard-21 and Pusa Bold. The differences between the simulated and observed seed yield were found to be -9.20, +3.32 and +2.47% (i.e. within ± 10 %)

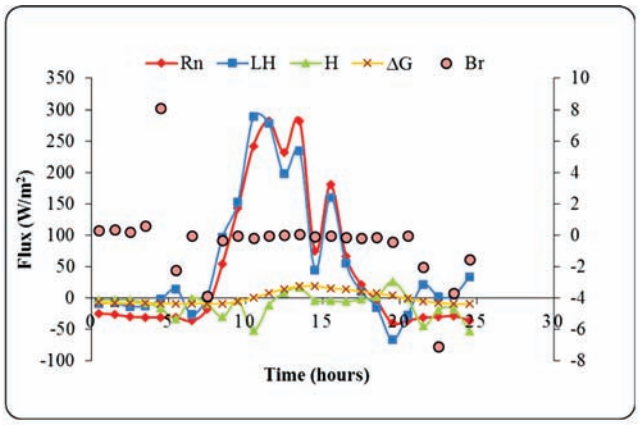
6.5.4.3 Estimate surface energy fluxes using BREB (Bowen Ratio Energy Balance) method

Bowen ratio energy balance (BREB) method is a micrometeorological method by combining Bowen ratio with energy balance components of earth. In this study, a field experiment was conducted on maize (variety: PMH-1) and wheat (variety: HD 2967) in the main experimental farm of ICAR during *kharif*, 2018 and *rabi* 2018-19. Homogeneous crop was grown in both the season and micrometeorological tower was installed inside the crop field. Micrometeorological tower is having temperature, humidity, wind speed in five levels (0.5 , 1, 2, 4, and 8m), net radiometer at 2m height, PAR sensor at 2m height, wind vane at 2m height, soil moisture and soil temperature at three different depths (5, 15, 25 cm) and soil heat flux plate at 2 depths (5 and 15 cm). During *kharif* 2018, sowing was done on 19th July. Cultivar PMH-1 emerged in 8-10 DAS and matured at 105 DAS. Wheat crop was grown

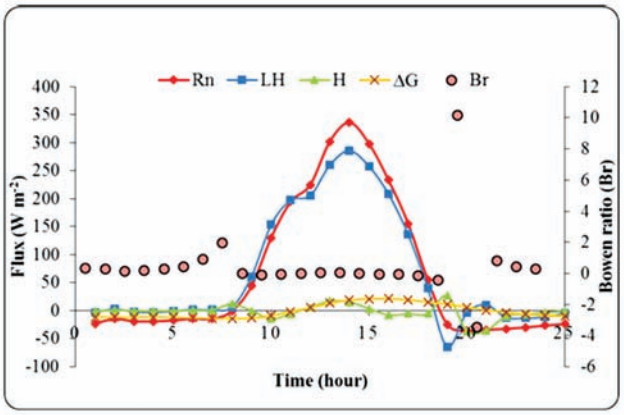
Observed and calibrated final biomass and yield of three mustard cultivars during *rabi* 2013-14

Cultivar	Biomass (t/ha)			Seed yield (t/ha)		
	Observed	Calibrated	Difference (%)	Observed	Calibrated	Difference (%)
V-1	11.2	12.71	+1.35	2.50	2.27	- 9.20
V-2	10.85	11.05	+1.80	2.11	2.18	3.32
V-3	9.97	9.81	-1.6	1.90	1.95	2.47

in *rabi* 2018-19. Crop was sown on 25th November, 2018. Cultivar HD 2967 germinated in 7-8 days. CRI stage was appeared in 22 DAS. Harvesting was done at 142 DAS. Highest LAI of maize was 4.56 at 82 DAS with a CV varied from 5.64 to 16.05 % and CI varied from 0.15 to 0.29. Mean grain yield of maize crop was recorded 5.76 t ha^{-1} during *kharif*, 2018. During *rabi* season 2018-19, wheat grain yield varied from 4.11- 4.42 t ha^{-1}. The mean grain yield was observed 4.25 t ha^{-1}.



(a)



(b)

Trend of energy balance and Bowen ratio for (a) a cloudy and (b) cloud free day over wheat crop during *rabi*, 2018-19

6.5.4.4 Weather based Agromet Advisory

Agro-met advisory bulletins are being prepared in Hindi as well as in English on every Tuesday and Friday based on past weather, real time weather and weather forecast received for next five days from IMD, New Delhi. The bulletin is passed on to the farmers through SMS / telephone / E-mail .The bulletins are also sent to ATIC, KVK Shikohpur, KVK Ujawa, IKSL, NGO, e-choupal, KrishiDarsan, All India Radio, DD Kisan, and local Hindi newspapers through E-mail for wider dissemination among farmers. These advisories were uploaded on the Institute website (www.iari.res.in) along with daily weather data and medium range weather forecast. These advisories were also uploaded on the IMD website (www.imdagrimet.gov.in) and farmer portal (http://farmer.gov.in) in both Hindi and English. These advisories along with crop status are sent to IMD, Pune for preparation of national bulletins. During 2019, total 105 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 is fruitful for farmers, through this they can select high yielding varieties of different crop and vegetables, other farming practices such as sowing, weeding, irrigation, fertilizer, pesticides spray (time and doses) can be done at right time. Feedback received from the farmers from different villages of NCR Delhi showed that agromet advisory bulletin is useful since as it helps in reducing cost of cultivation, saving of input resources and increases in net profit.

6.6 NATIONAL PHYTOTRON FACILITY (NPF)

The National Phytotron Facility continues to provide specific environmental conditions desired by the users to conduct critical experiments on various subjects including genetics, physiology, plant protection, biochemistry, plant-environment interaction and future climatic conditions. Experiments on climate resilient crop development, accelerated crop breeding, microbial interaction on biodegradable plastics, enhancing nutrient use efficiency, bio-fortified crop development, gene expression on model plants, etc. dominated the list of experiments conducted by the research scholars and scientists from ICAR institutes, University of Delhi South Campus, JNU

and IIT-Delhi. During the year, 144 new experiments were accommodated besides the on-going previous experiments. The NPF was visited by a number of domestic and foreign visitors including delegates, trainees and students.

Response of soybean genotype under elevated CO_2 and normal CO_2 condition in NPF. Under elevated CO_2, the growth of the genotype was better (left) than the normal (right) CO_2 Condition

Screening of segregating population of wheat for rust resistance under challenge inoculation in NPF

7. SOCIAL SCIENCES AND TECHNOLOGY TRANSFER

Agriculture plays a vital role in Indian economy. Given the importance of enhancing farmers' income and nutritional security by Government of India, School of Social Sciences, is focusing on recent and sensitive issues which has direct influence on farmers' income such as assessing improved IARI Technologies, impact of Cluster Frontline Demonstration, impact of credit in enhancing household income, performance of different marketing institutions in raising farmer's income, agricultural growth models, ecosystem services and its key determinants, impact and constraints of e-NAM. Climate change and innovative extension models, different climate resilient technologies, farmer led innovations (FLIs), agri-nutri linkages and gender empowerment are also other important areas of focus. These issues were studied in different 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 *Mera Gaon Mera Gaurav* programmes are well supported by the School of Social Sciences. Agricultural Technology Information Centre (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 Impact assessment of improved ICAR and IARI technologies

Impact assessment of ICAR-IARI wheat varieties by collecting primary data from Karnal and Kurukshetra districts of Haryana and Ludhiana and Jalandhar district of Punjab, Najafgarh and Narela blocks of NCR, Delhi revealed that HD 2967 and HD 3086 are the most adopted wheat varieties in sample areas covering 80-85 per cent of the area under cultivation. The potential economic benefits of these varieties was estimated as ₹ 3,837 and ₹ 2,586, respectively in NCR, Delhi for the year 2018-19.

A primary survey of 180 farmers (comprising of CFLD and non-CFLD in Pratapgarh district of Uttar Pradesh and Narayangaon in the Pune district of Maharashtra) were interviewed to assess the impact of Cluster Front Line Demonstration (CFLD) of ICAR in realizing better income and results showed that farmers realized higher net returns by adopting recent variety as compared with non-CFLD farmers.

Understanding the role of credit as a catalyst for technology adoption and resource use, the impact of credit in enhancing household income in Eastern India was examined and it indicated that credit borrower's and non-borrower's income increased to ₹ 35,085 and ₹ 31,234, respectively per household per annum. However, correlates of choice of source of credit and amount of institutional finance from a survey of rural households in Eastern India indicated that 52 per cent of households lack access to any type of loan.

7.1.2 Performance of different marketing institutions in raising farmer's income

A study was conducted to understand the status, stakeholder's participation and perception, impact and constraints of e-NAM. It was found that the number of APMC mandis registered and doing online trade were highest in Uttar Pradesh. The overall farmer's coverage under e-NAM was 13 per cent of total cultivators in India. Although, the highest number of farmers were registered in UP and MP, the highest coverage was in Haryana (94%), followed by Telangana (57.6%). The primary survey of APMC markets of Karnataka, Haryana and Punjab indicated that improved automation of the auction which enabled quick payment of sale proceeds. Focused group discussion with farmers in Tamil Nadu indicated that quality and grading aspects were the

major hindrances to participate in e-NAM. A study on Farmers Producers Organizations (FPOs) in Kolhapur, Maharashtra revealed that members were able to meet their current obligations as indicated by current ratios and acid-test ratios of more than one. Debt-equity ratios indicated that FPOs are financially healthy, but were unwilling to take risk showing conservative management. The Profit regression analysis revealed that the size of landholding and farm income were the major determinants of joining the FPO. Regression Adjustment model confirms that FPO's had a positive and significant impact on raising farm income to 26 per cent. The study conducted in Andhra Pradesh revealed that association with FPO has enabled the members to adopt the improved chilli cultivation practices more (66.6%) compared to non-members.

The role of MSP (Minimum Support Price) to ensure price assurance and its actual effect on price realization to the farmers was analyzed through 'anchoring effect' of MSP. The results from the sample of 1739 rice growing rural households from eastern India (Bihar, Eastern UP and Jharkhand) revealed that though 1174 farmers (68%) have heard of MSP, only 454 farmers (26%) are actually aware of exact MSP of rice. Estimated Average Treatment Effect (ATT) of MSP awareness on the price by 'Coarsened Exact Matching' (CEM) revealed that there is no evidence of anchoring effect of MSP on the prices received by the farmers.

Impact of export promotion of processed and unprocessed foods sector and its effect on output growth in farm and non-farm sectors was assessed using the Social Accounting Matrix (SAM), for the data point 2007-08 and 2012-13. Results indicated that structural transformation with raising the non-farm sector share to 91 per cent from 88 per cent, capital intensities increased from 51 to 67 per cent. From the policy simulation, it is understood that the promotion of processed foods accelerated more output growth in 2012-13, while unprocessed foods were more powerful in 2007-08 SAM. The results indicate that a 10 per cent increase in investment in Food processing industry (FPI) will lead to the highest growth in fish and fish products by 5.39 per cent, followed by 2.64 per cent of growth in meat and poultry.

7.1.3 Agricultural growth, ecosystem services and its key determinants

The model was developed to link agricultural growth with vital macro-economic variables to derive the effectiveness of public spending on welfare (in terms of poverty reduction in rural areas). Estimated elasticity for agricultural income suggested that one per cent increase in agricultural income would reduce rural poverty by 0.33 per cent. Private investment in minor irrigation and public investment in agricultural research and development, education, rural development, access to credit and energy would maximize efforts to raise agricultural income and alleviate rural poverty.

The trends in energy use in the crop production process of India and its drivers were analysed using secondary data from various published sources. Food grain production, mechanization, irrigation and fertilizer consumption are the key drivers of energy use. The energy use efficiency in Indian agriculture improved with the decline in the energy required to generate a unit value of output. However, the demand for energy in the organized sector (food and beverage industry) doubled from 1.51 to 3.26 millions of tonnes of oil equivalent (MTOE) between 2007-08 and 2010-11 and saw a quantum jump to 18.71 MTOE in the year 2015-16. All the sources of energy for the sectors like coal, electricity and petroleum products have contributed to this growth.

In order to ensure ecosystem services to operate at its pace, knowing and assessing its market value is key. A study was taken up to estimate Willingness to Pay (WTP) for tank ecosystem services in Warangal district of Telangana. Primary data were collected using a well-structured questionnaire from 209 tanks fed farmers. Estimated double-bound contingent valuation method indicated that WTP for the conservation of tank ecosystem services by beneficiaries was ₹ 1,440 per annum which is approximately about ₹ 4/- per day.

7.1.4 Role of technology intervention in agriculture to enhance nutritional security

India is facing a serious challenge of under nutrition throughout the country in varying degree. Based on district-level National Family Health Survey (NFHS, 2015-16) data, the study investigated the prevalence of malnutrition among children and adults in rural India and examines the possible association of different socio-economic factors with malnutrition across districts. The composite malnutrition indices were constructed separately for children and adults. The results revealed that the western and eastern regions of the country experienced the highest incidence of malnutrition as measured in terms of normalized combined malnutrition index followed by the northern region. The nutritional status of the north-eastern region was found to be the best as 95 per cent of the total districts have very low malnutrition level.

7.2 AGRICULTURAL EXTENSION

7.2.1 Development of innovative extension model

7.2.1.1 Institutionalization of IARI-Post Office linkage extension model

An institutional mechanism for upscaling IARI Post Office linkage extension model has been developed with Department of Posts, Government of India. An amount of 9.9 q quality seeds of improved IARI varieties of wheat (HD 2967) was disseminated in 10 districts of Uttar Pradesh covering 24.75 acres, while 1.92 q quality seeds of green gram (Pusa Vishal) was disseminated in 8 districts of 6 states along with and 0.26 q quality seeds of vegetables (bottle gourd, cowpea and okra). Socio-economic impact of this model was assessed. The study revealed that the information source preference had 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. The major impact observed was improved satisfaction on extension service, change in cropping pattern and yield, change in seed management practices, increased social status of post master and increased social security. The visibility of extension interventions conducted by Branch Post Masters (BPMs) like on-farm demonstrations and training had increased significantly.

7.2.1.2 Devising extension approaches for climate change adaptation and livelihoods security

The adoption pattern of different climate resilient technologies was studied under three different extension approaches in three experimental villages. The adoption index score in convergence led extension model (0.81) was better than the innovative farmers led extension model (0.68) and farmers club led extension model (0.47). The traditional rainfall pattern of Kalimpong hill was validated using last 50 years climatic data. The chi square test was significant at 1 per cent level indicating that observed rainfall and expected rainfall were not significantly different for *Sawneyjhari, Bhadueryjhari, Sohrasaradeyjhari, Bonshojhari, Titeyjhari, Sisneyjhari, Chuiajhari, Fapreyjhari, Bhangerajhari, Makureyjhari,* and *Ashwinajhari.* One climate smart village was developed at village Singimari of Jalpaiguri district. There was high level of adoption of climate resilient technologies such as PS-5 (80%), pheromone trap (77%), DSR (72%) and zero tillage (63%). Darjeeling mandarin health clinic was established at Sitong and Mungpoo of Darjeeling district. The healthy grafted planting materials of mandarin (3000) and model mandarin orchards (30 acre) were promoted and 12 training programmes were organized under health clinic.

A study was undertaken to model climate change exposure in coastal West Bengal. The South 24 (P) district was selected as a representative coastal district. Historical changes in regular climatic parameters, and occurrence of extreme climate events were taken as the indicators of exposure. Changes in temperature and rainfall related indicators for a period of 40 years (1974–2013) were considered for the said purpose. The indicators were weighted using Shannon's

entropy to longitudinally derive composite climate change exposure index values. Based on the year-wise exposure index values, it was observed that overall exposure in the district shows a gradually inclining trend. It is also seen that exposure is mostly determined by the deviation in occurrence of the extreme events, rather than the regular events. An attempt was made to validate the exposure model using an artificial neural network based regression approach with an MSE of as low as 0.2373.

A survey was undertaken in the villages Balakati and Sathilo of Khurda district and Manapada village of Puri district of Odisha to assess the impact of Fani cyclone. Almost all the farmers reported that about 90 per cent of paddy harvested could not be fetched home and got damaged and rotted in the field. The economic loss from paddy was around ₹ 30,000-40,000 per household. The farmers had also to go for distress sale. The coconut and banana growers suffered loss of ₹ 15,000 and ₹ 25,000 per household, respectively. There was heavy damage to fish ponds due to rotting of plant debris fallen inside the pond leading to mortality of fishes. The ponds became unfit for further production. The farmers estimated an economic loss of around ₹ 32,000 from fishery unit. There had been heavy damage to commercial poultry structures due to heavy wind. Due to the loss of previous crop, farmers were left with scarce resource to take up crop in ensuing season; hence, breeder seeds of CR Dhan 500 were provided and the farmers were sensitized to form community seed bank for future use of seeds and managing the distress.

7.2.1.3 Analysis of ICT based extension approaches

Digital information for rice, chilli, Darjeeling mandarin and large cardamom was developed and mobile based advisory services were provided to 500 farmers. One whatsapp group has been created and the impact of digital agro-advisory services was studied. One e-large cardamom crop calendar was developed and its effectiveness (0.86) was studied in terms of clarity, simplicity, visibility, comprehension, usefulness and attractiveness.

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 was conducted using semantic differential technique. A semantic differential scale of seven-point continuum with 27 bi-polar adjectives was developed. A questionnaire designed in Google Forms was emailed to 207 extension personnel of NARS including ICAR Institutes, State Agricultural Universities and *Krishi Vigyan Kendras* throughout India. Extension personnel perceived that the frontline demonstration is the most effective method with a mean score of 5.97 followed by whatsapp (5.57) and farm telecast (5.14) in extension service delivery to the farmers. Variables such as age, designation, education and experience are not correlated with their perception about effectiveness of extension methods.

7.2.2 Enhancing nutritional security and gender empowerment

A study conducted to understand variety in food consumption among rural households in Uttar Pradesh showed that an increase in income by INR 1000 raises dietary diversity by 0.02 units. A study on bio fortified varieties of IARI revealed that cost of development of bio fortified varieties was in the range of 4 to 7 crores and the human capital accounted for 40 to 65 per cent. The unit cost of micronutrients intake from different food crops estimated to be ₹/mg of Zn from rice costs ₹ 2.29/mg and cheapest source of zinc was from wheat i.e. ₹ 0.85/mg. Similarly, the cheapest source of iron was from pearl millet (₹ 0.57/mg). The incremental nutrient consumption in terms of monetary value from the annual consumption was highest in rice (₹ 1271.65) and lowest in sorghum (₹ 0.029). A study on knowledge, perception and willingness to pay (WTP) for bioforitified crops revealed that gender, education, food habits and income were the significant factors influencing consumers' awareness of biofortification. An estimation of consumers' WTP for biofortified mustard oil found that urban and rural consumers were willing to pay 36 per cent and 26 per cent more than the existing price.The biofortifiedmustard variety (PM 31) with low erucic acid content was promoted

in Darjeeling district and Jalpaiguri district of West Bengal and its performance was assessed (14 q/ha). An analysis of factors affecting WTP for pesticide safe vegetables of consumers brought into light that age, education, income, gender and children were the major influencing factors which affected WTP for pesticide safe cabbage, cauliflower, brinjal and bitter gourd.

A study with a health belief model revealed that the urban population had higher level of self-efficacy and confidence to overcome anaemia as compared to lower level of self-efficacy amongst rural respondents. Majority of both urban and rural respondents possessed medium level of perceived susceptibility and perceived barriers.

A multi-layer weighted, composite Food and Nutritional Security Index (FNSI) was developed and applied to the 13 Bundelkhand districts. The results of the study showed that Datia had the highest availability index (2.49), Hamirpur had the highest accessibility index (1.63) and Damoh had the highest utilization index (1.64).

A study on food consumption pattern amongst slum and homeless city dwellers in Delhi revealed that more than 50 per cent of the slum dwellers had poor food consumption practices in addition to unhygienic drinking water, poorly sanitized community toilets and residences.

A self-paced e learning module on "Gender Empowerment for Extension Personnel" was developed and validated on the parameters of relevancy, ease of understanding, quality, sufficiency and sequencing of content, interactive features, navigational features, chunking of content, visual design, labelling, storyboarding and utility of the module on five-point continuum. It was rated very high i.e. above four on a continuum ranging from 1-5 by majority of the respondents.

Under Agri-Nutri (A2N) Smart Village Model, various capacity building activities were carried out. The impact of nutri-kitchen garden was studied with a sample of 90 women and children and it was found that adoption of kitchen garden increased knowledge level of women on nutritional security.Multimedia modules on general nutrition, role of traditional foods in nutritional security, bajra, moringa and other value added products were shown to the project location beneficiaries.

Instruments were developed and standardized for Multidimensional Nutritional Health Locus of Control and Nutritional Health Belief Model using Confirmatory Factor Analysis. A scale on perception of farmers and extensionists on impact of climate change on nutrition was also validated. Strategies for promoting biofortified crops were identified using fuzzy Analytical Hierarchy Process The top five ranked strategies were (Rank I) Seed Production for ensuring seed availability (seed villages, participatory seed production); (Rank II) Inclusion of biofortified cereals in Government programs (*Poshan Abhiyan*, PDS, ICDS, Mid-day Meals etc.); (Rank III) Providing subsidized seeds of bioforitifed varieties and other related inputs; (Rank IV) Awareness (mass media) and (Rank V) Participation of Farmer Based Organisations (FPCs, SHGs) and ICT based networking for convergence of institutional interventions.

Digital competencies indices were developed for farmers and extensionists besides identifying Best Practices for ICT based strategies for Nutrition Sensitive Agriculture (NSA) using multi-criteria decision making technique TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions). The first ranked Best Practice was customized information on various aspects of NSA in local language.

7.2.3 Maximizing farm profitability through entrepreneurship development and farmer led innovations

Experiences of 170 innovative farmers from 6 states (U.P., Rajasthan, Haryana, Delhi, Bihar and Jharkhand) were documented. Two Farmer Innovators- Researchers Interaction meets were organized in collaboration with respective ATARI zones. A strategy for institutionalization of FLIs was

formulated in collaboration with four ATARIs and KVKs. Extrapolating learnings were drawn from success cases. Potential entrepreneurs were mobilized, trained, mentored and provided technological advisory support for Agripreneurship process development in project villages. Motivational interventions, training inputs, skill demonstrations and interaction meets with stakeholders were conducted. Ten women SHGs and two Farmer Interest Groups (FIGs) were mobilized. Pre and post training changes in behaviour were analysed. Mentoring and handholding activities and facilitation of linkages with banks, government departments, local non-governmental agencies, marketing agencies and processors was done. Analysis of linkages for production and marketing was conducted. Strengthening capacities to scale up, networking of extension services, allocation of resources for upscaling and mechanism to share updated knowledge were perceived as a major requisite to maximise farm income by innovator farmers. Awareness, entrepreneurial education, technical skill training, knowledge of licensing and certification procedures were perceived as major issues to enhance income by potential agripreneurs. Farmers were skeptical of adopting specialty agriculture due to non-awareness of marketing avenues, no demand in local markets and traditional crops having assured markets. Out scaling innovations in project villages was successful at micro level. Crop diversification, protected cultivation, value-addition was taken up. Entrepreneurial motives of farm innovators included earning more from farming, capitalising on resources available and skills possessed, working independently and running farm in a modern way. Risk taking behaviour of farm innovators ranged between 20-40 per cent of risk probability, whereas potential agri-preneur pre training was found to mostly safe players or high risk takers in the range of 40-60 per cent of probability. Linkages of Farm Innovators were mostly networking kind-cooperating without formal links or equity participation. Only 2.94 per cent firms were contractual alliances and 28 per cent were clustering linkages. Training interventions resulted in out-scaling of innovations, whereas for up-scaling institutional arrangement with ATARIs and KVKs was worked out.

7.3 TECHNOLOGY ASSESSMENT AND TRANSFER

7.3.1 Out scaling 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-Ramchandrapura cluster (Alwar, Rajasthan). During *rabi* 2018-19, the performance of location-specific improved varieties of wheat, mustard, lentil, onion, pea and palak were assessed through 294 assessment trials over an area of 103.85 ha. The performance of the IARI wheat varieties was found superior as compared to local check and no lodging has been reported in IARI wheat varieties at all the project village locations. In Khajurka, Palwal (Haryana) the highest average yield of wheat variety HD 2967 (6.21 t/ha) was reported from assessment trials followed by HD 3086 (6.05 t/ha), HD CSW 18 (5.93 t/ha) and HD 3059 (5.82 t/ha). Lentil variety L-4076 recorded an average yield of 1.35 t/ha with an economic gain of ₹ 38900/- per ha. At Rajpur, wheat varieties HD 2967 (6.17 t/ha), HD 3086 (5.83 t/ha) and HD CSW 18 (6.07 t/ha) yielded higher than local check (5.0 t/ha). HD 2967 and HD 3086 exhibited profuse tillering, no lodging and good chapati making quality. HD-3059 was found suitable under late sown conditions and farmers preferred the variety due to high yield and resistance to yellow rust disease. Guava wilt was diagnosed and control measures were suggested to the concerned farmers. Crop diversification and inclusion of mustard crop in the sugarcane-based cropping system helped the farmers to enhance their income by ₹ 65,000/ha. Disease samples of guava were also collected from the orchards for analysis. At Beenjpur, mustard variety Pusa Vijay was liked by farmers due to large grain size, good yield and oil content. However, the local check (Coral 432) gave a higher yield of 2.35 t/ha compared to Pusa Vijay (1.91 t/ha) and PM-30 (1.81 t/ha).

7.3.1.1 Results of *Rabi* Crop Demonstrations (2018-19)

Summary of *rabi* crop demonetisation (2018-2019)

Village	Crop	Varieties	Yield Demonstrations (t/ha)	Average yield and name of local Check (t/ha)	(%) increase in yield over local check
Khajurka palwal (Haryana)	Wheat	HD 2967	6.2	5.0 (HD 2851)	24.30
		HD 3086	6.1	5.0 (HD 2851)	21.04
		HD 3059	5.82	5.0 (HD 2851)	16.40
		HD CSW - 18	5.93	5.0 (HD 2851)	18.70
	Lentil	L-4076	1.35	1.1 (Local)	28.57
Rajpur, Aligarh (UP)	Wheat	HD 2967	6.17	5.0 (HD 2967)	23.52
		HD 3086	5.88	5.0 (HD 2967)	16.76
		HD 3059	4.84	4.0 (PBW 373)	21.00
		HDCSW 18	6.01	5.0 (HD 2967)	20.34
	Mustard	Pusa Vijay	2.72	2.5 (Pioneer)	9.00
		Pusa Mustard 30	1.46	1.20 (Deshi)	21.67
Beenjpur, Alwar (Rajasthan)	Wheat	HD 2967	6.46	5.35 (WH 711)	20.80
		HD 3086	6.24	5.35 (WH 711)	17.08
		HD 3059	5.35	4.42 (Raj 3765)	21.04
		HDCSW 18	6.18	5.35 (WH 711)	23.70
	Mustard	Pusa Vijay	1.91	2.35 (Coral 432)	-18.72
		Pusa Mustard 30	1.81	2.35 (Coral 432)	-22.76
Kutabi, Muzaffarnagar (UP)	Wheat	HD 3086	5.55	4.0 (PBW 226)	7.5
		HD 3059	4.35	4.0 (PBW 226)	13.0
	Mustard	Pusa Mustard 30	2.25	1.75 (Deshi)	28.5

During *kharif 2019*, a total of 188 assessment trials were conducted in all the adopted villages on paddy varieties (PB 1121, PB 1509, PB 1637, PB 1718, PB 1728 and Pusa 2511) and pigeon pea (Pusa 16), bottle gourd (Pusa Santusti), sponge gourd (Pusa Sneha) and Amaranthus (Pusa Lal Chaulai) covering an area of 75.80 ha. At Kutbi village in Muzzafarnagar (U.P.), the performance of the Pusa Basmati varieties was found superior as compared to the local check. The highest yield of PB 1509 (5.82 t/ha) was recorded, followed by PB 1728 (5.25 t/ha) and PB 1718 (5.20 t/ha). However, the performance of PB 1637 was poor due to the infestation of false smut. An assessment of the spread of IARI paddy and wheat varieties from 2016-2018 was also conducted. The results are presented.

Demonstrations details of Paddy and Wheat (2018-19)

Crop	Variety	Village Khajurka, Palwal		Village Rajpur, Aligarh		Village Beenjpur, Alwar	
		Spread (2016-2018) Area (ha.)	Diffusion Effect (No. of times)	Spread (2016-2018) Area (ha.)	Diffusion Effect (No. of times)	Spread (2016-2018) Area (ha)	Diffusion Effect (No. of times)
Paddy	PB 1121	3099.4	101.95	3991.74	117.4	-	-
	PB 1509	2694.2	102.0	2693.58	85.23	-	-
Wheat	HD 2967	859.6	43.85	825.54	28.66	574.56	32.09
	HD 3086	415.7	26.69	388.01	19.40	307.43	20.22
	HD 3059	79.9	13.31	110.17	9.49	92.17	12.12

7.3.1.2 Interventions on Kitchen gardens

Based on the assessment of nutritional status, dietary intake and deficiency patterns of rural women, interventions on seasonal vegetables were promoted among women farmers for enhancing the food diversity. In Khajurka, Palwal, during *rabi* 2018-19 nutrition garden demonstrations on pea (Pusa Pragati), spinach (P-All Green) and onion (P-Red, Pusa Riddhi); and during *kharif* season, nutrition garden on bottle gourd (Pusa Santusti) were conducted. In Beenjpur, Alwar, nutrition gardens on sponge gourd (Pusa Sneha) and amaranth (Pusa Lal Chaulai) were promoted. In Rajpur, Aligarh, in *rabi* 2018-19 spinach (P-All Green, P Bharti) and onion (Pusa Riddhi); and during *kharif* 19, nutrition garden on bottle gourd (Pusa Santusti) were promoted. The spinach (Pusa All Green) was well appreciated for its colour, leaf thickness, leaf area and higher yield than local cultivars. The consumption pattern, nutritional status and awareness level of rural households on nutritional food and dietary pattern were assessed. Nutrition gardens of winter vegetables were conducted by providing winter vegetable kits for promoting crop diversification and nutritional security. Village Knowledge Resource Centers equipped with farm libraries having a collection of farmer-friendly literature, booklets, leaflets, journals, magazines, periodicals dealing on various aspects of agriculture, horticulture, animal husbandry *etc*. have been established in all the villages for the benefit of the village community.

A total of 400 farmers (100 in each village) have been linked with mobile SMS services for regular messaging on Agro-advisory from the Institute. The farmers' feedback revealed that approximately 90 per cent of the respondents opined that they read the agro-advisory messages received from IARI, the language of the messages were easily understandable, clear and readable and messages received were included local and familiar words for easy understanding. Also, 80 per cent of the respondents expressed that information received through messages was adaptable in local field conditions and a majority (88%) of the respondents expressed that the length of the content of messages was adequate. The study has revealed that the information gathered through agro-advisory service has been very useful and helpful to the farmers and they have started gaining interest in accessing information and decision making on the management of the crops by utilizing agro-advisory. After seeing the success of biogas unit in the Beenjpur, project village of CATAT, four farmers of Kotputli, Rajasthan were also adopted biogas technology.

7.3.1.3 Capacity-building activities

Training on the importance of different bio-fertilizers, *e.g*. Azolla, BGA, *Azospirillum*, PSB and *Azotobacter* for rice and vegetable crops along with demonstrations on the application method were conducted at village Rajpur, Aligarh. Nutrition Awareness Programme for capacity building of farm

women was organized at Village Kutbi, Muzaffarnagar (UP). Training on waste management and preparation of compost from the biodegradable waste from kitchen and crop residue residue was also organized.. The use of Pusa Liquid Decomposer in preparation of compost was demonstrated. Exposure visits of farmers from project villages during the launching of *Kisan Samman Nidhi* Scheme at IARI (February 24, 2019) and *Pusa Krishi Vigyan Mela* 2019 were conducted.

7.3.2 Technology integration and transfer to strengthen the farming system in partnership mode

The partnership project is being implemented with selected ICAR Institutes / SAUs/VOs in different parts of the country. The sharing of results and their feedback on the trials using IARI varieties was carried out through joint workshops with partner institutions. Suitable farm production, plant protection and post-harvest technologies and farm enterprises were discussed based on participatory analysis and joint consultations for the profitable farming system during workshops held at Institute. The technologies were assessed through demonstrations, trainings, field days etc. by the partner organizations. During 2018-19, combining *kharif* and *rabi* season, 1274 demonstrations were carried out with NEP and VO partners.

7.3.2.1 Collaborative programme with ICAR institutes and SAUs

Under collaborative programme with ICAR institutes and SAUs, 447 demonstrations were carried out in *rabi* 2018-19 and *kharif* 2019. During *rabi* 2018-19 under NEP, a total of 257 demonstrations of wheat, mustard, onion, gram, spinach, pea, marigold, cowpea, brinjal, tomato and chickpea were conducted in 23 locations. During *kharif* 2019, 190 demonstrations were conducted on paddy, arhar, brinjal, spinach, sponge gourd and bottle gourd.

7.3.2.2 Collaborative programme with voluntary organizations

In collaboration with 16 voluntary organisations, during *rabi* 2018-19, 469 demonstrations, covering an area of 117 ha, were conducted for crops wheat, mustard, lentil, onion, gram, spinach, pea, marigold, cowpea, brinjal, carrot, fenugreek, mustard and during *kharif*, 358 demonstrations covering an area of 89.44 ha were carried out for crops like paddy, arhar, moong, bottle gourd, spinach, brinjal and marigold.

7.3.2.3 IARI-Insecticide India Limited (IIL) Collaborative Project: Social value system development about the judicious use of pesticides and other agro-chemicals and entrepreneurship among youth

The project is being implemented at Peernagar Soodna and Lalpur villages (Hapur) UP. During reporting period, demonstration of IPM technology in pigeonpea, sugarcane, rice, cabbage, brinjal, chilli was conducted to compare the effectiveness and cost of cultivation. Disease-free chilli seedlings were supplied to the farmers to initiate the crop, which was highly impressive to the farmers.

7.3.2.4 Assessment and dissemination of climate resilient agricultural technology in Bihar –A multi-stakeholder convergence (In collaboration with World Vision)

The project is being implemented in Muzaffarpur and Vaishali districts of Bihar to enhance the resilience of 200 farmers in selected villages to climatic variability and climate change through strategic research on adoption and mitigation**.** During the reporting period, 160 demonstrations of wheat HD 2967 and HD 2733 were laid, which resulted in an increase of 8-10 per cent yield along with crop diversification, IPM and demonstrations on bio-fertilizers.

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* 2018-19, 37.8 t of wheat HD 2967 seed was produced at PRDF Gorakhpur, and 13.4 t seed of Wheat HD 2967, 28.7 t of HD 3086 and 12 t of HD CSW 18 was produced at YFAP, Rakhra. During *kharif* 2019, 6.0 tonnes of PB 1509, 17.5 tonnes of Pusa 44 and 3.5 tonnes of Pusa 1121, 3.0 t of PB 1728 and 7.0 t of PB 1401 seed were produced at Rakhra.

Performance of FLD – IWBR (Wheat) during *rabi* 2018-19

Technology Demonstrated	No. of Demo	Area (ha.)	Yield Demo. Plot (t/ha)	Average yield and name of Check (t./ha)	(%) Increase in yield over check	Average Straw yield (t/ha)		Average Net Return (Profit) (₹/ha)		Benefit-Cost ratio	
						Demo plot	Checkplot	Demo plot	Checkplot	Demo plot	Check
Newly Released wheat variety (HD 3086) with Zero-tillage	10	4.00	4.86	4.72 (HD 3086)	3.02	4.62	4.48	71042	62067	2.71	2.31
Use of Bio-fertilizer (*Azatobactor* +PSB) in HD 3086	8	3.20	5.03	4.79 (HD 3086)	4.73	5.01	4.76	67775	63195	2.36	2.29

7.3.4 Front line demonstrations wheat (in collaboration with IWBR)

During *rabi* 2018-19, 18 FLDs on zero tillage and use of bio-fertilizer (*Azotobacter* + PSB) were conducted with newly released wheat variety HD 3086 at village Madanpur Dabas, North-West Delhi. The Zero-tillage practice saved ₹ 5800/ha. The cost of ploughing, 3 per cent 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 clusters 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 a regular basis by adopting villages. During *rabi* 2018-19, 372 demonstrations on wheat varieties (HD 2967, HD 3086, HD 3059 and HD CSW 18) and 338 demonstrations on mustard (Pusa Mustard-30, Pusa Mustard-31 and Pusa Vijay) were conducted at 83 and 68 locations in an area of 75 and 136 ha, respectively. During *kharif* 2019, 342 demonstrations on paddy PB-1728, PB-1718 and PB-1637 were conducted at 67 locations covering 137 ha area.

7.3.6 Pusa *Krishi Vigyan Mela* (March 5-7, 2019)

Pusa *Krishi Vigyan Mela* 2019 on the theme "Krishi Vikas: Innovative Technologies" was organized at the IARI *Mela* ground from March 5-7, 2019. Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR) inaugurated the *Mela* on March 5, 2019.

Inauguration of *Pusa Krishi Vigyan Mela* by Dr. T. Mohapatra, Secretary, DARE, and Director-General, ICAR

In his inaugural address, Dr. Mohapatra applauded the institute's 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); Dr. J.K. Jena, DDG (Fisheries Science); Dr. J.P. Sharma, Joint Director (Extension), ICAR-IARI and Dr. S.P. Kimothi, ADG (TC) also marked their presence and spoke on the occasion. Dr. A.K. Singh, Director, IARI (Add. Charge) welcomed the gathering and detailed the events to be organized along with IARI achievements, especially in developing popular basmati variety PB 1121, wheat variety HD 2967 *etc*.

Thirty-one awardees including farmers and scientists in different categories were also felicitated with ICAR Awards during the inaugural session. 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.

Dr. Ramesh Chand, Member, NITI ayog was the Chief Guest of the valedictory session which 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 the need for marketing of the surplus produce and the implementation of new agricultural policy for the 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 the income of farmers and assured support from DAC&FW to the farmers under PM *Kisan Samman Nidhi Yojana*.

DG, ICAR visiting the IARI thematic pandal

Honorable Secretary, DARE & Director-General, ICAR, Dr. T. Mohapatra, honouring a farmer with IARI Innovative Farmer Award

7.3.7 Participation in off-campus exhibitions

CATAT organised / participated in nine national/ international agricultural exhibitions for display/sale of IARI technologies, products, services and publications.

7.3.8 Training programmes organised

In total, 20 on-campus training programmes were organised for agriculture officials and Progressive farmers of different states. These programmes were attended by 514 participants from UP, Haryana, Uttarakhand, Punjab, MP, Gujarat, Rajasthan. Tripura, and NCR Delhi.

7.3.9 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.

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 IInd 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 and 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 and bio-fertilizers displayed at the centre.

In ATIC crop cafeteria, live demonstrations were laid out for *kharif* paddy varieties Pusa Basmati 1509, Pusa Basmati 1637, Pusa Basmati 1121, Pusa 1612, Pusa 2511 and Pusa 1401 (P.B.– 6), moong *var* Pusa Vishal, In *rabi* live demonstrations of wheat varieties: HD CSW 18, HD 3086, HD 2967 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. Pusa 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), Methi 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, Sadabahar,* Mint, *Tulsi* (Basil), lemon grass, Java citronella, Turmeric, *etc.*

New technological additions at ATIC:

1. One EPBAX machine with IVRS system installed at ATIC for Pusa helpline.
2. 20 LED display boards of IARI technologies have been fixed in the ATIC building corridor.
3. One POS machine has been fixed at ATIC for cashless transaction.

4. A model kitchen garden has been established in ATIC crop cafeteria having 18 types of winter and summer vegetables.

Visitors at ATIC during 2019

A total number of 32,251 farmers/ entrepreneurs, development department officials, students, NGO representatives *etc*. from 18 states of India visited ATIC during the year for farm advisory, diagnostic services, purchase of technological inputs/ products and trainings. Majority of the farmers (67.5%) visited ATIC to purchase / enquire about seeds / varieties followed by plant protection (18.5%), farm publication and others agro-advisory services (14%). A majority of them were from Uttar Pradesh (32%) followed by Haryana (18.5%), Delhi (16.5%), Rajasthan (13.5%), Punjab (10.5%) and others (9%). Besides, 8,620 farmers from 18 states were able to get information on various aspects of agriculture through PusaAgricom (A toll free Helpline Number-1800-11-8989), Pusa Help-line (011-25841670, 25841039, 25846233, 25803600) and Kisan Call Centre 1800-180-1551 (IInd level). Pusa seeds of the worth to ₹ 33,53,065/- and farm publication for to ₹ 33,600/- have been sold to the farmers during the year.

Four issues of *Hindi* farm magazine "*Prasar Doot*" were published by the centre during the reporting period. Besides, more than 700 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 stake holders.

7.3.10 *Krishi Vigyan Kendra*, Shikohpur, Gurugram

Honey Day cum training on Beekeeping: The *Krishi Vigyan Kendra* organized a farmers training on Beekeeping cum Honey day on March 26, 2019 at Farmers field at village Sakatpur, Gurugram. During this programme the rural youth and farmers were provided technical knowhow on beekeeping and motivated to take up this vocation as an entrepreneurial activity. This vocation help the farmers in two ways one- in generating income through sale of honey, wax etc. and second- enhancing the crop production through pollination by honey bees. A total of eight vocational training programmes in various areas were conducted.

Field days: Three field days on mustard crop under Cluster FLD programme, two field days on pigeon pea under CFLD, five field days on chickpea crop, two field days on pearl millet under FLD & OFT, two field days under OFT on Integrated weed management and on Integrated Nutrient Management in wheat were organized along with a Field Day under On Farm trial on diamond back moth management in cauliflower, one field day on summer moong. Various campaigns were held to create awareness including six days campaign on soil health & water sampling, four day

Cluster FLD programme on pulses

seed treatments campaign for the management of insect pests and diseases in *kharif* crops such as pigeon pea, green gram, cluster bean, cotton, bajra and jowar, three day campaign on soil health & water sampling.

Celebration of *Jal Shakti Abhiyan*: KVK organized *Melas* on *Jal Shakti* at Bilaspur village of Gurugram district & Hasanpur village of Nuh district on September 3, 2019, where in 841 & 837 farmers & students were participated, respectively. In both these *melas* the exhibition was organized. The basic theme of *mela,* was rain water harvesting and water conservation. A competition was organized among the students for models and posters on water conservation and water harvesting. The Chief Guest of *Melas* were Smt. Abhilasha Sharma, Asstt. Secretary, Ministry of Social Justice & Empowerment and Dr. A.R. Sen Gupta, Deputy Secretary, DARE, Govt. of India, respectively.

***Swachhata hi Sewa*:** It was organized under *Swacch Bharat Abhiyan* during September 11 to October 2, 2019. During *pakhwada*, the staff of KVK cleaned up the KVK campus including the administrative building, main road, lawns, farms and demonstration units. The KVK also organized awareness camps in nearby schools, *Anganwadi* centres and in the villages to sensitize the people about the importance of cleanliness in our life. The farmers were trained on the aspect of agriculture waste management and motivated to keep their home as well as surroundings clean. Animal health and hygiene was demonstrated to them. The women were told about maintaining hygiene during the whole process of cooking also make their children learn to follow the practice of hygiene and cleanliness.

National Animal Disease Control Programme: NADCP programme was organized at KVK Gurugram on September 11, 2019, where in 80 animals was vaccinated against FMD. Artificial Insemination was performed for 69 cattles with the help of Veterinary and Animal husbandry, Government of Haryana.

Celebration of Important Days: KVK celebrated important days such as International Women's Day, World Environment Day, International Yoga Day, *Mahila Kisan Diwas*, World Food Day, *Krishi Shiksha Diwas*, World Soil Day, *Kisan Diwas*, and *Kisanaur Vigyan Diwas.*

Celebration of *Mahila Kisan Diwas*

Celebration of *Kisan Siksha Diwas*

7.3.11 Transfer of technologies through IARI regional stations

7.3.11.1 Regional Station, Indore

Wheat Frontline Demonstrations (2018-19): Total of 22 demonstrations of five varieties were conducted in 11.80 ha area. These demonstrations were conducted in Indore and Dewas districts in M.P. Overall average increase in yield was 11 q/ha or 20 per cent in these demonstrations.

Wheat Demonstrations under TSP (2018-19): Total of 22 demonstrations of eight varieties were conducted in 11.80 ha area. These demonstrations were conducted at tribal Jhabua districts in M.P. Overall average increase in yield was 16 q/ha or 43 per cent in these demonstrations. Introduion durum wheat as health food was done for the first time.

Extension Activities during 2018-19 by KVK Gurugrame

Particulars/Activity	Number
Preparation of display exhibits viz. Posters and Banners *etc*.	65
Farmers group meetings organized (Field)	25
Kisan Mela / Field Day organized	2
Field Visits	65
Short Trainings for Farmers/ Extension officers and NGOs *etc*.	8
Visitors groups (Farmers/ Extension officers and NGOs)	54
Extension literature distributed to farmers, visitors & trainees.	14500
Participation in agricultural exhibitions / *Krishi Mela*	7
Number of farmers trained in "Wheat Production Technology"	3600
Answered farmers' phone calls	1280
News articles in National new papers	5
TV/ Radio Programmes/ Bytes	8
Popular articles	8

7.3.11.2 Regional Station, Pusa (Bihar)

Wheat Frontline Demonstrations: To reduce the yield gap between lab-to-land, 25 frontline demonstrations were laid out during the year 2019-20 in Dwarkanathpur and Mahmadpur Khaje of Muzaffarpur districts in Bihar. The demonstrations conducted were latest wheat variety DBW 187 (5) and HD 3086 on the use of bio-fertilizers- *Azatobactor* and PSB (15) and zero-tillage technology (5).

IARI Outreach Programme: In *rabi*, 2019-20 with a goal to popularize IARI wheat varieties among farmers under the IARI Outreach Programme on "Strengthening of wheat Programme in Eastern India", 750 minikits demonstrations of two timely sown wheat varieties HD 2967 and HI 1612 and three late sown wheat varieties HD 2985, HD 3118 and HI 1563 were laid out in 22 districts of Bihar, 2 districts of Jharkhand and 1 district of West Bengal through KVKs.

Exhibition and Participation in *Kisan Mela:* participated in four different *Kisan melas* from February, to December, 2019.

7.3.11.3 Regional Station, Karnal

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 viz*., PB 1509, PB 1121 and non-*Basmati* variety, Pusa 44, of worth ₹ 28.68 lakhs was sold to hundreds of farmers from Haryana, Punjab and Western Uttar Pradesh.

Off campus exhibitions/ Melas: participated in three *Krishi Mela*-cum-Exhibitions to display the technologies, products and publications of the institute.

7.3.11.4 Regional Station, Shimla

Field day/training: Disseminated IARI technologies to farmers of Chanju Panchayat of district Chamba (Himachal Pradesh) and provided three day training to 41 farmers of five Panchayats of Himachal for developing "*Vigyan Gaon*" under "Technological Interventions under *Vigyan Gaon* Scheme" through the project funded by HIMCOSTE. Farmers were trained on different techniques of orchard management and scientific cultivation of wheat and barley for increasing yield in their areas through adoption of new varieties. One exposure visit of farmers, two farmers' field school and one farmers' interest group meet were also organized.

Front Line Demonstrations: Five front line demonstrations on wheat variety HS 542 and 12 FLD on dual purpose barley variety BHS 380 were organized in different villages of Himachal Pradesh for their popularization among the hill farmers.

7.3.11.5 Regional Station, Kalimpong

Mera Gaon Mera Gaurav: The IARI (RS), Kalimpong has conducted numerous extension and technology transfer activities in the adopted villages under *Mera Gaon Mera Gaurav* programme. Total 26 training programmes, 18 demonstrations and 34 awareness

programmes covering 512 farmers were conducted. Improved technologies of IARI paddy varieties (PS 5, P1612), mustard varieties (PM 26, PM31, Pusa Vijay), vegetables (brinjal-chakra, beans-OP, pumpkin-OP, cabbage-Rare Ball F_1, cauliflower-Candid Charm, tomato-Romeo F_1, bottle gourd-OP) and planting materials of Darjeeling mandarin were distrebuted under the programme.

Tribal sub-plan: Under TSP, 3 awareness cum workshop was organized on "Doubling the income of tribal farmers: Strategies and Policies" with 250 tribal farmers of Jalpaiguri, Alipurduar and Kalimpong districts. The inputs like planting materials of Darjeeling mandarin, tomato hybrid seed, chilli hybrid seed, micro-nutrients, vermi-compost units and bio-fertilizer were distributed for demonstration.

7.3.11.6 Regional Station, Wellington

The IARI RS Wellington organised a Wheat Field Day at Chickusepalayam village in Kadampur block, Erode district. To popularize the wheat cultivation in non-traditional areas, 48 front line demonstrations were also conducted with wheat varieties HW 1098, HW 5207 and HW 5216 by IARI RS Wellington.

8. EMPOWERMENT OF WOMEN IN AGRICULTURE AND MAINSTREAMING OF GENDER ISSUES

Women are the backbone of agricultural workforce and are a vital part of Indian economy. Over the years, there is a gradual understanding of the key role of women in agricultural development and their contribution in the field of agriculture, food security, horticulture, dairy, nutrition, sericulture, fisheries, and other allied sectors. Despite of their importance in Indian economy, they are worst hit in terms of malnutrition. They are more likely to be underweight than men, especially those living in rural areas. With various targeted efforts, a number of interventions were carried out for mobilizing women into self help groups (SHGs), entrepreneurial development, seed production, vocational trainings etc. for their empowerment. Women play an important role in producing diverse, nutritious food and in enhancing household nutritional security and hence their capacity building is essential.

8.1 A NUTRITION LED EXTENSION MODEL OF COMMUNITY AGRI-NUTRI SECURITY CENTRES (CANSCS) FOR NUTRITION SECURITY OF WOMEN

Division of Agricultural Extension, ICAR-IARI in collaboration with DST initiated a project entitled "A Nutrition led Extension Model of Community Agri-Nutri Security Centres (CANSCS) For Nutrition Security of Women". CANSCs highlight how important it is for women to develop skills in preparing value added agri-nutri products and to be financially independent to address malnutrition. These centres act as a forum not only to conduct capacity building activities, but also 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.

Under CANSCs, appropriate machineries have been procured and set up in Lahchoda and Mukari villages of Baghpat district (U.P.) and rural women are trained in processing and making value added agri-nutri products. Adding value to the primary produce like green leafy vegetable, carrots, spinach, amla, curry leaves *etc* by drying them using solar dryer, preparing multi grain nutri cookies by using oven, soy nuts by using spice coating pan *etc* is the main activity of these centres. In these centers, rural women were trained in preparing value added nutri products such as soy nuts, dried moringa leaves, curry leaves, aonla candies, fruit candies *etc*. In addition to creating income generating activities, it has benefits like preventing post-harvest losses and act as a helping hand to restore nutritional security in rural areas. If the locally available produce are processed and packed in an attractive way, labelled with their nutritional facts, then, there will be ample avenues to get good prices. This will not only increase the income of rural women but also will indirectly aid in increasing households' nutritional security. Slowly bringing nutri foods and snacks in the consumption basket will counteract vitamin deficiency and malnutrition problems in rural areas. Ultimately, the target group will be empowered nutritionally, which is an important Sustainable Development Goal (SDG) to be achieved.

Project team in CANSC Centre, Lahchoda, Baghpat (U.P.)

8.2 SKILL BUILDING IN NUTRITION SENSITIVE AGRICULTURE (NSA) FOR EMPOWERMENT OF RURAL WOMEN

In collaboration with DBT, Division of Agricultural Extension, ICAR-IARI initiated a Project entitled "Skill Building in Nutrition Sensitive Agriculture (NSA) for Empowerment of Rural Women". The objective of the project is to integrate agriculture with nutrition. This project has been launched in four villages namely Bassi and Sunnehda from Baghpat, Uttar Pradesh and Hasankala and Jagdishpur from Sonipat district, Haryana. 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 target group. Thus, a survey on socio-economic, demographic and nutritional status of rural women in the project location has been conducted. Food consumption pattern and dietary diversity was measured (for both women and children) based on FAO methodology. Dietary diversity is an important indicator which is used for measuring nutrient adequacy. Simpson Index of Dietary Diversity (SIDD) was calculated to know the richness and variety of food items consumed. The SIDD scores ranged from 0.55 to 0.66. Slightly higher SIDD scores were found in Bassi than their counterparts. By keeping in mind, a total number of 6 trainings of three days each have been conducted in order to diversify their food basket. Efforts were made to highlight the importance of nutri products, including it in their food plates which may ultimately help in tackling malnutrition.

Rural Women participated in training of Nutrition Sensitive Agriculture

8.3 EFFECTIVENESS OF SHGS FOR GENDER EMPOWERMENT

Self Help Groups (SHGs) have been instrumental in women empowerment by enabling them to work together. Three SHGs named "Nai Pahal" (village- Shikohpur), "Naya Din (village- Harinagar) and Nari Shakti (village- Khwaspur) of Gurugram district which were covered under ARYA project and given training on value addition in March 2018 started their small enterprise at their own village. During 2019, the groups prepared various products of aonla like juice, squash, powder, pickle, candy, *murraba etc.* and pickles of other seasonal fruits and vegetables, potato chips, soynut, *bajra laddoo*, soy *laddoo* and earned an average annual income of ₹ 2.5-3 lakhs per SHG.

In January 2019, 40 women from 4 different villages (10 women from each village) were given 21 days training on "Food processing, preservation and value addition" under ARYA project and given support in the form of machines and utensils to help them start their own enterprise. A total of 4 groups namely "Prajapat" (village- Tajnagar), "Ekta" (village- Tajnagar), "Pragati" (village- KherkiMajra) and "Muqabala" (village- GarhiHarsaru) were helped to get FSSAI registration and linked with NRLM scheme of DRDA, Gurugam to get stalls in various melas organized in Haryana and other states of India which help in direct marketing as well as publicity of their products. During the year, Pragati SHG has sold their products worth ₹ 2.5 lakhs through various *melas* viz. Trade fair in Delhi, Geeta in Gurugram; Saraswati *Mahotsava* in Kurukshetra and Sarasmela in Jodhpur and thereby earned a net profit of ₹ 1.25 lakhs.The other three groups also earned a net profit of ₹ 1.0 to 1.8 lakhs by direct marketing The SHG entrepreneurial activity resulted in economic upliftment of the group members, leadership skills in managing the group, developed courage to think independently and inculcated great confidence in the members to succeed in their day to day life.

A review meeting under ARYA project

8.4 CAPACITY BUILDING FOR GENDER EMPOWERMENT

Evaluation of paddy cultivation practices (paddy transplanting, harvesting and threshing activities) on the basis of physiological and psychological ergonomics parameters was done in CATAT project village Rajpur, Aligarh (UP). Evaluation was done on the farm women who were regularly involved in farm operations in the age group of 25 to 45 years with normal health without any major illness. To evaluate the drudgery, Heart Rate, Blood Pressure, Energy Expenditure Rate, Total Cardiac Cost of Work, Physiological Cost of Work, Blood Pressure and Human Physical Drudgery Index for estimation of fatigue were recorded. For transplanting activity by traditional method, resting heart rate of 81.52 b/min increased up to 128.78 b/min with associated EER 11.75 (kJ/min), TCCW 728.68 beats and PCW as 48.53. The paddy harvesting and threshing activities were also evaluated and values of TCCW were 682 and 829.4 and PCW were 45.46 and 55.29 respectively. Transplanting activity was found most tedious operation which is generally performed by women in upright bending posture. To reduce drudgery of women farmers, suitable interventions like rest pause for breaking prolong work cycle and paddy trans planter as improved ergonomic intervention were suggested.

A hand on training on value added products of tomato (sauce, chutney, paste and soup) and Amla (candy, pickle, powder, supari, jam and squash) was conducted for capacity building of women farmers at village Rajpur, Aligarh.

Training on 'Preservation of fruits and vegetables at CATAT

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, 4162 M.Sc., 54 M.Tech. and 4885 Ph.D. students have been awarded degrees including 463 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 2019-2020

The PG School continues to attract students seeking admission to 26 disciplines in all five streamsof admission, namely, Open competition, Faculty upgradation,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 2019-20, 191 students (including 04 physically handicapped) were admitted to M.Sc./M.Tech. and 266 students (including 08 Physically Challenged, 10 ICAR in-service, 02 under faculty upgradation scheme and 03 under departmental technical scheme and 05 under CWSF) to Ph.D. courses. For PG outreach programme at sister institutes, 14 students for CIAE, Bhopal and 12 students in IIHR, Bengaluru were admitted. In addition, 11 international students (06 M.Sc. & 05 Ph.D.) from 09 foreign countries were admitted. At present, the total number of students on roll is 1298 (329 M.Sc., 22 M.Tech. and 947 Ph.D.), which include 37 international students (10 M.Sc. & 27 Ph.D.) from 19 foreign countries. During 2019-20 academic session as per the Govt. of India guidelines 10% reservation for the economically weaker section was adopted and M.Sc./M.Tech. and Ph.D. students were admitted under this category.

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 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

Lal Bahadur Shastri Memorial Lecture: The 49th Lal Bahadur Shastri Memorial Lecture was delivered by Dr. Renu Swarup, Secretary, Department of 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.

Foundation Day Lecture: The Foundation Day Lecture was delivered by Dr. Shekhar C. Mande, Secretary, DSIR & DG, CSIR on April 1, 2019. Dr. Trilochan

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

Mohapatra, Secretary (DARE) & Director General (ICAR), New Delhi presided over the function and distributed IARI Best Worker Awards to the staff of IARI for motivation

Dr. B.P. Pal Memorial Lecture: The 26th Dr. B.P. Pal Memorial Lecture was delivered by Dr. Ajay K. Sood, Honorary Professor, Indian Institute of Sciences, Bengaluru on the topic "Why do We Flock Together: A Physicist's View" on May 27, 2019. Dr. Trilochan Mohapatra, Secretary (DARE) & Director General (ICAR), New Delhi presided over the function.

Teachers' Day Lecture: The Teachers' Day Lecture 2019 was organized jointly by the P.G. School, and the Genetics Club, IARI on September 5, 2019. The dignitaries paid tributes to Dr. S. Radhakrishnan, the great philosopher, philanthropist and ex-President of India. On this occasion, Dr. D.P. Singh, Chairman, University Grants Commission, New Delhi delivered a lecture on the topic "Quality Higher Education". Prof. A.K. Misra, Chairman, ASRB New Delhi presided over the function.

Agricultural Education Day Lecture: The Agricultural Education Day Lecture was delivered by Dr. R.B. Singh, Former Chancellor, CAU, Imphal on the topic "Transforming Agricultural Education to Build New India" on December 3, 2019. Dr. A.K. Singh, DDG (Agril. Extension), ICAR and former Director (IARI), New Delhi presided over the function.

Dr. Renu Swarup delivering 49th Lal Bahadur Shastri Memorial Lecture

9.1.4 International Exposure

The excellence of IARI is recognized internationally. IARI has played a key role in the establishment of i) Afghanistan National Agricultural Sciences and Technology University (ANASTU), Afghanistan; and ii) Advanced Centre for Agricultural Research and Education (ACARE), Yezin Agricultural University, Myanmar.

ANASTU programme: Under ANASTU programme, IARI has imparted the teaching and research guidance to three batches of M.Sc. (Agronomy) students. The teaching of the third Batch of 20 M.Sc. Agronomy students of ANASTU was conducted at the IARI from December 1, 2018 to August 1, 2019. On the completion of courses, a valedictory function was organized on August 2, 2019 for Grade Card distribution. On the request of ANASTU, syllabi for the ANASTU M.Sc. courses on Agricultural Economics, Plant Protection and Horticulture have been developed with the help of Professors at IARI, New Delhi, and syllabus for a course on Animal Husbandry has been developed with the help of Professors at IVRI, Izatnagar. Besides, the 1st batch of M.Sc. students of ANASTU in the fields of Horticulture, Plant Protection, and Animal Husbandry arrived to India on September 28, 2019. The Animal Husbandry students proceed to IVRI, Izatnagar, and the Horticulture and Plant Protection students are being imparted teaching/training at IARI, New Delhi.

ACARE programme: Under the ACARE programme, to strengthen the postgraduate education and human resource development, IARI in collaboration with YAU conducted the following activities.

- Overhauled and upgraded the postgraduate (M.Sc. & Ph.D.) course curriculum for all the existing disciplines as well as the newly introduced disciplines of Agricultural Extension (AE), Food Engineering & Technology (FET) and Molecular Biology & Biotechnology (MBB) under the ACARE programme.
- Admitted 21 M.Sc. (8 in AE, 6 in FET & 7 in MBB) and 6 Ph.D. (all in FET) in the academic session 2018-2019.

- Faculty from different ICAR institutes delivered a total of 26 postgraduate courses in the academic session 2017-2018 and 24 postgraduate courses in the academic session 2018-2019 to the newly admitted students of the three newly introduced disciplines under the ACARE programme.
- Four faculties from ACARE (1 each in AE & MBB + 2 in FET) have completed their M.Sc. programmes at IARI in the academic session 2018-2019.

In addition to the above, IARI has developed the following facilities at ACARE: Twelve state-of-art laboratories (including requisite laboratory furniture, equipment, glassware, plasticware & consumables) for contemporary research in the fields of Molecular Biology & Biotechnology and Post Harvest Technology; state-of-art cold storage cum ripening chamber, controlled atmospheric storage chambers and silo for grain storage; One library containing relevant furniture and books; Tractor and farm implements; and Studio and video conferencing facility for contemporary research in the field of Participatory Knowledge Management (Agricultural Extension).

9.2 LIBRARY AND LEARNING RESOURCES

Prof. M.S. Swaminathan National Agricultural Science Library, established in 1905 with a collection of 5,000 publications is now the largest agro-biological library in south-east Asia housing more than 4 lakh publications comprising scientific journals, research bulletins, monographs, post-graduate theses, scientific reports, reprints and other reference materials. It has more than 2,000 members which include students, scientists and technical staff. More than 1,000 documents are consulted every day. The Library functions as the depository of Food and Agricultural Organization (FAO), and Consultant Group of International Agricultural Research (CGIAR) institutes' publications. The library is well equipped with student facility wing/reading halls having 15 PCs with Wi-Fi connectivity, internet and e-mail facility for the convenience of the readers. The Library received (i) Best usage of J-Gate @ CeRA award (Northern Region) and (ii) Wiley Library Award 2019 for highest usage of Wiley Journals – 2019 CeRA consortium Agriculture.

9.2.1 Acquisition Programme

9.2.1.1 Books

During the period of report the library received 1638 publications which includes 335 in Hindi books, 848 English books and 109 Advances & Annual Review. The Library also acquired 37 gift publications, 309 IARI Thesis. Uploaded CDs of 250 Thesis (Soft copy) in Krishikosh.

9.2.1.2 Serials

The Library received 1600 journals/serials through subscription, gifts and exchanges, subscribed to 43 foreign journals and 72 Indian journals 7 online journals 448 newsletters, gifts 60 titles and. Received 92 annual scientific/technical reports/bulletins of different institutions in the Library during report period.

9.2.2 Document processing

Total number of document processed 1537 consisting of 848 books, 309 post-graduate IARI thesis, Bulletins 45 and 335 Hindi books were processed in 2019 (classifying and cataloguing).

9.2.3 Resource Management

9.2.3.1 Reference, circulation and stack maintenance

Apart from 2400 registered members, the Library served 100 to 150 users per day who comes from different agricultural universities/ICAR Institutes who consulted approximately 400 to 600 documents every day. Registered 492 new members (23 staff and 464 students). During the period under report 714 publications were issued and 737 publication returned. Under the Inter Library Loan System 16 documents were issued to various institutions. 343 No dues Certificate were issued.

9.2.4 Rashtriya Krishi Hindi Pustakalaya

The library has got the status of Rashtriya Krishi Hindi Pustakalaya, and has approx 9734 books and approx 3000 journals on agricultural in Hindi.

9.2.5 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 4,04,068, total login session 48,196, searches 1,79,784, full text and abstract views 80,086. Total number of DDR request received 843 in last five year's through CeRA and requested articles uploaded in J-Gate.

9.2.6 PGS 501 Course

The Library is involved in the Post Graduate teaching programme with one credit compulsory course entitled PGS 501 (0L +1P) 'Library and Information Services' for M.Sc. & Ph.D. students of all discipline. Classes are conducted in all the three trimesters of the year. The objective of this course is to train the students to search the literature of their interest & literature search tools and given exposure for proper utilization of library resources / e-resources and to fulfill the growing needs of the scientific and user community.

9.2.7 Library Automation

The library has following automation services:

1. Bar coding of publications 2. Retro-conversion of bound volumes of journals and their bar coding 3. Digitization of IARI/ICAR theses. 4. Scanning of abstract/summary pages of each thesis, making the PDF file and making the database searchable 5. Creation of membership database and preparation of RFID bar coded library membership cards 6. Development of infrastructure hardware/software, and bandwidth and internet 7. All in-house technical activities are computerized using LIBSYS/ Koha SOFTWARE.

9.2.8 Krishikosh

Krishikosh provides ready software platform to implement all aspects of the open access policy, similar to 'Cloud Service' for individual institution 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 December 2019 library uploaded 5193 thesis in Krishikosh.

9.2.9 E-Language Lab

With the help of library Strengthening program Language lab was established with seating capacity of about 50 participants to facilitate English language classes for IARI foreign/ Indian students with modern facilities like 30 computers with internet facility, interactive board, visualizes, interactive panel, head phones etc. Time to time the language lab is also used for conducting trainings, PGS 501 Course, Summer and Winter School Courses of different divisions and Directorate for the benefit of Scientists/Technical staff.

9.3 AGRICULTURAL KNOWLEDGE MANAGEMENT UNIT (AKMU)

Currently, besides Bioinformatics activities, the Unit is entrusted with responsibility of developing ICT in agricultural research, maintaining and updating the Institute's website, Data centre and network management, ASRB Online examination centre, and MIS/FMS implementation. During the reported period the unit developed (i) Weather based prediction system for pests, (ii) Modified the web enable system (http://14.139.56.94/ccrpp) for prediction of models as well as data uploading, (iii) Developed the districts wise forecast models using Satellite based derived products (spatial data) for forecasting wheat yield (kg/ha) for 15 districts of UP, and (iv) maintenance and updating Krishikosh – a Digital Repository for NARES and also developed batch uploading and keyword extraction tools.

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	446
b)	Symposia/conference papers	325
2. Books/Chapters in Books		
a)	Books	17
b)	Chapters in books	172
3. Popular Articles		260

10.2 IN-HOUSE PUBLICATIONS

10.2.1 Regular Publications (English)

- IARI Annual Report 2018-19 (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 (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)
- Manual on Transmission of Plant Viruses and Phytoplasmas by Insect Vectors (ISBN 978-93-83168-50-7)
- Impact of Cluster Frontline Demonstration on Pulses in Northern India (ISBN 978-93-83168-51-4)
- 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)
- SOUVENIR: Central India- Perspective and Prospects of Wheat Research and Development (TB-ICN: 215/2019)
- Evolution of Proteomics – Uses in Agriculture-Towards Next Decade (TB-ICN: 216/2019)
- F4F: Food for Future - Millets: Key Supplements to Staple Grains (TB-ICN: 217/2019)
- Current Trends in Wheat and Barley Research and Development (TB-ICN: 218/2019)
- Hands on Training Manual on Scientific Bee Keeping (TB-ICN: 219/2019)
- Genomics Assisted Molecular Systematics of Fungi (TB-ICN: 220/2019)
- Omics Meet Plant Biochemistry: Applications in Nutritional Enhancement with One Health Perspective (TB-ICN: 221/2019)
- Genomics of Agriculturally Important Insects (TB-ICN: 222/2019)
- Biochemical Methods to Assess the Nutritional Quality in Pearl Millet (TB-ICN: 223/2019)
- POSHAN-II Pearl Millet Oriented Substitution for Healthy all Inclusive Nutrition (TB-ICN: 224/2019)
- Genomics Assisted Breeding for Crop Improvement (TB-ICN: 225/2019)
- Genome Assisted Diagnosis of Plant Viruses, Viroids and Phytoplasmas (TB-ICN: 226/2019)
- Breeding and Genomic Tools for Stress Resistance in Vegetable Crops (TB-ICN: 227/2019)
- Screening Technique for Stress Resistance in Vegetable Crops (TB-ICN: 228/2019)
- Seed Production and Quality Evaluation (TB-ICN: 229/2019)
- Omics Tools and Techniques for Nutritional Evaluation and Enhancement (TB-ICN: 230/2019)
- Genotyping of Whitefly Species Complex and its Associated Endosymbionts (TB-ICN: 231/2019)
- Plant Disease Monitoring for Timely Management Options (TB-ICN: 232/2019)
- Seasonal Climate Change scenario for India: Impacts and Adaptation Strategies for Wheat and Rice (TB-ICN: 233/2019)
- Genome Editing of Crops: Methods and Applications (TB-ICN: 234/2019)
- Pathophenotyping and Genome Guided Characterization of Rust Fungi Infecting Wheat and Other cereals (TB-ICN: 235/2019)
- Nutrient Dence Pigmented Rice: A Diet for Healthier People (TB-ICN: 236/2019)

10.2.3 fu;fer i=dk'ku ¼fgUnh½

- पूसा सुरभि (वार्षिक) (ISSN : 2348-2656)
- वार्षिक रिपोर्ट 2018–19 (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 rduhdh i=dk'ku ¼fgUnh½

- अध्येता एवं नवोन्मेषी किसान (ISBN 978-93-83168-43-9)
- पूसा उन्नत कृषि तकनीकी (ISBN 978-93-83168-46-0)
- गुणवत्तायुक्त बीज हेतु उचित कृषि क्रियायें (ICN :H-169/2019)
- वार्षिक कृषि कार्य एवं उन्नत प्रौद्योगिकियाँ (ICN :H-170/2019)
- फल व सब्जियों के मूल्यवर्धन की सरल विधियाँ (ICN: H-171/2019)
- पोषण और खाद्य सुरक्षाः आहार के नवीन आयाम एवं चुनोतियाँ (ICN :H-172/2019)
- खाद्य तथा पोषण सुरक्षा हेतु गेहूं की नवीन प्रजातियाँ (ICN: H-173/2019)

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 period, the Unit has organized following activities:

Glimpse of 'Technology Innovation Day', organized by ZTM & BPD Unit on August 30, 2019

11.1. TECHNOLOGY COMMERCIALIZATION

During the year 2019, under '*Lab to Land'* initiative, five (05) technologies of ICAR-IARI were transferred to 126 industry partners, resulting in total revenue generation of ₹ 80,38,840 (₹ Eighty Lakh and Thirty Eight Thousand Eight Hundred Forty only). The technologies transferred include Maize Hybrid Pusa Jawahar Hybrid Maize-1 (PJHM-1) and also Wheat varieties HD 3226 and HD 3086.

On August 30, 2019, the Unit organized the 'Technology Innovation Day', with participation from Small and Medium Enterprises (SMEs), seed companies. A total of 38 Licensing Agreement for single wheat variety HD 3226 were signed with SMEs. Wheat variety HD 3226 has been licensed to 70 industry partners.

11.2 INTELLECTUAL PROPERTY RIGHTS

During 2019, four (4) patents are granted, two (2) new patent applications, two (2) trademark applications and two (2) copyright applications have been filed.

Application No./ Registration No./ Grant No.	Name of Innovation/ Technology/ Product/ Variety	Date of Filing/ Registration/ Grant	Application Filed/ Granted/ Registered**
Patent			
201911014982	Natural carrier based anthocyanin formulation for targeted release in Git and process thereof	April 15, 2019	Filed
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, 2019	Granted
2053/DEL/2011 (313550)	Pigeonpea pod stripper	May 30, 2019	Granted
989/DEL/2014 (316692)	Nanofabrication of Phosphorus on kaolin mineral receptacles	July 24, 2019	Granted
3130/DEL/2012 (321722)	Heat stable anthocyanin rich composition and process of its preparation	September 27, 2019	Granted
201911051754	The 3' polymorphic primers for species-specific detection of begomovirus	December 13, 2019	Filed
Copyright			
15720/2019-CO/SW	InfoCrop v2.1	October 04, 2019	Filed
18536/2019-CO/SW	Irrigation and Fertigation Scheduler (IFSHED)	November 21, 2019	Filed
Trademark			
816491	IARI (Well Known Mark)	December 26, 2019	Filed
816492	PUSA (Well Known Mark)	December 26, 2019	Filed

11.3 AGRIBUSINESS INCUBATION

Incubation Activities

The year of 2019 yet again demonstrated the endeavour of ZTM & BPD Unit to amplify its capability and capacity as one of India's top agribusiness incubator. Further, a new foundation has been laid by coining the name of the incubator as Pusa Krishi Incubator, ZTM & BPD Unit, ICAR-IARI. This year, the Unit has become the 'Knowledge Partner 'in RKVY-RAFTAAR Scheme of Ministry of Agriculture & Farmer's Welfare, Govt. of India. Pusa Krishi Incubator has assisted the department in selecting twenty-four RAFTAAR-Agribusiness incubates and streamlining the procedures for agribusiness incubation. As aknowledge partner, the Unit has been bestowed with the opportunity to help 9 RABIs regularly in aligning their incubation policies and procedure to the set guidelines. The names of nine RABIs are as follows:

S.No.	Name of the RABI
1	Chaudhary Charan Singh Haryana Agricultural University, Hisar
2	ICAR-IVRI, Bareilly, Uttar Pradesh
3	IIM, Kashipur, Uttarakhand
4	IIT-BHU, Varanasi, Uttar Pradesh
5	CSK Himachal Pradesh Kirsh Vishwavidyalaya, Palampur, Himachal Pradesh
6	Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chattisgrah
7	Jawaharlal Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh
8	Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu & Kashmir
9	Punjab Agricultural University, Ludhiana, Panjab

The team of Pusa Krishi Incubator visited the campuses of nine RABI Incubators under its charge,

to help the staff of RABIs in organizing the bootcamps intended for their respective incubation proggrames. Also, the teampanelled in themeeting set for the selection of the incubates recommended for funding from RKVY RAFTAAR.

Programmes: The unit has launched various programmes for the development of the agribusiness incubation ecosystem.

1. SAMARTH – Innovation and Incubation Induction Program is a sector-focused and a year-long professionals training programme designed to train Scientists, PIs, Incubator Managers and other professionals from twenty-eight (28) established and new agribusiness incubators supported under RKVY-RAFTAAR scheme of MoA & FW. Under this initiative, a series of four workshops have been conducted and 174 agri-professionals were trained from 23 states. The details of the workshops organised are mentioned below:

Samarth	No. of Institute participated	Participation	Date	Theme and Focus
Workshop 1	28	45	11 to 13 February, 2019 at Virology Auditorium, ICAR-IARI, New Delhi	Innovation and Incubation Induction Program. It was focused on incubator planning and management.
Workshop 2	27	48	7 to 9 May, 2019 at NASC, Complex, New Delhi	Partnership and Prosperity for All: Planning and execution of the programme
Workshop 3	19	31	12 to 13 September, 2019 at NRL Auditorium, ICAR-IARI, New Delhi	Agri-Incubator Management Training Program: Specific for the Incubator Manager
Workshop 4	27	50	18 to 20 November, 2019 at NASC Complex, New Delhi	SAMARTH Review & Planning Workshop

Glimpses of SAMARTH

2. 'ARISE-Launchpad for Agri Startups' is an 'Agripreneurship Orientation Program', organized for idea/prototype stage startups to help develop their market-fit Minimum Viable Product (MVP). Out of the 422 applications received, 24 startups were selected. The 2-month in-residence incubation programwas organised from May 13, 2019 to July 12, 2019, with the purpose to make selected incubates well acquainted to various components of business management *i.e.*, company formation, financial prepositions, marketing strategy, accounting, tax planning, *etc.* with focus on their respective sector. A grant-in-aid support has been recommended to 15 startups.

The orientation programme included various panel discussions with corporate experts to discuss the threats, challenges, and opportunities present in India's agribusiness industry, along with business modelling & go-to marketing strategy. The cohort also visited facilities of IARI, NBPGR and Startup India. During the Arise programme, startups were also provided with a platform to showcase their innovations in ICAR Foundation Day, which is beneficial to the marketing & networking aspects of their agri-ventures. For greater media exposure at a national level, Pusa Krishi Incubator collaborated with the national television channel DD Kisan to feature its startups on its programme VAAD SAMVAAD. The purpose of the episode was to introduce the new-age technologies and services offered by the startups. On successful completion of a 2-month Residency Programme, avaledictory and graduation ceremony for startups was organized and the incubates were awarded 'Certification of Completion' .

3. 'UPJA – Launchpad for Lab to Market' is an incubation program for the startups at a Minimum Viable Product (MVP) stage. Out of the 610 applications received, only 30 agri start-ups were selected from various agriculture domains, *i.e.* from

Glimpses of ARISE 2019

'farm to fork'. Under this programme, a two-month in-residency workshop was conducted for the incubates to provide them a 360 degree perspective on business operations through adept mentoring in managerial, technical, financial, ethical and IP issues. They were also provided the opportunity to connect with regional farmers, industry experts, and professionals, as well as other agri startups to steadfast various stages of their product development and get it market-ready. Out of the 30, 18 startups were funded with a grant-in-aid of upto ₹ 25, 000,00 through RKVY-RAFTAAR scheme. Also, a special event was organized in which exchange of MoA with 18 incubates under the UPJA program that are recipients of funding under the RKVY-RAFTAAR scheme. The agreement signing ceremony was honoured with the keynote address of Dr. Trilochan Mohapatra, Secretary, DARE and DG, ICAR.

4. Maitri - Indo Brazil Agri-Tech Cross Border Incubation Program is a first-of-its-kind international cross-incubation program in agriculture, organized in collaboration with Embassy of Brazil, New Delhi and ICAR-IIMR in Hyderabad, funded by Department of Science and Technology. In this six-month long program, five Brazilian and five Indian start-ups at the stage of commercialization were selected together, to be trained in India and Brazil. From 9 to 21 December 2019, a two-week incubation workshop was organized for 10 selected startups at New Delhi and Hyderabad. It also explores the promotion of cross border trade, technology transfer, Joint venture opportunities and collaborations in innovation an research.

The Delhi-Chapter of the workshop was organized to introduce the Indian and Brazilian agri-startups to the contemporary agri-tech innovation scenarios in both the countries, respectively. Numerous mentoring sessions were held on varied topics like; 'Smart Agriculture', 'Panel session on Regulatory & Compliances', 'Agri-Fintech Scenario', 'Startup-Farmer Dialogues', 'Speed Dating with Investors' and one-two-one business mentoring sessions with leading agri-corporates. The on-field activities included a visit to NDRI, Karnal and conversation with progressive farmers on their field. The Hyderabad-Chapter focussed on giving flavour of visit to renowned Incubators/ facilities of IIMR, MANAGE, NAARM, ICRISAT, CCMB, IIIT, ICAR-NRC Meat, ICMR- NIN and accelerator like T-Hub to explore synergies and future associations.

Maitri - Indo Brazil Agri-Tech Cross Border Incubation Program

5. IP Spectra

The Intellectual Property Facilitation Centre, *i.e.* IP Spectra established by M/o MSME at ZTM & BPD Unit, ICAR-IARI has proactively worked on Intellectual Property Protection of the inventions of its Start-ups and other enterprises. Among the various tasks handled by the IP Spectra in terms of providing IP assistance to the third-parties, in the FY 2019-2020, two (2) patent applications and nine (9) trademark applications have been filed.

Other Activities

A. Startup to Corporate: Pusa Krishi Incubator is hosting a series of 'Startup to Corporate' – a flagship

program between startups and corporates to explore the synergies between innovation and entrepreneurship. Second in series was held on May, 30, 2019 at NASC Complex, IARI-Pusa. The workshop helped them to understand the cores of consumer psychology, characteristics of the developing markets and business management in Indian agricultural space.

B. Startup Farmers Dialogue: To give startups a ground-level experience with farmers, on May 29, 2019, Pusa Krishi incubator organized a special visit to a farmer's community in Shikarpur, a village located in the Bulandshahr district of Uttar Pradesh. The objective of this exercise was to sensitize startups with the real-time problems of the farmers, their expectations and usage behaviour with regards to new innovations and technologies. More than 80 farmers voluntarily gathered for the meeting including opinion leaders, large farmers, influencers and village leaders. The visit enriched incubates with useful insights and critical feedback from the farmers.

C. IP Management: Apart from its incubation activities, the unit has filed the applications for IARI logo and PUSA well known mark, a notable achievement.

Corporate Membership

ZTM & BPD Unit manifests its avidity to create a strong and meaningful relationship with the industry and commercial enterprises for dissemination of the seed varieties of IARI, with the objective to benefit the society and farmers. The unit welcomes partnership through 'Corporate Membership'. In total, 312 corporate members have been enrolled so far in the FY 2019-2020, generating a revenue of ₹ 13,32,000 (Rupess Thirteen Lakh Thirty Two Thousand) only.

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, centers, 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-the-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 on 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 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.

In 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, Bengaluru and CIAE, Bhopal. The institutes is helping in the establishment of two IARI like institutions 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 and plant breeding, 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.*

International Cooperation

The Division of Fruits and Horticultural Technology is the Registrar, International Crop Registration Authority for Mango Varieties affiliated to the Royal Horticultural Society-ISHS Special Commission for Cultivar Registration, Belgium. Similarly, the Division of Floriculture and Landscaping is the Registrar for Bougainvillea.

The number of externally funded projects in operation during the period from 1.1.2019 to 31.12.2019 is given below:

Funding Agencies	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)	216
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, International Rice Research Institute, (IRRI), Centre for Agriculture and Bioscience International (CABI), United Kingdom, HarvestPlus-International Food Policy Research Institute, (HPIFPRI), USA, JIRCAS, Japan, HarvestPlus Consortium IFPRI Washington, USA	13
Total	**229**

13. AWARDS AND RECOGNITIONS

- Team Brassica (Drs. D.K. Yadava, Sujata, K.V. Prabhu, T. Mohapatra, B. Dass, S.C Giri, S.K. Yadav, A.K. Yadav, Raj Kumar, Raj Kumar, Karnal) was awarded with 'ISGPB appreciation certificate' for landmark variety 'Pusa Mustard 25'.
- Team Brassica (Drs. D.K. Yadava, Sujata Vasudev, Naveen Singh, K.V. Prabhu, S.K. Yadav, M.S. Yadav, Rajkumar, B. Dass, S.C. Giri and Rajendra Singh) were awarded with 'ISGPB appreciation certificate' for landmark variety 'Pusa Mustard 30'.
- Dr. D.K. Yadava, Head, Division of Seed Science and Technology was awarded with 'NAAS Recognition Award' for Genetic improvement of rapeseed mustard.
- Nanaji Deshmukh ICAR Award for Outstanding Interdisciplinary Team Research in Agricultural and Allied Sciences 2019 (Drs. M. Sivasamy, Sanjay Kumar, Vikas, V.K., P. Jayaprakash, T.R. Das).
- Dr. K. Annapurna, Head, Division of Microbiology awarded (i) Excellence Award in PGPR Research-Asian PGPR Society, and (ii) INSA Visiting Scientist-2018, Germany.
- Dr. Radha Prasanna, Professor, Division of Microbiology awarded with Fellowship of the Academy of Microbiological Sciences (FAMSc).
- Dr. Govind P. Rao, Principal Scientist, Division of Plant Pathology awarded with Prof. S.N. Das Gupta Memorial Award of Indian Phytopathological Society.
- Dr. Lata, Principal Scientist, Division of Microbiology awarded with Prof. Ramalingaswamy Award (AMI).
- Dr. Dinesh Singh, Principal Scientist, Division of Plant Pathology was elected Fellow of Indian Mycological Society, Kolkata.
- Dr. M. S. Saharan, Principal Scientist, Division of Plant Pathology awarded with Sh V.P. Gokhale Award.
- Dr. Lakshman Prasad, Principal Scientist, Division of Plant Pathology was elected Fellow of Indian Phytopathological Society (IPS).
- Dr. T.K. Das, Professor, Division of Agronomy was elected NAAS Fellow.
- Dr. Y.S. Shivay, Principal Scientist, Division of Agronomy received Bharat Ratna Dr. C. Subramaniam Award, ICAR.
- Dr. R.R.Sharma, Principal Scientist, Division of Food Science & Post Harvest Technology (i) elected NAAS Fellow, (ii) Dr. J.C. Anand Medal, IAHS and (iii) Pusa Pravakta award of IARI.
- Dr. Gopala Krishnan S, Principal Scientist, Division of Genetics was elected Fellow of the ISGPB, New Delhi.
- Dr. Vikas V. Scientist, IARI-Regional Station Wellington was elected as NAAS Associate.
- Dr. Atul Kumar, Principal Scientist, Division of Seed Science and Technology awarded with Prof. S. Sinha Memorial Award.
- Dr. S.K. Yadav, Principal Scientist, Division of Seed Science and Technology awarded with ISST Scientist of Eminence Award-2018.
- Dr. (Mrs.) Anuja Gupta, Principal Scientist, IARI Reginal Station, Karnal elected Fellow of Indian Phytopathological Society (FPSI).
- Dr. Neeru Bhushan, Incharge & Principal Scientist, ZTM&BPD Unit awarded with Rashtriya Icon Award.

- Dr. Jai Prakash, Principal Scientist, Division of Fruits and Horticultural Technology awarded Sh. D.P Ghosh Young Scientist Award of IAHS.
- Dr. R.M. Sharma, Principal Scientist, Division of Fruits and Horticultural Technology elected Fellow of the Indian Society for Arid Horticulture.
- Dr. O.P. Awasthi, Professor, Division of Fruits and Horticultural Technology elected Fellow of the Indian Society for Arid Horticulture.
- Dr. A. Nagaraja, Principal Scientist, Division of Fruits and Horticultural Technology elected Fellow of the Indian Society for Arid Horticulture.
- Dr. V.B. Patel, Principal Scientist, Division of Fruits and Horticultural Technology awarded Fellow Award 2016 (Society for upliftment of rural Economy), Lucknow
- Dr. Manish Srivastav, Principal Scientist, Division of Fruits and Horticultural Technology elected Fellow of the International Society for Noni Science.
- Dr A.K. Shukla, IARI-Regional station Shimla elected Fellow of the Indian Society of Arid Horticulture.
- Dr. S.S. Rathore, Principal Scientist, Division of Agronomy was elected SRMR Fellow.
- Dr. Vijay Poonia, Scientist, Division of Agronomy was awarded with IZA-FAI award.
- Dr. C.M. Parihar, Senior Scientist, Division of Agronomy was awarded (i) FAI award and (ii) Young Scientist Award (Mosaic).
- Dr. Kapila Shekhawat, Scientist, Division of Agronomy was awarded with FAI award (Best article).
- Dr. Shankar Lal Jat, Scientist, Division of Agronomy was awarded with FAI award (Fertilizer use research).
- Dr. Veda Krishnan, Scientist, Division of Biochemistry selected Fulbright Nehru Post-Doctoral Fellowship-2019.
- Dr. Rajkumar U. Zunjare, Scientist, Division of Genetics was awarded with Jawaharlal Nehru Award for Outstanding Doctoral Thesis Research in Agricultural Sciences by ICAR.
- Dr. L. Muralikrishnan, Scientist, Division of agricultural Extension received Young Scientist award of ISEE.

In addition, a large number of our scientists received various awards instituted by the professional societies/ academies 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 & UTILIZATION

Statement showing Budget Estimates (B.E.) & Revised Estimates (R.E) for the year 2019-20 under Unified Budget

(Rs. in Lakhs)

		B.E. 2019-20					R.E. 2019-20				
Sl. No.	**Head**	**Other than NEH & TSP**	**NEH**	**TSP**	**SCSP**	**Grand Total**	**Other than NEH & TSP**	**NEH**	**TSP**	**SCSP**	**Grand Total**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Grants for creation of Capital Assets (CAPITAL)										
1	Works										
	A. Land										
	B. Building										
	i. Office building	2216.19			100.00	**2316.19**	747.24			115.00	**862.24**
	ii. Residential building	559.75				**559.75**	2339.86				**2339.86**
	iii. Minor Works										
2	Equipments	1175.99		65.00	100.00	**1340.99**	839.52		64.56	77.40	**981.48**
3	Information Technology	0.00		3.00	0.00	**3.00**	13.00		3.44	4.09	**20.53**
4	Library Books and Journals	451.60				**451.60**	422.86				**422.86**
5	Vehicles & Vessels	144.38				**144.38**	74.74				**74.74**
6	Livestock	1.38				**1.38**	0.00				**0.00**
7	Furniture & fixtures	51.84		3.17	15.00	**70.01**	55.46			13.51	**68.97**
8	Others										
A	**Total – CAPITAL (Grants for creation of Capital Assets)**	**4601.13**	**0.00**	**71.17**	**215.00**	**4887.30**	**4492.68**	**0.00**	**68.00**	**210.00**	**4770.68**
	Grants in Aid - Salaries (REVENUE)										
1	Establishment Expenses										
	Salaries										
	i. Establishment Charges	23254.50				**23254.50**	22054.50				**22054.50**
	ii. Wages										
	iii. Overtime Allowance										
	Total – Establishment Expenses (Grant in Aid - Salaries)	**23254.50**	**0.00**	**0.00**	**0.00**	**23254.50**	**22054.50**	**0.00**	**0.00**	**0.00**	**22054.50**

	Grants in Aid - General (REVENUE)										
1	Pension & Other Retirement Benefits	18060.00				**18060.00**	19360.24				**19360.24**
2	Traveling Allowance										
	A. Domestic TA / Transfer TA	169.50				**169.50**	154.85				**154.85**
	B. Foreign TA	0.50				**0.50**	2.59				**2.59**
	Total – Traveling Allowance	**170.00**	**0.00**	**0.00**	**0.00**	**170.00**	**157.44**	**0.00**	**0.00**	**0.00**	**157.44**
3	Research & Operational Expenses					**0.00**					**0.00**
	A. Research Expenses	1044.30		1.16	0.00	**1045.46**	1071.39		39.29	24.69	**1135.37**
	B. Operational Expenses	1322.52		40.00	0.00	**1362.52**	1522.18		0.00	73.57	**1595.75**
	Total - Research & Operational Expenses	**2366.82**	**0.00**	**41.16**	**0.00**	**2407.98**	**2593.57**	**0.00**	**39.29**	**98.26**	**2731.12**
4	Administrative Expenses					**0.00**					**0.00**
	A. Infrastructure	3142.67			300.00	**3442.67**	3110.67			251.89	**3362.56**
	B. Communication	55.00				**55.00**	32.17				**32.17**
	C. Repairs & Maintenance					**0.00**					**0.00**
	i. Equipments,Vehicles & Others	400.00				**400.00**	359.37				**359.37**
	ii. Office building	1350.00			150.00	**1500.00**	1298.88			70.43	**1369.31**
	iii.Residential building	950.00			140.00	**1090.00**	970.36			29.57	**999.93**
	iv. Minor Works	300.00				**300.00**	267.23				**267.23**
	D. Others (excluding TA)	1100.00				**1100.00**	889.71				**889.71**
	Total - Administrative Expenses	**7297.67**	**0.00**	**0.00**	**590.00**	**7887.67**	**6928.39**	**0.00**	**0.00**	**351.89**	**7280.28**
5	Miscellaneous Expenses					**0.00**					**0.00**
	A. HRD	97.11				**97.11**	39.48				**39.48**
	B. Other Items (Fellowships, Scholarships etc.)	1038.39				**1038.39**	1324.16				**1324.16**
	C. Publicity & Exhibitions	27.47		1.30		**28.77**	12.53		0.75		**13.28**
	D. Guest House – Maintenance	120.00				**120.00**	116.75				**116.75**
	E. Other Miscellaneous	370.74	400.00	10.00	0.00	**780.74**	235.88	100.00	9.96	101.85	**447.69**
	Total - Miscellaneous Expenses	**1653.71**	**400.00**	**11.30**	**0.00**	**2065.01**	**1728.80**	**100.00**	**10.71**	**101.85**	**1941.36**
	Total Grant in Aid-General	**11488.20**	**400.00**	**52.46**	**590.00**	**12530.66**	**11408.20**	**100.00**	**50.00**	**552.00**	**12110.20**
	Grand Total (Capital + Revenue)	**29548.20**	**400.00**	**52.46**	**590.00**	**30590.66**	**30768.44**	**100.00**	**50.00**	**552.00**	**31470.44**
B	**Total Revenue (Grants in Aid - Salaries +Pension+ General)**	**52802.70**	**400.00**	**52.46**	**590.00**	**53845.16**	**52822.94**	**100.00**	**50.00**	**552.00**	**53524.94**
	Grand Total	**57403.83**	**400.00**	**123.63**	**805.00**	**58732.46**	**57315.62**	**100.00**	**118.00**	**762.00**	**58295.62**

15. STAFF POSITION

(As on 31.12.2019)

Sl. No.	Category	No. of posts	
		Sanctioned	Filled
A.	**SCIENTIFIC STAFF**		
1)	Research Management Personnel	06	02
2)	Principal Scientist	65	31
3)	Senior Scientist/Scientist (S.G.)	170	121
4)	Scientist	337	336
	Total	**578**	**490**
B.	**TECHNICAL STAFF**		
1)	Category III	14	08
2)	Category II	277	181
3)	Category I	332	242
	Total	**623**	**431**
C.	**ADMINISTRATIVE STAFF**		
1)	Group A	18	18
2)	Group B	243	204
3)	Group C	162	118
	Total	**423**	**340**
D.	**SKILLED SUPPORT STAFF**	**740**	**653**

16. POLICY DECISIONS AND ACTIVITIES UNDERTAKEN FOR THE BENEFIT OF DIFFERENTLY ABLED PERSONS

16.1 POLICY DECISIONS AND ACTIVITIES

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 2019-20, 12 physically challenged students (04 M.Sc./M.Tech. and 08 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 differently abled candidates are available for filling these seats.

16.2 NUMBER OF BENEFICIARIES AND THEIR PERCENTAGE IN RELATION TO TOTAL NUMBER OF BENEFICIARIES

The number of beneficiaries with disabilities and their percentage in relation to total number of beneficiaries as on 31.12.2019 are as follows:

Category	Number of beneficiaries with disability	Total number of beneficiaries	Percentage
Technical	5	431	1.16
Administrative	9	340	2.65
Skilled Support Staff	7	653	1.07

17. OFFICIAL LANGUAGE (RAJ BHASHA) IMPLEMENTATION

According to Article 343 of the Constitution, Hindi shall be the Official Language of the Union Government. To implement the objectives in letters 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) is 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, subcommittees were also constituted in different Divisions, Regional Stations and the Directorate.

17.1.1 Inspection of Progressive Use of Official Language

As per the recommendations of the OLIC and to achieve the targets fixed in the annual programme 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, Agriculture Engineering Division. 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 third Prize by NARAKAS, North Delhi in Large Member Office category for the year 2018-19 for doing maximum writing work in Hindi and Ms. Shivani and Mr. Neeraj Kumar, Assistant of this institute were awarded with consolation prizes in cash, certificates and momento for participating in Proverb pallavan competition.

17.3 AWARD SCHEMES/ COMPETITIONS

During the year 2018-19 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 04 employees of the institute were given cash awards for doing their maximum official work in Hindi in a year.

17.3.2 Hindi Vyavhar Pratiyogita

Hindi Vyavahar Pratiyogita was 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 Fruit and Horticultural Technology and Division of Agricultural Chemcals amongst the divisions and Personnel –III Sec., Directorate and Seed Production Unit amongst the sections/units, Regional Station Shimla, Reigonal Station Indore amongst the Regional stations awarded were chosen to be.

17.3.3 Awards for Popular Hindi Science Writing in Different Journals

A competition for Popular Hindi Science Writing was organized for scientists/technical officers of the institute, and winners were awarded first (Rs.7,000), second (Rs.5000), third (3,000) and three consolation (Rs.2000 each) prizes for their published Hindi articles in different journals/magzines.

17.3.4 Dr. Ram Nath Singh Award

Dr. Ram Nath Singh Award was given jointly to three scientists of the Institute for writing books entitled "*Kisano ki doguni aay – Naveentam Prodyogikiyan evam Yojnayien*" in Hindi. The award carries a cash Prize of Rs.10,000/ and a certificate.

17.3.5 Pusa Vishisht Hindi Pravakta Puraskar

Pusa Vishisht Hindi Pravakta Puraskar was given jointly to two scientists for their outstanding lectures in different training programme. 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.

17.3.6 Power Point Presentation In Hindi

To promote science writing in hindi, A Power Point Presentation Competition was also organized on September 27, 2019 on the topic 'Zero budget natural Farming' for scientist and technical staff of the Institute. The cash awards of ₹ 10000/-, 7000/, 5000/-, 3000/- and 2000/- were given to the successful participants.

17.4 HINDI CHETNA MAAS

Like every year the month of September-2019 was celebrated as *Hindi Chetna Maas* in the institute. This month was inaugurated on September 2, 2019 by Joint Director (Admin.), Mr. Ratnesh Kumar and Dr. Indramani, Head, Agricultural Engineering and co-chairman of the Institute Official Language Inspection Committee. On this occasion 'Hindi Poem Recitation' competition was organized. In order to encourage the officials/employees to do their official work in Hindi, various competitions such as Hindi essay writing, 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 10 competitions were organized. Employees from all the categories of the institute participated in these competitions enthusiastically. Hindi Week/Hindi Day/Hindi Fortnight were also celebrated in different divisions and regional stations of the institute. Many competitions were organized and participants were given prizes.

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". Under NAHEP-CAAST Project on "Genomics assisted crop improvement and management", seventeen programme were organized during 2019. In addition, some special training programmes were also organized for the benefit of professionals, farmers and extension workers.

Important training programmes organized

Name of the training programme	Dates/Month	No. of trainees
Division of Agricultural Engineering		
Appropriate Small Farm Mechanization for Enhancing Farm productivity and Income" for African nationals.	August 17-26, 2019	12
Division of Agronomy		
Technical Staff Training on "Good Agricultural Practices (GAPs) for enhancing resource-use efficiency and farm productivity"	January 2-11, 2019	24
Technical Staff Training on "Layout and Maintenance of Field Experiments and Recording Observations"	January 14–23, 2019	25
Training on Layout and Maintenance of Field Experiments and Recording Observations	October 29 - November 11, 2019	15
Division of Biochemistry		
ICAR sponsored CAFT training on Omics Meet Plant Biochemistry: Applications in Nutritional Enhancement with One Health Perspective	September 7-27, 2019	16
ICAR-Niche Area of Excellence Programme sponsored training on Biochemical methods to assess the nutritional quality in pearl millet	October, 10-23, 2019	20
Division of Agricultural Economics		
Analytical Approaches on Doubling Farmers' income	October 1-21, 2019	16
Division of Entomology		
Genomics of Agriculturally Important Insects	September 18-28, 2019	25
Genotyping of Whitefly Species Complex and its Associated Endosymbionts	December 5-6, 2019	29
NAHEP CAAST training on "Genomics of agriculturelly important inseets"	September 18-28, 2019	25
Division of Agricultural Extension		
ICAR Winter School on 'Extension Approaches for Integrated Technological Options and Institutional Arrangements for Doubling Farmers' Income	January 4- 24, 2019	21
HRD training on 'Capacity Building of Farmers for Climate Change Adaptation and Enhancing Income	March 29- 30, 2019	41
CAFT training Programme on ICT Based Strategies for Nutrition Security for Extension Functionaries	August 16- September 05, 2019	19
Division of Floriculture and Landscaping		
Training programme on Ornamental Horticulture & Landscape Gardening for section officers (Horticulture) of DDA	February 1-7, 2019	40

Training cum Exposure Visit of Gardener's from Jammu on Skill Development in Floriculture & Value addition	February 14-18, 2019	20
Division of Plant Pathology		
NAHEP-CAAST sponsored training on "Genemics assisted molecular systematics of fungi"	September 9-17, 2019	25
NAHEP-CAAST sponsored training on "Genemics assisted diagnosis of plant viroides and phytoplasmas"	October 15-24, 2019	24
Division of Plant Physiology		
ICAR Short Course: Non-destructive high throughput phenotyping for gene discovery and development of climate resilient crops	March 14-23, 2019	16
NAHEP-CAAST sponsored training on "Genome editing in crops: Methods and applications"	December 27, 2019 – January 8, 2020	32
Division of Post Harvest Technology		
Training programme on 'Valorization of Horticultural and Arable Crops'	December 02 – 07, 2019.	20
Division of Soil Science and Agricultural Chemistry		
16th Advanced Level Training on Soil Testing, Plant Analysis and Water Quality Assessment	July 25 – August 14, 2019	08
ICAR sponsored training on 'Advanced Tools and Techniques for Analysis of Pollutant Elements	November 14-28, 2019	20
DST-SERB sponsored awareness training on 'Metal and Metalloid Pollution in Water-Soil-Plant-Human Continuum'	December 16-18, 2019	31
Division of Genetics		
NAHEP-CAAST sponsored training on "Genemics assisted breeding of crop mprovement"	September 30-october 12, 2019	
Division of Seed Science and Technology		
International training programme on "Seed Production and Quality Evaluation" for nine officials from AARDO member countries. Sponsored by MoRD, Govt. of India	February 12 – 25, 2019	10
International training programme on "Seed Production and Quality Evaluation" for nine officials from AARDO member countries. Sponsored by MoRD, Govt. of India	November 04-15, 2019	10
Division of Vegetable Science		
Breeding and Genomic Tools for Stress Resistance in Vegetable Crops	October 23 - November 12, 2019	17
Hybrid seed production of vegetable crops for enhancing productivity and nutritional security	February 12-19, 2019	20
Division of Microbiology		
Spirulina Cultivation and Value Addition	April 23-25, 2019	17
सहायक कर्मचारियों के लिए ''अच्छे प्रयोगशाला अभ्यास'' पर आधे दिन का प्रशिक्षण	01 मई, 2019	15
To farmers on biocomposting and bio fertilizer technology.	September 21, 2019	30
Jaivik Kheti and Pramanikaran prashikshan	November 11, 2019	30
Training on Uses of Biofertilizer for Organic Farming	July 23-24, 2019	30
ICAR sponsor CAFT Training on Plant Disease Monitoring for timely management options	December 4, 2019	18
Water Technology Centre		
Advanced Irrigation System" organized by National Institute of Plant Health Management (NIPHM), Hyderabad	August 19-21, 2019	15
Water security assessment for nation building at NIH, Roorkee	July 23-27, 2019	21
Bilateral workshop on Building an Operational Composite Drought Index (CDI) for India	January 22-23, 2019	150

Centre for Protected Cultivation and Technology (CPCT)		
Training on "High-Tech Horticulture Techniques and modern irrigation system for flower, fruit and vegetables production", Udaipur (Rajasthan)	July 15-19, 2019	50
Training on "Micro irrigation Technology", Himanchal Pradesh	January 3-6, 2020	30
Training on " Installation and Operation of Micro Irrigation Technologies", Meerut, UP	March 5-7, 2020	28
ZTM & BPD Unit		
Intellectual Property Rights & Business for SMEs and Startups	September 04-06, 2019	09
Valorization of Horticultural and Arable Crops	December 02-07, 2019	16
AKMU		
Sensitization cum Training Program on "Krishikosh Repository for Strengthening Agricultural Knowledge"	November 15, 2019	230
Seed Production Unit		
सब्जी बीज उत्पादन के द्वारा कृषकों की आमदनी बढ़ाना	January 21, 2019	48
बीज उत्पादन - आमदनी बढ़ाने के व्यावसायकि आयाम	January 12, 2019	42
Regional Station, Indore		
Wheat and Wheat Seed Production Technology	February 8, 2019	40
Regional Station, Karnal		
Farmers training Good Agricultural practices for quality seed production	March 6-8, 2019	20
Regional Station, Katrain		
Model training course on Advances in vegetable and flower supply chain management for livelihood security	March 12- 19, 2019	12
Regional Station, Katrain		
ATMA sponsored training on Organic farming for sustainable environment and livelihood	June 17 - 21, 2019	21
ATMA sponsored training on Training on sustainable hill agriculture	September 23-27, 2019	25
ATMA sponsored training on Capacity Building on Emerging Agricultural Technologies and Practices for Doubling Farmers' Income	November 16-20, 2019	21

18.1.1 Training Programmes Organized by the Institute's Centre for Agricultural Technology Assessment and Transfer (CATAT)

In all, 20 on-campus training programmes were organised for agriculture officials and Progressive farmers of different States. These programmes were attended by 514 participants from UP, Haryana, Uttarakhand, Punjab, MP, Gujarat, Rajasthan. Tripura, and NCR Delhi.

18.1.2 Other Capacity Building Activities

- Organized training on the importance of different bio-fertilizers e.g. Azolla, BGA, Azospirillum, PSB and Azotobacter for rice and vegetable crops along with demonstrations on the application method were conducted at village Rajpur, Aligarh.
- Organized nutrition awareness programme for capacity building of farm women was organized at Village Kutbi, Muzaffarnagar (UP).
- Organized training on waste management and preparation of compost from the biodegradable waste from kitchen and crop residue. The use of Pusa Liquid Decomposer in preparation of compost was demonstrated.
- Conducted an exposure visits of farmers from project villages during the launching of Kisan Samman Nidhi Scheme at IARI (February 24, 2019) and Pusa Krishi Vigyan Mela 2019.

19. MISCELLANY

I. Ongoing Projects at IARI as on 31.12.2019

(A) In-house Research Projects	**:**	**225**
School of Crop Improvement	:	58
School of Horticultural Sciences	:	56
School of Crop Protection	:	17
School of Natural Resource Management	:	50
School of Basic Sciences	:	12
School of Social Sciences	:	32
(B) Flagship Programmes	**:**	**13**

II. Scientific Meetings Organized

a) Workshops	21
b) Seminars	07
c) Summer institutes/Winter school	11
d) Farmers' day (s)	64
e) Others	304
Total	**407**

III. Participation of Personnel in Scientific Meetings

India

a) Seminars	149
b) Scientific meetings	217
c) Workshops	106
d) Symposia/conference	97
e) Others	83
Total	**652**

Abroad

a) Seminars	03
b) Scientific meetings	06
c) Workshops	04
d) Symposia/conference	06
e) Others	11
Total	**30**

IV. Suggestions Given / Decisions Taken at the Meetings of Senior Management Personnel

Academic Council

- Approved two new courses for PG students, namely, Science and Society (PGS 508) and Non-coding RNAs (BI 644) keeping in view the latest innovations and changes in global scenario.
- To improve the quality and visibility of Post graduate student research work, the Academic Council decided to enhance the NAAS rating requirement > 6.0 out of 10.0 for meeting the requirement of Ph.D. thesis submission from 2019-20 academic session with exception to few disciplines (Agricultural Engineering, Agricultural Extension, Agricultural Economics, Agricultural Statistics and Computer Application).

Research Advisory Committee:

School of Crop Improvement

- In the varietal development programme for conservation agriculture, water use efficiency (WUE), nutrients use efficiency (NUE), physical, chemical and biological properties of soil should also be taken into consideration.
- Special efforts are required to popularize bio-fortified maize hybrids for crop diversification in rice-wheat cropping system.
- Focus to be given on pre-breeding and use of innovative methods like genome editing for crop improvement.

School of Horticultural Sciences

- Biotic stress in solanaceous crops should be focused especially on *Phomopsis* and bacterial blight in brinjal and tomato, respectively as well as abiotic stress against salt and cold resistance.

- Iron deficiency is major threat and anaemic population is increasing in India. Therefore, vitamin and mineral rich bio-fortified vegetable varieties should be developed to alleviate nutritional hunger.
- Comparison of vegetable production under traditional farming *vis-a vis* natural or good agricultural practices (GAP) production systems should be done.
- Pre-breeding should be integral part of different horticultural crops for transferring specific traits in otherwise popular varieties/rootstocks.
- Rootstock breeding should be given emphasis. In vegetables, grafting should be attempted using indigenous rootstock species to address the problems of bacterial wilt and other diseases in tomato, brinjal, chilli and melon etc.
- To minimize the post harvest losses, research on extending the shelf-life, primary and secondary processing and scalable value-addition technologies should be strengthened to enhance farmers' house-hold income and to meet demand of industry.
- Processing technologies needs to be developed and optimized to improve the yield, functionality, shelf-life and bioavailability of various macro-, micro- and phyto-nutrients in the processed and fortified foods for enhancing their consumer acceptability and economic viability.
- More impetus to vertical farming particularly on scheduling and fertigation and minimizing cost of cultivation is required.

School of Basic Sciences

- Rice germplasm and RILs have been identified for variation in diurnal and nocturnal transpiration using phenomics facility. The physiological and molecular mechanisms of nocturnal transpiration need to be addressed for its use in crop improvement.
- Water use efficient germplasm identified in rice and wheat in the phenomics facility should be taken forward for their use in QTL mapping and crop improvement.
- Interaction of elevated CO_2 on WUE of crops needs to be studied considering the climate change scenario.
- Genome editing need to be given more emphasis for development of elite mutants with high resource use efficiency, stress tolerance and quality.
- Abscisic acid receptors play key role in stress tolerance and developmental process. Role of different ABA receptors on reproductive development and stress tolerance may be analysed using functional genomics approach.
- Studies on physiological interventions such as spray of MOP or other growth regulators to enhance heat stress tolerance and grain yield in wheat may be undertaken.
- Research work on P and K, and micronutrient efficiency and tolerance to heat stresses may be taken up in the new projects.
- In addition to rice and wheat, millets, oilseeds and pulses may be included in the basic research.
- Research work on changes in quality of crops under abiotic stresses may also be taken up.
- Targeted nutrient profiling should be attempted in major cereals (wheat, rice, pearlmillet), pulses (chickpea and pigeonpea) and oilseeds (soybean) to identify nutrient-dense donors and factors controlling their accumulation need to be unearthed to develop nutritionally enhanced food crops, with improved content and bioavailability of essential nutrients.

School of Natural Resource Management

- Field experiments need to be conducted to evaluate STFR Meter-based recommendations with the conventional fertilizer recommendations.
- Research on risk assessment of arsenic-contaminated soils should be strengthened including the areas with high possibility of such contamination.

- For CA experimentation, specific varieties developed by the Crop Improvement School should be used.
- Complete analysis of treated waste water with respect to heavy metals and other contaminants, impact on soil physical and chemical properties, micro-organisms and the food safety of produce needs to be studied. Guidelines for use of waste water should be developed.
- In Integrated Farming System model interaction among different enterprisers in terms of nutrient, water and energy saving needs to be analyzed.
- Research work on sensor-based soil and plant health characterization and inputs application should be initiated.
- Research work on drone-based monitoring of crop disease, pest, nutrient and irrigation should be strengthened.
- Potential use of alternate sources for urea coating in mitigation/mitigation-adaptation of greenhouse gas emission in agriculture should be explored.
- The efficacy of plant-based oil extract (eg Karanj oil) and its use with urea should be compared with neem coated urea for their GHG mitigation potential in agriculture.
- Crop residue management technologies integrating mechanical and microbial solutions should be demonstrated at farmers' fields to alleviate residue burning problems.
- Use of green energy (solar and bio) powered technologies should be demonstrated at farmers' fields.
- Efforts may be intensified for obtaining patent, license and commercialization of developed technologies.
- Saving of water due to hydrogel application must be worked out and hydrogel should be aggressively promoted along with precision irrigation.

School of Plant Protection

- A document on potential biocontrol agents/ bioformulations with proven bio efficacy be prepared for generating toxicological data before commercialization.
- A clear roadmap with timeline needs to be developed for discovery and commercialization of the potential new molecules. A strategy needs to be developed by the Institute in line with industry requirements and partnership, for the validation of bio efficacy, safety and toxicological data required before offering the products to the industry.
- Work on the development of indigenous quality formulations, particularly those of biopesticides, should be supported to keep pace with the current international interest in these products. Economics of bioformulations developed should be estimated.
- Impact assessment of the formulations already commercialised should be done.
- Concerted efforts must be made to promote and commercialize the new version of Pusa Hydrogel technology viz. Pusa SPG 1118 hydrogel and constraints in large scale adoption, if any, should be identified and addressed.
- Emphasis should be given on establishment of pilot plant facility for synthesis of bulk materials like hydrogels and extraction/ synthesis of bio- actives.

School of Social Sciences

- Impact analysis of various flagship programmes of the Government should be undertaken.
- Latest and robust research methodologies should be used in Social Sciences research.
- Impact assessment of IARI technologies should be carried out and documented.

Post Graduate School

- Student intake should be increased to improve ranking in National Institute Ranking Framework.

Administration/ Finance

- Vacancies of technical and supporting staff should be filled on priority.

General recommendations

- Institutional Mechanism for field testing/ on-farm testing of technology developed by Divisions/ scientists which are not field oriented, be developed.
- Since many institutes have come up in ICAR, there should be clear distinction of work between IARI and other institutes.
- We should get out of divisional approach and integrate in cross cutting interdisciplinary mode.
- Some of our disciplines are thinly populated in expertise. To become internationally competitive, this issue should be addressed.
- Worldwide concerns of restricted water and pesticide use should be addressed.
- Discipline wise 3-4 focused areas should be identified while formulating the project for 2020-25 period.
- Efforts should be made to develop processable varieties of vegetables and other crops.

V. Resource Generation

1) Consultancy & other services

Consultancy services: ₹ 0.00

Contract research: ₹ 34,82,004/-

Contract service: ₹ 11,77,471/-

Training: ₹ 3,05,934/-

Total (A): ₹ 49,65,409/-

2) Revolving fund

Sale Proceeds Revenue Generated

(a) Seed: ₹ 4,13,72,085/-

(b) Commercialization: ₹ 19,49,604/-

(c) Prototype manufacturing: ₹ 1, 84, 93, 410/-

Total (B): ₹ 6, 18,15, 099/-

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 : ₹ 17,60,600

(c) Receipt from Registrar (A) Account No. 5432 (9029.201.4314) all fees except institutional economic fee, including sale of information bulletin through D.D. : ₹ 10,43,380

(d) Cash transferred from Syndicate Bank to Director's Account No. C-49 (9029.305.17) from sale of Information Bulletin through DD : Nil

(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): ₹ 22,13,034

Total (C) : ₹ 50,17,014

Grand Total (A+B+C): ₹ 49,65,409 + ₹ 6, 18,15, 099 + ₹ 50,17,014 = ₹ **7,17,97,522/-**

VI. All India Coordinated Research Projects in Operation during the year January 1, 2019 to December 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 Improvement
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 Crops
14. AINP on Whitegrubs and other Soil Arthropods (AINPWOSA)
15. All India Coordinated Wheat & Barley Improvement Project (AICW&BIP)
16. Front Line Demonstration on Pearl Millet – AICRP Pearl Millet under National Food Security Mission (NFSM)
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 Programme on Onion & Garlic (AINRPOG)

VIII. Foreign visitors during January 1, 2019 to December 31, 2019

	List of foreign visitors during the period January 1, 2019-December 31, 2019	
S.No.	**Details of Visit**	**Date of visit**
01	A delegation from Egypt, Tunisia and Yemen led by Mr. Ayman Elsayed Ibrahim Shahin, Sector Head, Egyptian Ministry of Water Resources & Irrigations	08.01.2019
02	A delegation from Morocco led by H.E. Khalid Samadi, Secretary of State for Higher Education and Scientific Research, Ministry of National Education Vocational Training	21.01.2019
03	A delegation from Argentina led by Mr. ING. Carlos Friguin, Commercio, Exterior Minister (Ministry of Foreign Trade)	16.02.2019
04	A delegation from Mozambique led by Mr. Victor Canhemba, Permanent Secretary, Ministry of Agriculture and Food Security	15.03.2019
05	A delegation from Palestine led by Mr. Eng. Abdullah Lahlouh, Under Secretary, Ministry of Agriculture	18.03.2019
06	A delegation from UAE led by H.E. Mariam Saeed Hareb Al Muhairi, Minister of State for Food Security	27.03.2019
07	A delegation from UAE led by Mr. Saif Mohammed Al Shara, Assistant Under Secretary, Ministry of Climate Change and Environment	08.04.2019
08	A 28 Members delegation from Nigeria led by Maj. Gen. GA Wahab (Rtd.), Director General, Nigerian Army Resource Centre, ASOKORO, Abuja,	14.05.2019
09	A 6 Member delegation from China led by Mr. Pan Xianzheng Director General, Department of Personnel and Labor, Ministry of Agriculture & Rural Affairs, China	15.05.2019
10	A delegation from Indonesia led by Dr. Hermanto, Senior Researcher, Center for Agricultural Socio Economic and Policy Studies, Ministry of Agriculture	17.06.2019
11	A delegation from Lesotho led by H.E. Mr. Mahala Motapo, Hon'ble Minister of Agriculture & Food Security, Government of Lesotho	20.08.2019
12	A delegation from Afghanistan led by Dr. Khalilullah Kaliwal, Chancellor, Balkh University	12.09.2019
13	A delegation from Chile led by Mr. Eugenio Agnilo, The Agricultural Attache for Chile in India	09.10.2019
14	A 23 Member delegation from BIMSTEC led by Han Thein Kyaw, Director, BIMSTEC Secretariat	12.12.2019

Lesotho Delegation

Palestine Delegate

Chile Delegation

Indonesian Delegation

Appendix 1
Members of Board of Management of IARI
(As on 31.12.2019)

Chairman
Dr. A.K. Singh
Director (Additional charge), IARI

Members
Mr. Bimbadhar Pradhan
Additional Secretary & Financial Advisor
DARE/ICAR

Dr. T.R. Sharma
DDG, Crop Science
ICAR, Krishi Bhawan

Dr. R.R.B. Singh
Director, NDRI

Dr. S.K. Malhotra
Agriculture Commissioner
Deptt. of Agril. and Cooperation
Ministry of Agriculture & FW
Krishi Bhawan, New Delhi

Mr. A.P. Saini
Secretary-cum-Commissioner (Development)
Development Department
Govt. of NCT of Delhi

Dr. A.K. Singh
Joint Director (Research) (Acting)
IARI

Dr. J.P. Sharma
Joint Director (Extension), IARI

Dr. Rashmi Aggarwal
Dean & Joint Director (Education) (Acting), IARI

Member - Secretary
Sh. Ratnesh Kumar
Joint Director (Adm.), IARI

Appendix 2
Members of Research Advisory Committee of IARI
(As on 31.12.2019)

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. B.S. Parmar
Former Joint Director (Research)
IARI, New Delhi

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, Bengaluru

Director
ICAR-IARI, New Delhi

DDG (CS), ICAR Krishi Bhawan
As per the nomination on the Management Committee under Rule 66(a) (5)

Member – Secretary

Joint Director (Research), IARI
New Delhi

Appendix 3
Members of Academic Council of IARI
(As on 31.12.2019)

Chairperson
Dr. A.K. Singh
Director (Additional charge)

Vice-Chairperson
Dr. Rashmi Aggarwal
Dean & Jt. Director (Edn.)
(Additional charge)

Members
Dr. R.C. Agrawal
Deputy Director General (Edn.)
(Additional charge)
ICAR, New Delhi

Dr. Kuldeep Singh
Director (NBPGR)
New Delhi

Dr. N.K. Singh
Director (Acting) (NIPB)
New Delhi

Dr. Taukeer Ahamad
Director, (Additional charge)
(IASRI) New Delhi

Dr. P.R. Ojasvi
Director, IISWC, Dehradun

Dr. M.R. Dinesh
Director, IIHR, Bengaluru

Dr. P.S. Tiwari
Director, (Additional charge)
CIAE, Bhopal

Dr. A.K. Singh
Joint Director (Res.) (Additional charge)

Dr. J.P. Sharma
Joint Director (Extn.)

Dr. P.K. Joshi
Director, South Asia
International Food Policy Research Institute, NASC Complex
New Delhi

Dr. A.K. Singh
Former VC, RVSKVV, Gwalior
Flat No. 71, Ashirvad Apartments
Patparganj, New Delhi

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
(Additional charge)

Dr. (Ms.) Neera 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. Anil Dahuja
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 Landscape Architecute

Dr. S.K. Jha
Professor, Post Harvest Technology

Dr. O.P. Awasthi
Professor, Fruits Science

Dr. Vinod
Professor, Genetics and Plant Breeding

Dr. (Ms.) Radha Prasanna
Professor, Microbiology

Dr. Debasis Pattanayak
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

Mr. V.R. Srinivasan
Comptroller

Dr. A Nagaraja
Principal Scientist, Fruits and Hort. Tech.

Dr. Mahesh C. Yadav
Principal Scientist, NBPGR

Ms. Rajshree Anand
Incharge, Prof. M.S. Swaminathan Library

Mr. Jagmohan Singh
President PGSSU

Ms. Rahul Kumar
Students' Representative to the Academic Council

Member Secretary
Mr. Ratnesh Kumar
Registrar, Joint Director (Admn.)

Appendix 4
Members of Extension Council of IARI
(As on 31.12.2019)

Chairperson
Dr. A.K. Singh, Director
IARI, New Delhi

Members
Dr. A.K. Singh, Head
Genetics, School Coordinator
Crop Improvement

Dr. J. P. Sharma, Jt. Director
(Extension), IARI, New Delhi
Jt. Director (Research), IARI
New Delhi

Dr. Uma Rao, Head, Nematology
School Coordinator, Plant
Protection

Dr. C. Vishwanathan, Head, Plant
Physiology, School Coordinator,
Basic Sciences

Dr. S.S. Sindhu, Head
Floriculture, School Coordinator
Horticultural Sciences

Dr. K. Annapurna, Head
Microbiology, School
Coordinator, Natural Resource
Management

Dr. Indra Mani, Head
Agril. Engg., IARI

Dr. B.S. Dwivedi, Head
SSAC, IARI

Dr. V.K. Singh, Head
Agronomy, IARI

Dr. Sanjay Kumar
I/c. Seed Production Unit, IARI

Dr. J.P.S. Dabas, I/c CATAT, IARI

Dr. Man Singh, Project Director,
(Atg.) WTC, IARI

Dr. V.K. Pandita, Head, IARI
Regional Station Karnal

Dr. S.K. Malhotra, Agril.
Commissioner, MOA & FW

Mr. A.P. Saini, Jt. Director (Agri.)
Delhi Development Department

Smt. Sakshi Mittal, IAS, Vice-
Chairman, Delhi Agricultural
Marketing Board, New Delhi

Dr. K.S. Kadian, Head, Dairy
Extension Division, NDRI, Karnal

Dr. Shailesh Kumar Mishra,
Director (Farm Information Unit),
Directorate of Extension, *Krishi
Vistar Sadan*, New Delhi

Dr. A. K. Singh. Dy. Director
General (Agricultural Extension)
ICAR

Sh. Ratnesh Kumar, Jt. Director
(Admn.), IARI, New Delhi

Mr. Anil P. Joshi, Chairman, Hesco
(V.O. Representative), Dehradun,
Uttarakhand

Mr. Abrahan Daniel, World Vision
(V.O. Representative), Technical
Manager – Agriculture and Food
Security, World Vision India

Mr. Rajesh Aggarwal, Managing
Director, (Agro Industry
Representative) Insecticide India
Limited, Delhi.

Mr. Alok Agrawal (DD
Representative), The Additional
Director General, DD Kisan, New
Delhi

Ms. M. Sailaja Suman (AIR
Representative), The Additional
Director General, All India Radio,
Akashwani Bhawan, New Delhi

Sh. V. R. Srinivasan, Comptroller,
IARI, New Delhi

Member-Secretary

Dr. Premlata Singh, Head, Agril.
Extension, & School Coordinator,
Social Sciences, IARI, New Delhi

Farmers:
1. Mr. Sandeep Goel,B-1,
Industrial Estate, Bazpur
Road, Kashipur, Uttarakhand

2. Ms. Pooja Sharma, W/o Sh
Manoj Kumar, Vill–Chander
Post-Budhera, Dist. Gurugram

Special Invitees
1. Dr. Rashmi Aggarwal, Dean
& Jt. Director (Edn.), IARI,
New Delhi

2. Dr. Anamika Sharma, I/c
K.V.K. Shikohpur, Gurugram

3. Dr. N.V. Kumbhare, I/c ATIC,
IARI, New Delhi

4. Dr. R.N. Padaria, Principal
Scientist & Professor, Division
of Agril. Extension, IARI,

5. Dr. R.R. Burman, Principal
Scientist, Division of Agril.
Extension, IARI

6. Dr. D.K. Yadava, Head, Seed
Science & Technology, IARI,
New Delhi

7. Shri. Satyendra Kumar, A.A.O
(E & P), IARI, New Delhi

Appendix 5
Members of Institute Research Council (IRC)
(As on 31.12.2019)

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 31.12.2019)

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, Division of 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 Section, Directorate

Secretary (Staff side)
Shri Raj Kumar
UDC, Directorate, IARI

Appendix 7
Members of Grievance Committee of IARI
(As on 31.12.2019)

Chairperson
Dr. Rashmi Aggarwal
Dean and Joint Director (Edn.)
(Acting)

Members (Official Side)
Dr. V.K. Singh
Head, Agronomy

Mr. A.K. Maithani
Sr. A.O., Directorate

Mr. Pawan Gupta
F&AO, Directorate

Members of the Staff Side (Elected)
Dr. Manish Srivastav
Principal Scientist, Division of Fruit & Hort. Technology

Mr. Sunil Kumar
T-2, Division of Agricultural Engineering

Mr. Jag Mohan Tiwari
UDC, Division of Entomology

Mr. Bijender Kumar Tanwar
SSS, Directorate

Member-Secretary
Mr. Kumud Kausal
AAO (P-I), Directorate

Appendix 8
Personnel
(As on 31.12.2019)

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. Ratnesh Kumar

Incharge, PME
Dr. M. Jayanthi

Incharge, Publication Unit
Dr. G.P. Rao

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. Anil Dahuja

Entomology

Head (Acting)
Dr. Debjani Dey

Professor
Dr. Subhash Chander

Floriculture and Landscaping

Head
Dr. S.S. Sindhu

Professor
Dr. Kanwar Pal 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

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