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ICAR-Indian Agricultural Research Institute
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ICAR - Indian Agricultural Research Institute
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PREFACE

To meet the global food demand in 2050, agricultural production must be increased by 60 per cent. The Indian Agricultural Research Institute continues its' efforts to ensure food and nutritional security, and enhance the profitability of 55% of the India's population involved in agriculture sector. The institute has deployed conventional and genomic tools for development of new high yielding and pest resistant crop varieties and crop management technologies to enhance the productivity, profitability, environmental sustainability and climate resilience of agriculture.

The genomics-aided precision breeding programmes resulted in the accelerated development of 12 varieties and hybrids in field crops, 14 in vegetables and 6 in fruit crops with improved yield, quality and adaptability. IARI wheat varieties contribute 60% of the Nation's wheat production. Four new wheat varieties have been released including a heat tolerant wheat variety HD 3298 rich in iron and protein. IARI Basmati rice varieties occupy 98% of the basmati grown area of the country and contribute to ₹ 30,000 crores of export earnings every year. This year, IARI has released an early maturing Basmati rice variety Pusa Basmati 1692, which matures in 115 days. In lentil, two salt tolerant varieties have been released for cultivation in salt affected areas of the country. High yielding mustard varieties of IARI occupy about 50% of the mustard grown area of the country and thus contribute to reduction in edible oil import bill. This year, IARI has released Pusa Mustard 32, a low erucic acid content variety, with an average oil content of 38% and seed yield of 2.71 t/ha.

Significant achievements have been made in development of remote sensing, machine learning and artificial intelligence based methods for assessing and managing crops and resources. IARI has made a breakthrough in developing and popularizing "Pusa Decomposer", a fungal consortium, for *in situ* and *ex situ* crop residue decomposition which will help to mitigate residue burning problems. To reduce the fertilizer nitrogen wastage, the Institute has developed nanoclaypolymer composites (NCPCs)-based fertilizer products with a potential to reduce up to 50% N application requirement.

Under *'Lab to Land'* initiative, thirteen technologies of ICAR-IARI were transferred to 52 industry partners. The Institute registered 4 trademark and 7 varieties with PPV&FRA and was granted with 7 patents during 2020. Continuing its leadership role in incubation of agristartups, this year 'Pusa Krishi' of IARI initiated Agri India Hackathon for empowering Indian Agriculture Innovation which was launched by Shri Narendra Singh Tomar, Hon'ble Union Minister of Agriculture & Farmers Welfare, Government of India.

Human resources developed at IARI continue to contribute to the global food security. It is a matter of great pride for this institute that 2020's World Food Prize was conferred upon Prof. Rattan Lal, an alumnus of IARI. During 58th Convocation of the Post Graduate school on February 14, 2020, 242 candidates (144 M.Sc., 9 M.Tech. and 89 Ph.D.) including 15 (11 M.Sc. and 4 Ph.D.) international students were awarded degrees. A MoU was signed

for dual and joint Ph.D. programme of ICAR-IARI students with Western Sydney University, Australia. Under the ICAR-NAHEP CAAST project, 15 students were trained at international laboratories abroad.

Pusa *Krishi Vigyan Mela 2020* with a major theme *"IARI Technologies towards Achieving Sustainable Development Goals"* was organized by IARI during March 1-3, 2020. Shri Narendra Singh Tomar, Hon'ble Union Minister of Agriculture and Farmers Welfare, Panchayati Raj and Rural Development, Government of India felicitated 5 farmers with IARI Fellow and 39 farmers with IARI Innovative Farmers' Awards. Over 80,000 visitors and 270 public and private exhibitors from across the country participated in the mela.

The scientists of IARI have published 539 publications in peer reviewed journals with international impact factor. I congratulate the staff and students for their invaluable contributions and bringing laurels to the institute. The Institute's achievements during this year will help significantly enhance farm productivity, profitability and contribute towards achieving sustainable development goal "Zero Hunger".

I would like to thank Dr. D.K. Yadava, ADG, (Seed) and Dr. T.R. Sharma, DDG (Crop Science), ICAR to their constant support. I also thank Dr. Trilochan Mohapatra, Secretary, DARE, and Director General, ICAR, for his keen interest in the institute's activities, innovative ideas in research for addressing natural problems and providing full financial support and continuous guidance to the institute that enabled us to achieve the excellence. I acknowledge the funding agencies such as NASF (ICAR), NAHEP (ICAR), DBT, DST and other International agencies which supported 203 externally funded projects with a budget of ₹ 200 crores for the financial year of 2020-2021 that contributed significantly to the frontier areas of research and quality human resource development.

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

March 08, 2021

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.

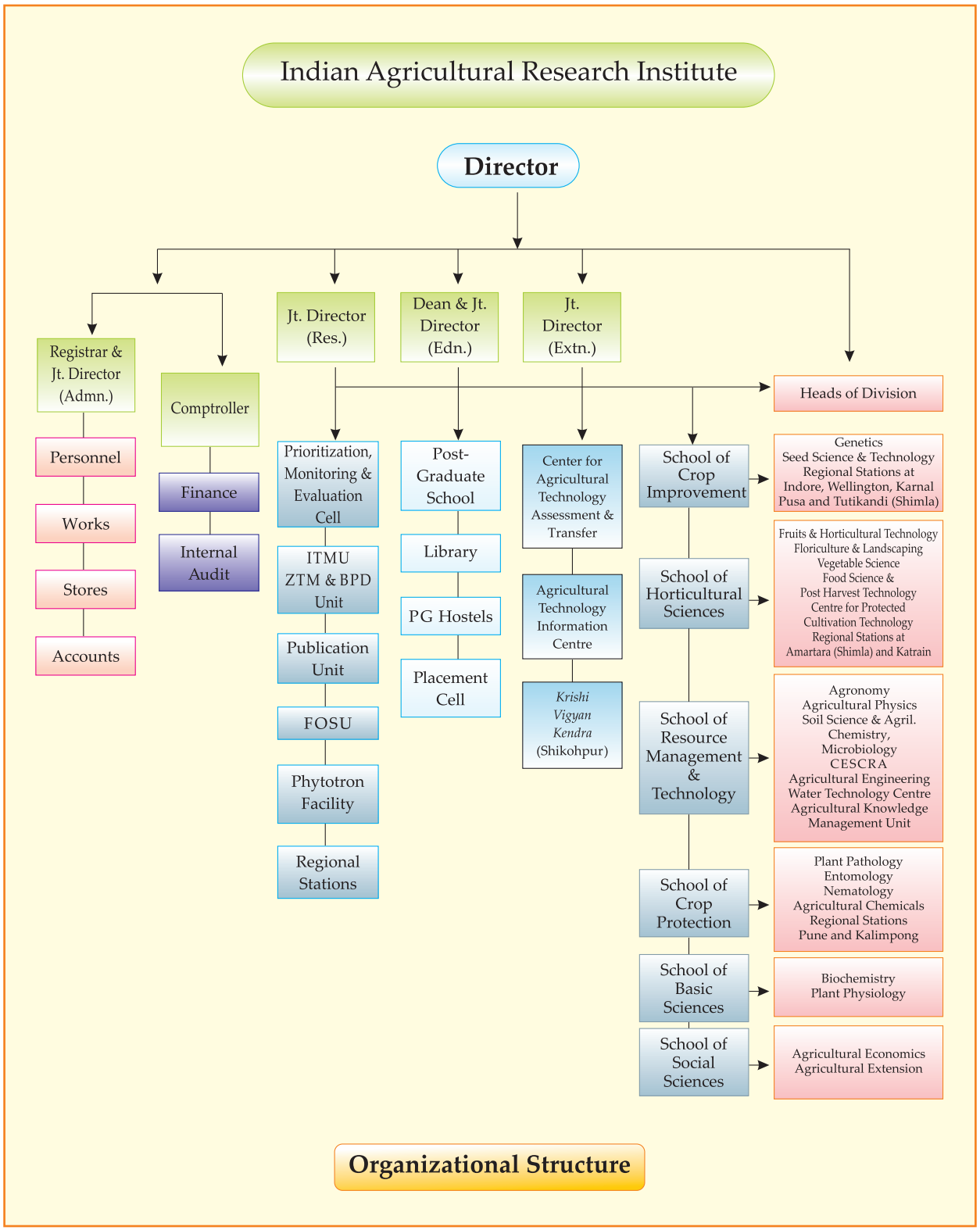
The growth of India's agriculture during the past more than 100 years, is closely linked with the researches done and technologies generated by the Institute. The Green Revolution stemmed from the fields of IARI. Development of high yielding varieties of all major crops which occupy vast areas throughout 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 28.38'23'' N and 77.09'27'' E with altitude of 228.6 meter above mean sea level. The climate is sub-tropical and semi-arid with warm and dry summer and cold winters. The daily maximum temperature during the hot period (April 2020-Sepember 2020) ranges from 28.4°C to 46.5°C and the daily minimum temperature ranges from 15 °C to 31.7°C. June to September are rainy months during which 682.7 mm of rainfall received. Winter sets in from mid-November and is delightful. The daily maximum temperature during winter (November-March 2020) ranges from 13.5°C to 32.0°C and the mean minimum temperature from 0.6 °C to 16.4°C. During winter 228.1 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 ₹ 48,804.52 lakh (Unified Budget after 20% cut) for the year 2020-21.



Organizational Structure

EXECUTIVE SUMMARY

The Indian Agricultural Research Institute (IARI) continued its leadership role in agricultural research education and extension. The Institute has developed several new agrotechnologies for food and nutritional security, and enhancing agricultural exports. Omics-assisted accelerated crop breeding programmes of the Institute resulted in the release of several varieties/ hybrids with improved yield, quality and adaptability to climate change in field and horticultural crops. The Institute has also developed several technologies for crop and natural resource management, plant protection, and post-harvest processing, new farm machineries for enhancing input use efficiency, farm profit and minimization of global warming potential. The salient achievements of IARI in research, extension and education during 2020 are summarized here.

The School of Crop Improvement has developed and released 12 improved varieties in different crops viz., wheat, rice, corn, chickpea, lentil, mustard and soybean, with higher yield, better nutritional quality and resistance to biotic and abiotic stresses during the year. A heat tolerant wheat variety HD 3298 was released for irrigated, very late sown conditions of North West Plain Zone. It has an average yield of 4.37 t/ha, rich in iron and protein, and best suitable for *chapati* making. Wheat variety HD 3293 was released for restricted irrigated conditions of North East Plain Zone with an average yield of 3.93 t/ha. It matures in 129 days and showed resistance to wheat blast along with stripe rust and leaf rust. Wheat varieties HI 1633 and HI 1634 were released for late sown, irrigated conditions of Peninsular Zone and Central Zone, respectively. An early maturing Basmati rice variety Pusa Basmati 1692 was released for Delhi, Haryana and Uttar Pradesh (Basmati GI area) under irrigated conditions. It has average yield of 5.26 t/ha. Since it matures in 110-115 days, timely harvesting of paddy crop will provide sufficient time for sowing of next crop with no compulsion for residue burning. AH-7043, a single cross baby corn hybrid with yield potential up to 2.4 t/ha with green fodder yield up to 24 t/ha was released for cultivation for NHZ, NEPZ and PZ.

Fusarium wilt resistant chickpea variety Pusa Chickpea 20211 was released for commercial cultivation in Central India. It was developed through introgression of "QTL region" for wilt resistance on LG 2 having QTLs 1, 3, 4 and 5 from WR 315. Its average seed yield is 2.39 t/ha and it matures in 108 days. Bold-seeded and short duration (103 days) lentil variety L 4729 with high yield (1.7-1.8 t/ha) potential was released for Central Zone. A salt tolerant lentil variety PDL-1 was released for Haryana and Uttar Pradesh. It is rich in iron (93.0 mg/kg) and zinc (52.5 mg/kg) and yields 0.983 t/ha under salt stress condition. Another salt tolerant lentil variety PSL-1 was also released for Haryana and Uttar Pradesh. It has average seed yield of 0.950 t/ha under salt stress. Pusa Mustard 32, a low erucic acid (1.32% in oil) mustard variety was released for North Western Plain Zone for timely sown irrigated conditions. Average seed yield of this variety is 2.71 t/ha with 38% oil content. A soybean variety Pusa Soybean 6 was identified for release in Delhi NCR region. It has high oil content (20.08%) and matures in 120-125 days. A large number of promising genotypes in several crops are under various stages of evaluation in All India Coordinated trials.

Vegetable crop varieties Brinjal Pusa Vaibhav (DBPR-23) and Pusa Gynoecious Cucumber Hybrid-18 were notified by the Central Sub-Committee on Crop Standard, Notification and Release of Varieties for Horticultural Crops. Similarly, brinjal variety DBR-03 was identified for zone IV (Punjab, Uttar Pradesh, Bihar, Jharkhand), cauliflower variety DCEH-1467 for Zone IV, tropical carrot variety IPC3 for zone VI and VIII, and dolichos bean variety DB 5 for zone V were identified by AICRP (VC). Nine varieties/hybrids *viz.*, tomato Pusa Rakshit, brinjal Pusa Unnat, Pusa

Cauliflower Hybrid 3, Pusa Pickling Cucumber 8, *satputia* DSat 4, summer squash DS-17, muskmelon Pusa Kazri, muskmelon Pusa Sunehari, and spinach Pusa Vilayati Palak were identified by the Institute Variety Identification Committee.

Two promising cherry tomato selections were identified for release. In brinjal, a white fruited phenolics rich brinjal line DBWR-190-44-3-2-5 was developed through inter-specific hybridization. Three new brinjal hybrids, namely, DBHL-1407, DBHL-112407 and DBHR-4070 were found highly resistant to *Fusarium* wilt. At RS Shimla, four capsicum hybrids (KTCH-27, KTCH-28, KTCH-26 and KTCH-8) were identified most promising. In cauliflower, five F_1 hybrids for October maturity, and four hybrids for November maturity were identified. Four hybrids (KTCFH-5, KTCFH-15, KTCFH-2 and KTCFH-1) were most promising for curd yield (>38 t/ha). The lines BR-207 and BR 161 were found to be resistant to black rot disease (*Xcc* race 1). At Katrain, five cauliflower hybrids (KTCFH-50, KTCFH-16, KTCFH-57, KTCFH-101 and KTCFH-55) were found superior over 'Pusa Snowball Hybrid-1. In cabbage, 'No-chill type' genotype 'PA-2' was potential for head yield and December maturity (60-65 DAT). In okra, three hybrids (DOH-3, DOH-7, DOH-9) was found highly resistant to Bhendi Yellow Vein Mosaic Virus (YVMV) and Enation Leaf Curl Resistance (ELCV) under field conditions. Okra hybrids DOV-6490, DOV-6126, DOV-6128 and DOV-6496 (>25 long fruits), were having high yields, dark green fruits with resistance to YVMV and ELCV. One red fruited hybrid, DOH-68 was resistant to both the viruses. In *rabi* onion, Pusa Shobha had recorded the highest yield (30.3 t/ha), while in *kharif* season 20PKOSW and 20PKOSR were most promising. Leek (*Allium ampeloprasum* L.) was found to be immune to *Stemphylium* blight. Amongst promising genotypes, KP-62 (24.35 t/ha), followed by KP-127(23.34 t/ha) and KP-41 (22.81 t/ha) were identified.

Four new varieties in fruit crops, *i.e.* mango hybrids H 8-11 (Pusa Manohari) and H 11-2 (Pusa Deepshikha); pummel Pusa Arun and grape Pusa Purple Seedless have been proposed to be released by the Delhi State Seed Sub-Committee. Two varieties, Pusa Round sweet orange and Pusa Aditi grape were released by the Delhi State Variety Release Committee. Registration of new germplasm *viz.*, six in mango, 13 in grape and 6 in pummel were registered with ICAR-NBPGR. From the draft genome of mango, 245 hyper-variable SSRs were screened for polymorphism between the parent genotypes. In papaya, five promising gynodioecious advance lines have been identified for early release. Six wild *Vasconcellea* sp. have been introduced, *V. parviflora* has been used as bridge species for hybridization with *Carica* genotypes. In guava, white, pink and red pulped new guava hybrids, namely, GH-2017-7A (Hisar Safeda x Purple guava), GH-2016-6D (Shweta x Punjab Pink) and GH-2017-8E (Thai Variant x Lalit) have been found potential with excellent fruit quality. "Pusa Khor" a unique walnut and dwarfing *Malus* rootstock, Pusa apple rootstock-101, have been identified for release.

In rose, SD-6-2015, a selection from open-pollinated seedlings of var. Rose Sherbet belonging to floribunda type with high fragrance, compact and pink coloured flowers was identified. A promising mutant RM-1-2018a bud sport of *cv*. Folklore was identified, which produced light orange coloured large sized blooms having white coloured stripes. Genotypes, PBL-R-PM-8-2016 and PBL-R-PM-17-2016 were identified as pre-breeding lines having moderately resistant for powdery mildew. Protocol was developed using achene as explant following direct shoot organogenesis in the inter-specific hybrid (Dr Bharat Ram × *Rosa brunonii*). In marigold, promising lines were selected from species, *Tagetes erecta*, *T. patula* and *T. minuta* for both *kharif* and *rabi* season growing. *In vitro* protocol for DH production from unfertilized ovaries in African marigold was standardized. Sel. Af./W-1 and Pusa Narangi Gainda recorded high carotenoids in florets. In gladiolus, variety Pusa Shanti (Yellow Stone x Melody) was identified for release. A novel coloured spontaneous mutant from Pusa Vidushi was identified. In ornamental kale, DH inbred lines, namely, were identified as most promising. Two kale hybrids (KtDH-1-29 x KtDH-1-30 & KtDH-1-29 x KtDH-1-27 were found superior with respect to plant height and spread.

The Institute also made commendable contribution to the identification, improvement and characterization several genetic stocks possessing unique economically important traits were identified, in different crops, microbes and insects. Evaluation of some wheat

lines derived from interspecfic hybridization showed resistance to multiple biotic stresses. Wheat genotypes HI 1619, HI 8791, HS 628 and IC290150 were also registered as genetic stocks with ICAR-NBPGR for various traits. A set of 10,086 rice landraces conserved in the National Gene Bank were evaluated for yield and components during *kharif* 2020. 'Sikkim Primitive' is a maize landrace native to Sikkim and is an excellent source of 'prolificacy'. However, heterogeneous population cannot be directly used in the breeding programme as target gene(s) may segregate. By continuous inbreeding, a homozygous breeding line, MGU-SP-101 has been developed. It possessed up to five ears per plant in Delhi condition. This genetic stock has been used in studying the genetics and mapping QTL for prolificacy in 'Sikkim Primitive'. MGU-SP-101 is also being used as a donor for prolificacy in the baby corn breeding programme.

In cauliflower, conversion of 30 elite inbred lines using refined *Ogura* sterile cytoplasm and seven lines with *Eru (napus)* sterile cytoplasm have been advanced to BC_{6-9} stages. In cucumber, new carotene rich lines AZMC-1 and KP1291 were collected from Mizoram. A new line DGC-102 has been submitted for registration to ICAR-NBPGR. In onion, 65 long day onion accessions were imported from NRI, UK and NIAS, Japan. In mango, 10 exotic and indigenous mango germplasm have been procured from different sources, besides over 200 genotypes including, hybrids, indigenous and exotic genotypes are being maintained for evaluation, hybridization and mapping poulation. Wild indigenous grape, *V. himalayana,* and exotic species *V. ficifolia* and *V. arizonica* have been established. In guava, 35 new guava genotypes were introduced from the USDA, Hilo, USA. Comparative genome annotation of pearl millet blast (*Magnaporthe grisea*) and rice blast (*M. oryzae*) revealed the hypothetical host specific pathogen determinants (virulence factors). To identify interacting partners for key pathogenicity factors of a highly pathogenic *R. solani* isolate, RIRS-K, the host specific phytotoxin and candidate pathogenicity gene(s) were isolated and characterized. The whole transcriptome of germinating and dormant teliospores of *T. indica*was performed using RNA Seq. The transcriptome data of teliospores of *T. indica* deposited to the database. Similarly, whole-genome of *Bipolaris sorokiniana* has been sequenced and deposited in DDBJ/ENA/GenBank.

In crop protection, studies on pathogen diagnostics, genomics, host-pathogen interactions, host resistance sources, epidemiology and integrated management of important pests and pathogens of national importance were undertaken. Pathogenic and genetic variability was studied among *Fusarium graminearum* which causes head scab of wheat. A novel primer pair specific to *Tilletia caries* was designed with sensitivity of 100 pg. Molecular characterization and haplotyping of *Blumeria graminis* f. sp. *tritici* (Bgt) of wheat was carried out based on translation elongation factor (*tuf*) gene sequence, and *Fusarium falciforme*, *F. metavorans* and *F. striatum* were found predominantly among the eight identified cryptic species. Twenty *Trichoderma spp*. were characterized based on ITS and ß-tub gene.

PCR-based diagnostic kits were developed for the major begomoviruses infecting tomato, chilli, okra and grain-legumes. Rapid on-site assay using recombinase polymerase amplification for identification of *Thrips palmi* was developed. A duplex PCR assay was developed for the simultaneous detection of chickpea chlorotic dwarf virus and a peanut witches' broom phytoplasma associated with the chickpea stunt disease. Association of aster yellows phytoplasma with flat stem and witches' broom disease of *Hibiscus cannabinus* Linn. in North East region of India was confirmed based on RFLP pattern and 16 S rRNA sequence camparison. Serological and molecular diagnostics of important viruses affecting brinjal and carrot was done.

Cotton leaf curl Multan virus-Rajasthan (CLCuMuV-Raj) strain was found the cause of cotton leaf curl disease in North West India. Transcriptome comparison of tolerant PS3 and susceptible PM papaya cultivars against PRSV infection revealed that differentially expressed genes (DEGs) were higher in tolerant papaya line than in susceptible cultivar. Presence of chickpea chlorotic dwarf virus was confirmed in 37 chickpea samples. The report of association of 16SrII-C sub-group phytoplasma with chickpea stunt disease and the report of 16SrII-D subgroup phytoplasma association in *C. sparsiflora* and *C. roseus* are the new host records in world and from India, respectively. Phytoplasmas were detected in the symptomatic papaya leaf samples by nested PCR of 16S rRNA and secA genes. This is the first report of

16SrI-D subgroup association with a papaya little leaf disease. *Candidatus* Phytoplasma australasia' related strain of 16SrII-D subgroup was detected first time in *Phaseolus vulgaris*. The sequence analysis of amplicons and virtual RFLP analysis confirmed the classification and placed the phytoplasma into 16SrII-D subgroup. Using DAC-ELISA and PCR, most of the citrus samples from Assam and NE India revealed that CTV and *Ca.* Las are prevalent and considered to be cause of citrus decline in Assam and NE India. 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.

A forewarning model developed earlier for BPH, based on weather and the pest data over long period of time had indicated that a greater number of rainy days (>30) during June to September months perhaps played an important in the flareup of BPH population. Higher proportion of macropterous form of BPH observed towards start (July-August) and end of the crop season (November), indicating towards migratory behavior of the pest. Weather based forewarning model depicted that maximum temperature, minimum temperature, evening relative humidity and wind speed influenced the whitefly dynamics while maximum temperature, morning relative humidity and wind speed influenced the mite population. Unusual occurrence and outbreak of *Tetranychus truncates* Ehara in North India was noticed during November, 2020. Fumigation toxicity of different monoterpenoids against pulse beetle, *Callosobruchus maculates* revealed carvacrol as the most effective fumigant. The positive biological attributes of *C. sexmaculata* on *A. gossypii* could contribute to its mass production for augmentative biological control. Compounds influencing oviposition of Fall Armyworm (FAW), *Spodoptera frugiperda* were identified from methanol extracts of its larval frass.

The draft genome assembly of *Meloidogyne graminicola* has been finalized. To investigate the molecular mechanisms conferring *M. graminicola* resistance to rice, the transcriptome of an activation tagged mutant line-9 was compared to susceptible parent JBT 36/14 at 24 h post-infection. The draft genome of *A. tritici* (using Illumina MiSeq platform) was assembled with a size of 164 MB having 39,965 protein coding genes. The KEGG analysis revealed the involvement of these genes in 375 different pathways. Comparative genomic analysis showed the presence of 13,497 ortho-groups among *Bursaphelenchus xylophilus, Caenorhabditis elegans, Ditylenchus destructor, Globodera pallida, G. rostochiensis, Meloidogyne hapla, M. incognita* and *A. tritici. Photorhabdus akhurstii* produces a variety of toxins that aid this bacterium and its mutualistic nematode vector, *Heterorhabditis indica* to kill the insect host. Txp40, a 37 kDa protein, characterized from different *P. akhurstii* strains conferred insecticidal activity against economically important insects *Helicoverpa armigera, Spodoptera litura* and *S. exigua* (*Galleria mellonella* used as the reference).

Chemo and bioprospecting for agrochemicals through design, discovery and development of novel processes was undertaken. A series of 21 imidazolyl chromones evaluated against tomato stem rot pathogen *Sclerotium rolfsii* and 6, 8-Dichloro-2-imidazol-1-yl-chromen-4-one (6r) was found with good activity. The citronella oil, geranium oil and extract of *Annona squamosa* and their combinations were evaluated for their nematicidal activity against J2s of *Melodogyne graminicola* and *M. incognita* using *in-vitro* bioassay. Bioactivity of essential oil of Indian black mustard was tested against two important pests of tomato namely *Meloidogyne incognita* and *Fusarium oxysporum.* A novel premix suspension concentrates formulation (TCS) of CCC and tebuconazole was developed for preventing lodging in wheat.

A lab validated analytical method for detection of 140 pesticides was used for assessment of contaminants in cabbage, brinjal, bhindi, tomato, potato, cucumber, chilli, cauliflower, capsicum, apple and persimmon samples collected from different vegetable markets in Delhi and Himachal Pradesh. Samples were processed as per modified QuEChERS technique and analyzed. A method involving sample processing using liquid-liquid extraction technique and analysis using LC-MS/MS for simultaneous identification and quantification of 140 pesticides under Electrospray Ionization was developed using Shimadzu LCMS/MS-8030. LC-MS/MS method was developed for simultaneous detection and quantification of acrylamide, N, N'-methylene-bis-acylamide and acrylic acid using LC-MS/MS.

The research on crop and natural resource management led to developing efficient resource

management technologies towards enhancing agricultural productivity and profitability of farmers. Integrated farming system (IFS) models for small and marginal farmers were developed with integration of multiple enterprises (crops, livestock, poultry, duckery, fishery, mushroom production, beekeeping, agri-horti system, etc.) to ensure income and employment of a farming family throughout the year. The IFS model for marginal farmers can provide an annual income of ₹ 153,246 from one acre land. A long term conservation agriculture (CA)-based triple zero till (ZT) rice-mustard-mungbean system provided 30.3% higher mustard seed yield and 44% higher system productivity and 59.1% higher net returns than transplanted puddled rice-conventional till mustard. This CA-based system could be a better crop diversification option. A CA-based maize–wheat–mungbean system under ZT + residue retention and 100% N gave 13.6% higher system productivity and reduced lodging in wheat. The long term CA practices could exert significant influence on the total organic carbon (TOC), labile organic carbon (LOC) and non-labile organic carbon (NOC) in maize-mustard system. A triple ZT system with residue had 14% higher soil TOC, however, double ZT without residue led to the highest NOC pool.

In zero-till residue-laden 10-year-old conservation agriculture (CA) based rice-wheat cropping system, the tank mix application of clodinafop-propargyl 0.060 kg/ha + metsulfuron-methyl 0.004 kg/ha at 30 DAS was highly effective towards reducing weed dry weight and increasing weed control index and wheat yield. Tank mix pre-emergence application of atrazine and pendimethalin (0.5+ 0.75 kg/ha) and early post-emergence application (15 DAS) of Tembotrione at 120 g/ha were found superior treatments in reducing weeds infestation and in increasing grain yield of maize. Zero tillage along with residue retention 3 ton/ha in pigeon pea and wheat resulted in highest weed control efficiency, which was 19.28 and 23.61% higher over zero and conventional tillage, respectively.

Soil and nutrient management research revealed that nanoclaypolymer composites (NCPCs)-based fertilizer products have potential towards significant enhancement in nitrogen-use efficiency in crops, namely, wheat. The NCPC loaded with urea ammonium nitrate performed better and gave 31.7% higher grain yield of wheat than that of urea. The use of nano-fertilizers namely, nano-N and nano-Zn led to higher nutrient use efficiency in wheat and mustard and could reduce up to 50% N application. Application of nano-N alone or in combination with nano-Zn resulted in 10.2 and 13.9% higher mustard seed yield than recommended N. Biodegradable clay-polymer (PVA/starch) blended coating film for fertilizers significantly reduced N and P losses.

Irrigation water applied at 80% of crop evapotranspiration using surface drip and sub-surface drip and fertilized with 100% recommended dose of fertilizers led to higher grain and straw/stover yield of wheat, green gram and maize than surface irrigation method. The surface or sub-surface drip could save 35-40% of irrigation water. An integrated soil moisture and canopy temperature sensing device was developed by integrating soil moisture, air humidity and temperature and plant canopy temperature sensors for irrigation scheduling in wheat. A composite drought index (CDI) was developed using satellite data and validated for one of the most drought-prone Marathwada region of Maharashtra. This CDI had better spatio-temporal drought capturing capability than the existing drought declaration protocol. The multi-metal sequestering bacterial isolates for bio-augmentation of wastewater treatment were isolated from the 12 mixed cultured mesocosms [*viz*. *Typha latifolia* + *Phragmites karka* (TA); *Phragmites karka* + *Arundo donax* (PA); *Arundo donax* + *Typha latifolia* (AT) and *Vetiver zizinoids* +*Typha latifolia* (VT)]. The four Gram +ve strains *viz*., strain No. 47, 59, 71 and 92 were identified with sufficient reduction efficiency of Ni, Cr and Pb from waste water.

Protected cultivation techniques were developed for highly profitable crop cultivation. Greenhouse cultivation of tomato using fortified organic amendments *viz*., FYM and vermicompost in combination with bio-agents *viz*., *Purpureocillium lilacinum*, *Pseudomonas fluorescens* and two strains of *Trichoderma harzianum* led to better management of root-knot nematodes. Nematicides fluopyram and fluensulfone were also promising in controlling nematodes. Standardized vegetable grafting protocol for solanaceous vegetable crops using wild relatives revealed that about 78% success was achieved when tomato was grafted using vedge grafting on brinjal

rootstock. An artificial lighting module using smart LEDs system was designed and developed for suitable bud induction exclusively for off-season flower production of chrysanthemum.

Eco-friendly and profitable crop residue management centre (EPCRMC) was established at KVK, Tepla, Ambala. Customized complete feed block making machine, compost turner-cum-mixer, compost sieving machine, power chaff cutter, urea molasses mineral block (UMMB) etc. were demonstrated for *in-situ* and *ex-situ* management of paddy straw as a solution to paddy straw burning. The second hybrid farm sunfridge (FSF)/solar refrigerated evaporatively cooled (SREC) structure was built at Chamrara, Panipat, Haryana. A pedal-cum-solar operated paddy thresher was designed and developed for small and marginal farmers in rural areas where there is lack of electricity or having erratic supply. Small instruments such as battery-assisted minielectric agri prime mover and ginger washer were developed with no-emission of harmful gases into environment. The sensor based Pusa sanitizing tunnel and foot operated smart hand wash were designed and developed to sanitize or protect for sanitization of person from COVID-19 virus.

Layer-by-layer coating of carboxy methylcellulose, chitosan and mixed plant extract of moringa + eucalyptus + marigold was highly effective in reducing fruit decay and weight loss in Nectarine fruit. The application of hexanal dip treatment (0.01%, 0.02%, 0.03% for 2 and 3 min) at 1 month post cold storage extends post-harvest storage life of apple under ambient conditions. Extraction protocol for beetroot betalains has been standardized through thermal extraction process. The extract can be used as natural colorant for acidic to neutral range food products. Ready-to-eat Pusa corn nut was developed using thermal processing having six months product shelf life at ambient condition and a process for flaking of corn grits was also developed with lower solid loss, higher degree of gelatinization and induced higher ductility properties.

A BGA based composite liquid formulation (BGALF) for sustaining crop productivity and soil health was developed. The application of BGALF gradually improved organic C and available N, P and K in soil and provided 10% higher rice yield at farmers' field. Spore multiplication capacity of indigenous AM fungi in rice and wheat in various CA regimes revealed that rice recorded 16% increment of AMF spore over wheat. Diversified use of *Azolla* biomass in relation to nutritional quality for its efficientutilization as feed supplement and value added products were evaluated and it replaced 10% concentrate mixture and improved the digestibility of dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in lactating buffaloes. Two novel yeast strains *viz*., *Meyerozyma* and *Lodderomyces* were used with mixed sugar fermentation for production of biofuels/bio ethanol from rice straw. Both the strains ferment all glucose to ethanol with >75% efficiency and use 33% of xylose. Large scale demonstration and validation of Pusa Decomposer Technology was carried out in farmer fields in Delhi and Punjab. Four capsules of this product can be scaled up to 25 L liquid formulation and applied *in- situ* to 1.0 ha rice field with 5-6 ton of paddy straw residue. On-farm evaluation of microbial inoculants (*Rhizobium, Azotobacter, Azospirillum*, Phosphate solubilizing bacteria, VAM fungi, ZnSB and KSB) in different crops under 163 frontline demonstrations (FLDs) at different locations, MGMG villages, and IARI adopted model villages showed 2.4-12.5% improvement in yield of different crops.

The estimation on regional GHG emission from wheat fields using InfoCrop model which could capture variation in N_2O emission. The simulated N_2O emissions were higher in lower latitudes such as central India than in higher latitudes (Northern parts of India). Under organic rice production, soil bulk density negatively correlated with CO_2 emission from rice, but soil organic carbon (SOC) exhibited positive and significant correlation with CH_4 flux from rice, and CO_2 flux from rice, wheat, and mungbean crops. An inventory of CH_4 emission from different rice ecosystem in India was updated using the inter-governmental panel on climate change (IPCC) inventory preparation methodology, which revealed that Indian rice paddies emitted 3.47 Tg of CH_4 annually from different rice ecosystems. Application of *Azotobacter* and *Mycorrhizae* along with recommended dose of N, P and K for wheat significantly reduced ammonia flux and denitrification losses from wheat field. Chitosan grafted slow release

modified urea fertilizers were observed beneficial for enhancing agronomic-use efficiency and rice yield under field condition. The water management practices like sub-surface drip fertigation reduced GWP by 84% in rice and ~51% in wheat with considerable water saving (37-48%) in both crops. Heavy metals content (As, Cd, Cr, Hg, and Pb) in vegetables in Delhi region and their risk assessment suggested that accumulation of heavy metals in vegetables was within the acceptable limits as given by WHO, except for Cd, which had greater contamination in all vegetables at most sites, including cultivated and marketed sites. Heavy metals accumulation potential of leafy vegetables (spinach, mustard) were higher as compared to root (potato, carrot) and fruit vegetables (okra, tomato).

In basic strategic research programme of the Institute, genomics and next generation phenotyping approaches were used to decipher mechanisms and identify genes/QTLs and donors for resource use efficiency and stress tolerance. Genome-wide analysis led to the identification of 11 genes for the plant stress hormone Abscisic acid (ABA) receptor from rice genome. Transgenic rice cv. MTU1010 overexpressing one of the rice ABA receptors, *Pyrabactin Resistance-Like 1* (*PYL1*) showed enhanced tolerance to drought and salt (NaCl 200 mM) stresses at vegetative stage. CRISPR-Cas9 system was employed to develop gene edited mutants of farnesyltransferase alpha subunit (*FTA*) gene in rice cv. MTU1010. Two different mutant alleles *viz*., 9 bp deletion (fta^{9bp}) and one bp insertion (fta^{+1bp}) in the 5th exon of *FTA* gene showed enhanced sensitivity to ABA and flowered about 2 weeks early as compared with WT plants, suggesting the pivotal role of protein farnesylation in ABA signaling and flowering.

Precision phenotyping of 300 diverse rice germplasm during *Kharif* 2019 at Nanaji Desmukh Plant Phenomics Centre (NDPPC) during *Kharif* 2019 led to the identification of genotype with less transpiration and and high tolerance to nitrogen deficiency stress. Germplasm lines with nitrogen utilization efficiency (NUtE) > 40g grain/g N uptake were identified. Improving photosynthesis is key for enhancing the crop yields. About 430 Nagina 22 mutants were phenotyped for the leaf vein density (LVD) and identified the mutant SM67-1 with higher LVD (6 veins mm^{-1}) and photosynthesis capacity (155% over WT). Studies on physiological basis of high night temperature stress tolerance in rice revealed that Nagina 22 is tolerant with an ability to maintain grain weight at both superior and inferior spikelets. Towards elucidation of role of miRNAs in N deficiency stress tolerance, three genotypes, BT-Schomburgk (*T. aestivum*), D17 (*T. dicoccum*), S3 (*T. sphaerococcum*) were subjected to miRNAseq analysis and about 100 differentially regulated miRNAs in response to N deficiency were identified.

Biochemical studies showed that activation of retrotransposons modulates the expression of Programmed Cell Death (PCD) responsive genes under GBNV (*Groundnut bud necrosis virus*) infection and hormonal signaling genes under ToLCNDV (*Tomato leaf curl New Delhi virus*) infection leading to the necrosis and leaf curl disease respectively, in tomato. Methylome analysis in root of the contrasting rice genotypes [Nagina-22 (N-22): drought tolerant, and IR-64: drought sensitive] grown under control and reproductive stage drought stress revealed increase in methylation at CG and CHG contexts, while decrease in methylation at CHH context in N-22, compared to that in IR-64. PearlOmics led to the identification of candidate genes linked with pearl millet grain quality.

The use of pearl millet is limited due to rancidity and off-odor development in the flour during storage. To solve this problem, an efficient processing technology with "hydro treatment (HT)-hydro thermal (HTh) and thermal near infrared rays (thNIR)" successive treatments was optimized, which was found to be highly effective in reducing the rancidity in pearl millet flour when stored up to 90 days at room temperature. Analysis of four landraces of pearl millet (Jafarabadi, Chanana bajra-2, Chadi bajri and Damodarabajri) and the popular composite variety Dhanshakti showed that all the four landraces were less rancid with better keeping quality than Dhanshakti. Soymilk is an excellent alternative to dairy products but its consumption in India is limited due to the presence of anti-nutritional factors and limited bioavailability of isoflavones The *L. plantarum* and *L. rhamnosus* fermentations resulted in an increase in total antioxidant activity, Fe and Zn availability, reduction

in phytic acid levels, and bioconversion of conjugated isoflavones into more bioavailable aglycones.

In wheat, QTLs for leaf rolling trait under drought a stable QTL Qlr.nhv-5D.2 was identified on 5D chromosome flanked by SNP marker interval AX-94892575–AX-95124447. A new leaf rust resistance gene named *LrM* was introgressed from the diploid non-progenitor species *Ae. ma*rkgrafii into common wheat using the nulli-5B mechanism. In rice, novel genotypes for non-functional LOX3 were identified and the marker for null alleles of *OsLox3* were developed which will be useful for enhancing bran stability and quality.

Similarly QTLs for various traits were mapped in different crops. In chick pea, major QTL (CaqIL5.1) for internode length was identified on CaChr05 (23603436 to 23853931 bp) was identified. Genome wide association study was conducted using 55,634 SNPs and root architectural traits of 153 mungbean genotypes unde normal and low P. This led to the identification of 71 protein coding genes including 13 genes associated with PUE in mungbean. Transcriptome analysis of the Al tolerance in lentils identified 135 DEGs. A major QTL was mapped for malate (*qAlt_ma*) secretions with phenotypic variations of 60.2% in lentil. Speed breeding protocol was standardized for soybean genotypes and with this approach, at least 4 generation of soybean would be feasible to grow under controlled condition.

Four QTLs have been identified one each in Ch 4, 10 and two in Ch 11 by using whole genome re-sequencing of the two bulks (cluster bulk and solitary bulk) obtained from the segregating F_2 population of Pusa Safed Baingan 1 (cluster bearing) and Pusa Hara Baingan 1 (solitary bearing). Four cold tolerant hot pepper genotypes have been identified namely DLS-CT-IR2-1, DLS-P-1R-3, DLS-L-2R-5, DLS-CT-IR2-2 which exhibited better agronomic performance during the cold winter conditions of Delhi.

Non-invasive sensors, remote sensing, machine learning and artificial intelligence approaches were developed to characterize soil and plant health. Machine learning approach such as SVM was developed for predicting hydraulic conductivity (HC), soil water content at field capacity (SWC_{FC}) and mean weight diameter (MWD). Soil texture, OC, and BD can be used to predict soil structural stability effectively using SVM. Thermal imaging and multivariate techniques based Normalized Water stress Index (NWSTI) was developed for characterizing wheat genotypes under drought stress. A methodology was developed for detecting yellow rust in wheat early and accurately, using diverse image processing techniques and artificial neural network (ANN) from RGB images. Hyper-spectral remote sensing technique was standardized and two indices, namely, Normalized Difference Blast Index (NDBI) and Ratio Blast Index (RBI) were developed to detect blast disease in rice.

Using thermal satellite images, spatio-temporal monitoring of the active fires due to paddy residue burning was carried out in real-time for the three states of Punjab, Haryana and UP from Oct 1 to Nov 30, 2020 on daily basis and daily bulletin of fire events were prepared and fire locations were put on CREAMS Geoportal (http://creams.iari.res.in). The residue burning events in 2019 were less as compared with those monitored during previous years. IARI participated in collaboration with ISRO and NASA in the science campaign of AVIRIS NG (Airborne Visible Infra Red Imaging Spectrometer - Next Generation) and models developed were evaluated for both ground and air borne sensors for parameters like pH, EC (dS m^{-1}), SOC (%) and available P and K (kg ha^{-1}).

The School of Social Sciences and Technology Transfer focused on extension approaches, climate change, nutrition, and livelihoods system. Besides assessment of improved IARI technologies for food and nutritional security as well as climate resilience, the current status of e-NAM and the performance and supply dynamics of farmer producer organization (FPO) were also assessed. Studies were conducted in the areas of farmer led innovations (FLIs), agri-nutri linkages, gender empowerment, entrepreneurship development, and agricultural development inspirational districts through improved technologies.

A structural equation modelling analysis suggested that on an average one percent increase in non-farm employment would reduce the rural poverty by 0.18 percent. A study on farm size and productivity relationship in Eastern Yamuna canal command area

of Western Uttar Pradesh (WUP) revealed that the cost of water extraction in case of electric tube wells was quite high for small farmers (₹ 53/h) as comparison to that of large farmers (₹ 35/h). A performance study of e-NAM indicated that Haryana was the leading state in e-trading with the share of 32 per cent followed by Madhya Pradesh (11%), Punjab (10%), Telangana (9.5%), Uttar Pradesh (9%), Andhra Pradesh (7%), Tamil Nadu (6%), Maharashtra and Rajasthan (5%) and rest 15 % shared by other eight states and UTs which were linked in e-NAM.The survey conducted in Yavatmal district of central Marathwada region of Maharashtra to assess the functioning performance and supply dynamics of FPOs revealed that lack of awareness among the farmers, marketing risk, less Government support and nexus between mandis and village traders were the major constraints in the FPOs. The study on the knowledge of minimum support price (MSP) and influence on the bargaining power revealed that farmers who were aware about MSP didn't get a better price than those who weren't aware of MSP in the farm gate negotiations. The study to analyse the status and impact of protected cultivation of horticultural crops in Pune and Nasik districts of Maharashtra pointed out that the total establishment cost under protected cultivation was higher in case of rose (₹ 16.15 lakh) followed by gerbera (₹ 13.79 lakh), carnation (₹ 12.99 lakh) and capsicum (₹ 10.05 lakh) for the polyhouse size of 1000 sq. m area. The impact study on Cluster Front Line Demonstration (CFLD) on pulses showed that during the period 2016- 18, there was 23 per cent increase in area and 29.06 per cent in increase production. The total economic surplus generated from Pusa Mustard 25 was estimated at ₹ 44,694 crores (at 2018 prices) during the period 2010-18 and was distributed between producers and consumers in the ratio of 51:49.

Assessment of the socio-economic impact of IARI-Post Office Linkage Extension Model revealed that the information source preference 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. Continuous demonstrations of climate resilient technologies (direct seeded rice, zero-till wheat, IPM in cotton) yielded significant change in knowledge, skill and adoption of such technologies among the famers in Mewat, Haryana. The demonstrations on direct seeded rice secured higher benefit cost ratio with varieties Abhishek (1.24) and Sahbhagi (1.21) as compared to conventional transplanted system in Gaya district of Bihar. Analysis of adoption of low erucic acid PM 30 revealed that the lack of knowledge about the health benefits of the low erucic acid PM 30 variety of mustard resulted in an adoption gap of 38.01 percent. Under Agri-Nutri (A2N) Smart village model, various capacity building activities were carried out along with the demonstrations of nutri-rich seeds of IARI. Demonstrations of improved varieties of field and horticultural crops of IARI and various capacity building activities were organized in the aspirational districts of Rajasthan, Haryana, and Uttar Pradesh under Biotech Kisan Hub project.

The institute is implementing *Mera Gaon Mera Gaurav*, a flagship programme of ICAR, along with adjoining ICAR institutes IASRI and NBPGR in 120 clusters comprising of 600 villages through 480 scientists of the Institute. During *rabi* 2019-20, 400 demonstrations on wheat varieties (HD 2967, HD 3086 and HD CSW 18) and 350 demonstrations on mustard (Pusa Mustard-28 and 31) were conducted at 82 and 73 locations in an area of 80 ha and 140 ha, respectively. Under NEP collaborative program with ICAR institutes and SAUs,197 demonstrations involving 22 varieties of 9 crops were conducted covering an area of 34.16 ha during *rabi* 2019-20 and 200 demonstrations on 7 crops with 16 varieties covering an area of 51 ha were conducted at 11 locations during *Kharif* 2019-20. Agricultural Technology Information Center (ATIC) is effectively providing products, services, technologies and information services to the different stakeholders through a 'Single Window Delivery System'. Farmers were given farm advice through Pusa Helpline, PusaAgricom, exhibitions, farm literatures and letters. A total number of 24,590 farmers/entrepreneurs, development department officials, students, NGO representatives *etc*. from 15 states of India visited ATIC during the year for availing various services.

The Institute's KVK at Shikohpur, Gurugram, conducted one On Farm Trial (OFT) on integrated nutrient management in pearl millet at Sakatpur village in 4 ha area and four front line demonstrations (FLDs) in 146.6 ha area. It also organized 24 trainings on diversified agriculture for 861 farmers

of aspirational district Nuh of Haryana under *Krishi Kalyan Abhiyan* phase III and 13 farmers' training programs benefitting 269 farmers and farm women. The IARI Regional Stations based at 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 front line demonstrations (FLDs) and other extension interventions like trainings, exhibitions and farmers' friendly literatures.

Pusa *Krishi Vigyan Mela* 2020 with a major theme *"IARI Technologies towards Achieving Sustainable Development Goals"* was organized by IARI during March 1-3, 2020. The *mela* was inaugurated by Shri Narendra Singh Tomar, Hon'ble Union Minister of Agriculture and Farmers Welfare, Panchayati Raj and Rural Development, Government of India. He felicitated 5 farmers with IARI Fellow and 39 farmers with IARI Innovative Farmers' Awards which included 5 women entrepreneurs, belonging to 26 States/UTs of the country. The *mela* was graced with the presence of Honorable Minister(s) of State for Agriculture and Farmers Welfare, Sh. Parshottam Rupala and Sh. Kailash Choudhary. Dr. Trilochan Mohapatra, Secretary, DARE and Director General, ICAR, was the Guest of Honour. Different ICAR institutes, SAUs, development agencies, leading companies from public and private sectors and voluntary organizations participated and displayed their technologies and products. Over 80,000 visitors and 270 public and private exhibitors from across the country participated and gained from the *mela*. A health camp on concept of 'One Health' was organized for the first time for the benefit of the farmers.

During this year, seven patents have been granted, four trademarks were registered, one copyright was obtained and six genotypes were registered in PPV & FRA. In addition, seven patent applications and two copyright applications have been filed. Under '*Lab to Land'* Initiative, thirteen technologies of ICAR-IARI were transferred to 52 industry partners.

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, 4306 M.Sc., 63 M. Tech. and 4974 Ph.D. students have been awarded degrees including 478 international students. The Institute has received accreditation from the National Assessment and Accreditation Council of UGC (3.51/4.00, A+; 2016-2021). The 58th Convocation of the Post Graduate school of the IARI was held on February 14, 2020. Hon'ble Vice-President of India, Shri M. Venkaiah Naidu was the Chief Guest. During this Convocation, 242 candidates (144 M.Sc., 9 M. Tech. and 89 Ph.D.) were awarded degrees, including 15 (11 M.Sc./M. Tech. and 04 Ph.D.) international students.

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 15 students for training at international laboratories, and conducted 11 trainings for students of NAREES.

The Institute brought out 539 publications in scientific peer reviewed journals with international impact factor. In addition several 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. Several national and international short-term training courses and refresher courses were conducted in specialized areas for the scientists of NAREES. In addition, some special training courses, and other capacity building programmes were also organized for the benefit of professionals, farmers and extension workers. New linkages and collaborations with several national and international institutions were initiated. Many scientists, students and faculty of the Institute received several prestigious awards and recognitions, and brought laurels to the Institute.

1. CROP IMPROVEMENT

The crop improvement programme of the institute is primarily aimed at enhancement of productivity and nutritional quality of various field crops. Modern tools of molecular breeding are used to complement the conventional methods of crop improvement. 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 significant 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 3298: Released for irrigated, very late sown conditions of North West Plain Zone with an average yield of 4.37 t/ha. It matures in 103 days. It is a biofortified variety with 43.1 ppm iron and 12.1% protein content. HD 3298 has multiple resistance to stripe rust, leaf rust, Karnal bunt, powdery mildew, foliar head blight and flag smut along with tolerance to heat stress. This variety has perfect Glu score of 10 and best suitable for *chapati* making.

Field view of HD 3298

HD 3293: Released for restricted irrigated conditions of North East Plain Zone with an average yield of 3.93 t/ha. It matures in 129 days. HD 3293 has resistance to wheat blast along with stripe rust and leaf rust. It has also displayed high level of resistance to major diseases like Karnal bunt, leaf blight and powdery mildew. The variety has tolerance to heat stress.

Field view of HD 3293

HI 1633: Released for late sown, irrigated conditions of Peninsular Zone with an average yield of 4.17 t/ha. It matures in 100 days. It is a biofortified variety with

Field view of HI 1633

high levels of protein (12.4%), zinc (41.1 ppm) and iron (41.6 ppm) content. It has high levels of field resistance to stem and leaf rusts.

HI 1634: Released for late sown, irrigated conditions of Central Zone with an average yield of 5.16 t/ha. It matures in 108 days. It has exhibited high levels of field resistance to all the pathotypes of stem and leaf rusts. It also possesses a good level of resistance to leaf blight, Karnal bunt, *Fusarium* head blight, loose smut, foot rot and flag smut. It has excellent *chapati* and biscuit making quality.

Field view of HI 1634

1.1.1.2 Genotypes contributed to AICRP trials

During the year under report, 70 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	HD3349, HD3354, HD3360, HD3368, HD3369, HD3406, HD3407, HD3411, HI1636*, HI1650, HI1651, HI1653, HI1654, HI1655, HI1667, HI8823(d)*, HI8826(d), HI8827(d), HI8828(d), I8830(d), HI8832(d), HI8833(d)
NIVT	HD3385, HD3386, HD3387, HD3388, HD3389, HD3390, HD3391, HD3392, HD3393, HD3394, HD3395, HD3396, HD3397, HD3398, HD3399, HD3400, HD3401, HD3402, HI1656, HI1657, HI1658, HI1659, HI1660, HI1661, HI1662, HI1663, HI1664, HI1665, HI1666, HI8834, HI8835, HI8836, HI8837, HI8838, HI8839(d), HI8840(d), HP1971, HP1972, HP1973, HS682, HS683, HS684, HS685, HS686, HS687.
Special trials	HD3410, HD3403, HD3404, HD3405, HD 3412 and HD3413

1.1.1.3 Promising genotypes under IARI common varietal trials

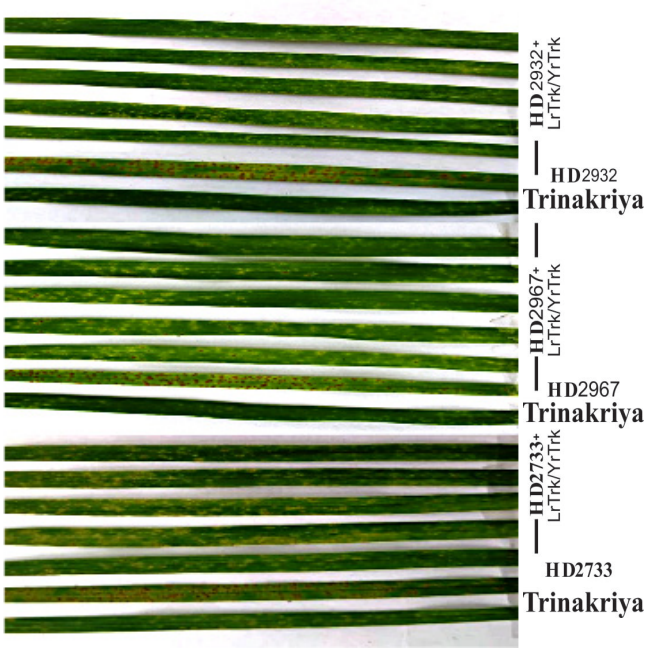
Total 170 promising genotypes superior for grain yield and disease resistance identified in station trials at Delhi, Indore, Pusa, Shimla and Wellington in previous crop season are being evaluated in different IARI common multi location varietal trials under various production conditions.

1.1.1.4 Evaluation of wheat genotypes for resistance to leaf rust at Tutikandi, Shimla

Thirty six wheat genotypes of diverse origin were characterized for race specific (*Lr*19/*Sr*25, *Lr*24/*Sr*24) and race non-specific (*Lr*34/*Yr*18/*Pm*38/*Sr*57, *Lr*46/*Yr*29/*Pm*39) rust resistance genes using STS and SSR molecular markers. On molecular marker analysis, 4 of the 36 genotypes *viz.*, G16, G19, G22 and G36 amplified 140bp fragment with marker Gb, revealing the presence of *Lr*19/*Sr*25. Among these 4 genotypes, G16, G19 and G36 had expressed resistance to all the pathotypes 104-2, 77-5, 77-9 including 77-8 which is virulent to *Lr*19/*Sr*25.

1.1.1.5 Marker-assisted transfer of genes for rust resistance

Marker assisted backcross breeding was used to incorporate several SR (Seedling Resistance) and APR (Adult Plant Resistance) genes in three varieties. In the



Rust resistance response in MAS-derived progenies

variety HD 2967 NILs carrying *Lr19/Sr25*, *Lr34*, *LrTrk/YrTrk*, *Yr10*, *Yr5* and gene combinations were developed. Similarly, in HD 2932 NILs carrying *Lr19/Sr25*, *Lr24/Sr24*, *Lr34*, *LrTrk/YrTrk*, *Sr26*, *Yr5*, *Yr10*, *Yr15*, and gene combinations of these were developed. The variety HD 2733 which was released for NEPZ was improved for leaf and stripe rust resistance by incorporating SR genes, *Lr19/Sr25*, *Lr24/Sr24*, *LrTrk/YrTrk*, *Yr5*, *Yr10* and *Yr15* and APR genes *Lr34*, *Lr46*, *Lr67* and *Lr68*. The NILs HD 2967+*LrTrk/YrTrk* and HD 2932+*Lr19/Sr25+Lr24/Sr24+Yr10* were entered in AVT I of AICRP testing. One of the NILo, HD 2932+*Lr19+Sr26+Yr10* was also nominated to NIVT testing.

1.1.1.6 Evaluation of wheat genotypes against stem and leaf rust resistance at Indore

A total of 541 genotypes of Preliminary Disease Screening Nursery were evaluated for field resistance to stem and leaf rusts under artificial inoculation condition using mixtures of important pathotypes during *rabi* 2019-20. Of these, 236 entries including 67 bread wheat genotypes showed resistance to both stem and leaf rusts at Indore. Indore entry, HAS 2709 was found to be resistant to all three rusts under multi locations screening. The common varietal trials entries (166) were evaluated for seedling response to stem rust pathotype 40A and leaf rust pathotype 77-5. Out of these, 27 entries were segregating for resistance against test pathotypes and 53 entries were observed to be resistant to both stem and leaf rust pathotypes.

1.1.1.7 Development of wheat genotypes with superior quality traits

Six genotypes were identified as promising stocks/donors after three years (2017 to 2019) of multi-location testing in Quality Component and Wheat Biofortification Nursery. These are HD 3215, HD 3241 and HD 3304 for sedimentation value (76-78 ml), QBP18-8 and QBP18-10 for test weight (80.2-82.5 kg/hl), QBP17-7 for iron concentration (48-49.1 ppm).

1.1.1.8 Development of soft wheat

Soft wheat is not available in our country but is highly sought by the baking industry. Therefore, soft wheat development is an important objective in quality breeding. Advance lines with soft grain developed through marker-assisted backcross breeding were evaluated for yield and grain quality traits in station trials. Large scale testing and investment for future programme is being discussed with industry.

Grain characteristics of soft wheat (QBI19-20 and QBI19-21) and their recurrent parent (DBW14)

1.1.1.9 Development of wheat strains with reduced celiac immunogenicity

Development of wheat that can be safely consumed by individuals suffering from celiac disease is a challenging task. The wheat lines should be devoid of gliadins that carry the immunogenic epitopes. Lines lacking either chromosome 1A (Nulli-1A) or 1AS (Ditelosomic 1AL) and those lacking chromosome 6A (Nulli-6A) or 6AS (Ditelosomic 6AL) were developed using the EST-marker- assisted selection and these will be pyramided to obtain lines lacking gliadins completely.

1.1.2 Barley

1.1.2.1 Barley entries in coordinated trials

Among 30 barley entries evaluated under station trials, 5 genotypes *viz.*, BHS 483, BHS 484, BHS 485, BHS 486 and BHS 487 were contributed for testing in AVT-TS-RF-Dual/Grain purpose of Northern Hills Zone under AICW&BIP.

1.1.3 Rice

1.1.3.1 Variety released

Pusa Basmati 1692: Pusa Basmati 1692 (IET 26995) has been released for Delhi, Haryana and Uttar Pradesh (Basmati GI area) under irrigated conditions. It is an early maturing basmati rice variety with a seed to seed

maturity of 110-115 days and average yield of 5.26 t/ ha. Owing to its early maturity, timely harvesting of paddy crop will provide sufficient time for sowing of next crop with no compulsion for residue burning.

Field view of Pusa Basmati 1692

1.1.3.2 Elite lines in All India Coordinated Rice Improvement Programme

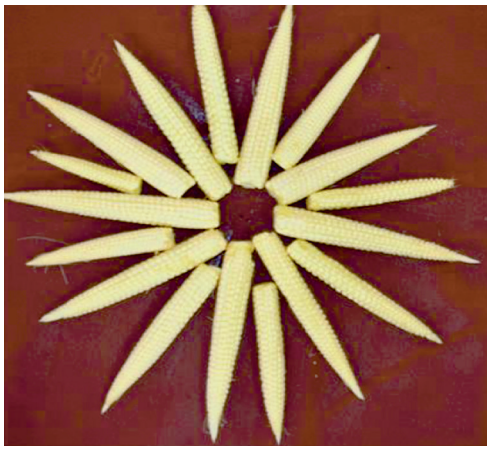
A total of 39 genotypes is being tested in the AICRIP trials during *Kharif* 2020, which includes 23 promotions and 16 new nominations for testing in *Kharif* 2020.

Genotypes	Trial
Pusa 1979-14-7-33-99-15, Pusa 1979-14-7-33-99-66, Pusa 1985-15-7-112-25 and Pusa 1895-15-7-58-190	AVT2-BT (HT)
Pusa 1885-13-242-9-3, Pusa 1885-13-125-20-6, Pusa 1847-12-62-190-39-7-15, Pusa 1847-12-62-184-36-9-155, Pusa 1847-12-62-64, Pusa 1886-13-91-26-9 and Pusa 1886-13-201-18-13	AVT2-BT
Pusa 1882-12-111-7 and Pusa 1882-12-111-20	AVT2-BT-NILs–Drt
Pusa 1853-12-288	AVT2-NILs–Blight+Blast
Pusa 1823-12-62 and Pusa 1823-12-82	AVT2-NILs–Drt
Pusa 1301-95-12-5-2-4-2, Pusa 1630-07-12-2-62 and Pusa RH 55	AVT1-BT
Pusa 5173-3-5-1-1-1-7	AVT1-IME
Pusa 2070-10-2 and Pusa 1824-12-84-17-7-2	AVT1-IM
Pusa 5159-1-2-1-1-1-3-3	AVT-L
Pusa 1557-06-8-186, Pusa 1989-15-10-8-2, Pusa RH 62 and Pusa RH 63	IVT-BT
Pusa 2090-17-20	IVT-IME
Pusa 5278-3-7-1-93-1-1-2, Pusa 5000-1-1-1, Pusa 5000-1-2-1	IVT-IM
Pusa 5315-2-5-1-62-1-3-4	IVT-L
Pusa 5278-3-7-1-93-1-1-1, Pusa 5287-4-6-2-61-1-1	IVT-MS
Pusa RH 61	IHRT-ME
Pusa RH 59, Pusa RH 60	IHRT-E
Pusa 5417-15-11-9-54-17 and Pusa 5417-15-11-9-50-27	IVT-LPT

1.1.4 Maize

1.1.4.1 Hybrid released and notified

AH-7043: It is a single cross baby corn hybrid released for cultivation for NHZ, NEPZ and PZ. It has baby corn yield potential up to 2.4 t/ha with green fodder yield up to 24 t/ha. AH-7043 is an early maturing, fertilizer responsive and stem borer tolerant hybrid. It possesses light cream baby corn ears with ~ 9-10 cm length and 1.7-2.0 cm girth.



Ear characteristics of AH-7043

1.1.4.2 Entries in AICRP trial

Biofortified hybrids (APH-1, APQH-1 and APQH-8 in AVT-II (quality trial); APH-3 in AVT-I and APH-4 in NIVT) were evaluated in AICRP trials. Among

specialty corn, male sterile baby corn hybrid (ABHS4-1 in BC-III) was evaluated. Pop corn hybrids, *viz.*, APCH-2 and APCH-3 were contributed to PC-II trial. Field corn entries in early maturity group (AH-8067, AH-8106, AH-8727 and AH-1619 in NIVT), medium maturity group (AH-8628, AH-8741, AH-8798, AH-4164, AH-4152, AH-4654, AH-4167, AH-4272, AH-4139 and AH3001 in NIVT; and AH-4142 and AH-1625 in AVT-II) and late maturity group (AH-1634) were tested in different zones under AICRP trials. Further, one entry (AFH-7) was also evaluated in forage trial (AVT-I).

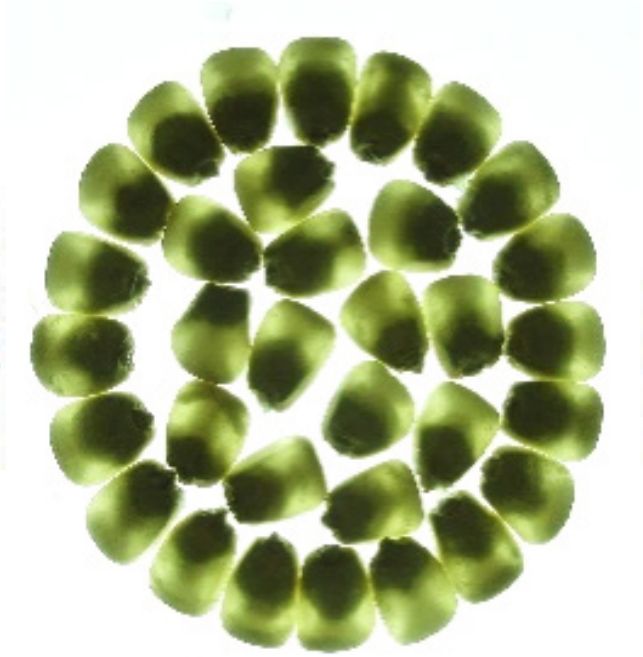
1.1.4.3 Accelerating the breeding cycle

Development of gene-based markers for *mtl* and *dmp* genes responsible for haploid induction: Mutant version of *mtl* and *dmp* genes responsible for haploid induction were targeted for selection in segregating populations. In Del-based markers for *mtl* and SNP-based marker for *dmp* were developed. The markers could be run in simple agarose gel and therefore are breeder-friendly. These markers were successfully used in genotyping segregating populations.

Development of locally adapted 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 markers developed and standardized in the lab were used to screen F_2 populations segregating for both *mtl* and *dmp* genes responsible for induction of maternal haploids. Segregants homozygous for mutant version of (i) *mtl*, (ii) *dmp* and (iii) *mtl* + *dmp* genes were selected. Besides, colour markers in both plant and seeds have been combined.

1.1.4.4 Nutritional quality

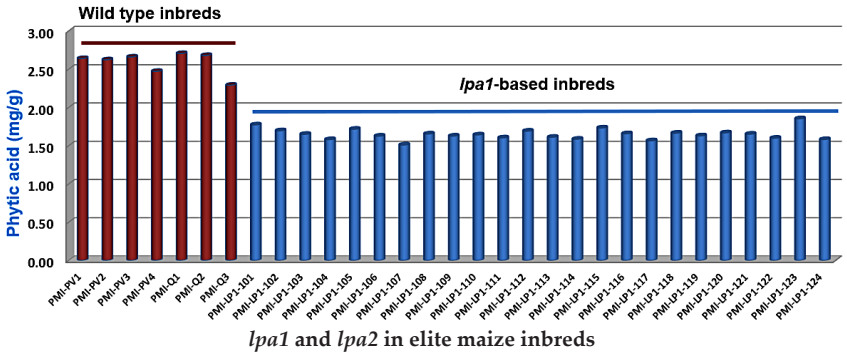
White maize with *opaque2* and *opaque16*: White maize is a preferred option as human food. Parental lines of white grained hybrids *viz.*, HM5 (HKI1344 × HK1348-6-2) and HM12 (HKI1344 × HKI1378) were improved by marker-assisted introgression of *opaque2* and *opaque16*. The promising QPM hybrids (*o2o2/o16o16*) with >0.480% lysine and >0.120% tryptophan, higher yield and 25-50% opaqueness in the grains were selected.



Extent of kernel hardness in newly developed *o2o2/o16o16* hybrid

MAS for high oil in biofortified maize: Mutant *dgat1* and *fatB* genes were crossed with elite QPM and provitamin-A rich inbreds *viz.*, HKI161PVA+PVE, HKI163PVA+PVE and HKI193-1PVA+PVE using exotic donor lines. BC_2F_1 and BC_2F_2 populations were genotyped. Segregants homozygous for *dgat1* and *fatB* genes were selected. Segregants with >90% recovery were advanced for further analysis.

MAS for *lpa1* and *lpa2* in elite maize inbreds: Three elite QPM inbreds *viz.*, HKI323Q, HKI1105Q, HKI1128Q; and four elite QPM + provitamin-A inbreds, HKI161-PV, HKI163-PV, HKI193-1-PV and HKI193-2-PV which are the parents of nine hybrids (HM4, HM8, HM9, HM10, HM11, HQPM1, HQPM4, HQPM5 and HQPM7) were targeted for introgression of *lpa1-1* and *lpa2-1* alleles separately through MAS. The material is now in BC_2F_2 and BC_2F_3 stage and selected homozygous progenies were advanced through selfing.



***lpa1* and *lpa2* in elite maize inbreds**

Characterization of *lpa1* and *lpa2*-based inbreds: Twenty four inbreds with *lpa1* and *lpa2* mutants were evaluated. The average phytic acid in *lpa1* and *lpa2* inbreds was 1.71 mg/g and 1.90 mg/g, respectively compared to 2.56-2.61 mg/g in the wild type inbreds. This amounted to 35 and 25% reduction in phytic acid in the *lpa1* and *lpa2*-based inbreds, respectively. The low phytic acid inbreds were agronomically similar to the wild type inbreds, thus were suitable in the breeding programme. Genotyping using 60 SSR markers depicted the diverse nature of the *lpa1* and *lpa2* -based inbreds.

1.1.4.5 Specialty corn

Development of maize with high amylopectin: High amylopectin or 'sticky' maize is a popular food in North-Eastern states. Recessive *wx1* has been introgressed in seven elite inbreds (HKI323, HKI1105, HKI1128, HKI161, HKI163, HKI193-1 and HKI193-2) that are the parents of nine popular hybrids. Promising progenies possessed high amylopectin (>95% of starch) compared to 68-75% amylopectin in original inbreds.

Development of silkless baby corn: Parental lines (HKI323 and HKI1105) of popular baby corn hybrid, HM4 was targeted for introgression of *silkless1* (*sk1*), *tasselseed1* (*ts1*) and *tasselseed2* (*ts2*) genes. BC_2F_2 populations segregating for each of the three genes separately were genotyped, and homozygous plants (*sk1sk1*, *ts1ts1* and *ts2ts2*) were selected. The desirable plants will be crossed to pyramid *sk1sk1/ts1ts1* and *sk1sk1/ts2ts2*.

Introgression of *teosinte branched-1* from teosinte: *Teosinte branched-1* (*tb1*) gene of teosinte is responsible for prolificacy in maize. Seven elite inbreds (HKI323, HKI1105, HKI1128, HKI161, HKI163, HKI193-1 and HKI193-2) which are parents of nine hybrids were targeted for marker-assisted introgression of *tb1* allele from teosinte. Backcross populations (BC_2F_2) were genotyped using *tb1*-specific marker, and foreground positive plants with phenotypic similarity were selected.

1.1.4.6 Selection for high grain yield

Identification of new potential experimental hybrids: Total of 25 medium to late maturing hybrids were evaluated over two locations *viz*, Delhi (IARI) and Dharwad (RRC, IARI). Total four hybrids including three for medium and one for early were found promising over national checks, Bio 9544 and DKC 7074. Another set of 24 hybrids were evaluated at Delhi and Mandasaur, MP for its adaptability during *rabi*. Three hybrids were superior over national check, Bio-9544 and one hybrid was found superior to CMH-02-282. Theses superior hybrids were contributed to AICRP trials, of these, two medium maturing hybrids, AH-4142 and AH-1625 were promoted to AVT-I.

Selection of promising inbred lines: Two set of inbred lines comprising 25 each with yellow/orange grain color and white grain color were evaluated in IARI, Delhi. Total 10 inbred lines, five each in yellow/orange (AI 43, AI 27, AI 36, AI 22 and AI 39) and white (BM1312, BM1326, BM1378, BM1441 and BM1466) gain colour were selected based on *per se* yield (> 3000 kg/ha). These will be used as parental lines in future hybrid development program.

Identification of field corn hybrids with stay green trait: A set of 39 medium maturing hybrids with a

check, Bio-9544 were evaluated for yield component traits, harvest index and stay green nature. One of the hybrids, AH-4142 showed high yield (10 t/ha), good harvest index (0.43) and stay greeness up to 10 days after 75% dry husk.

Stay green nature of promising field corn hybrid AH-4142

Heterotic grouping of inbred lines: Thirty inbred lines of tropical origin were classified in two heterotic groups. CIMMYT based tropicalized heterotic tester, CML-395 (A) and CML-442 (B) were used as pollen donor in the study. Eight lines were grouped in group A and 11 in group B. Remaining inbreds were unclassified (AB).

1.1.4.7 Resistance to biotic stres

Development and evaluation of single cross hybrids: Of the 250 single cross hybrids developed and evaluated for yield superiority and biotic stress resistance, H-8622, H-7670, H-7241 in early group, H-7581, H-7956, H-8134 in medium category and H-8461, H-8464, 7726, H-7777 in late category were promising with more than 15% standard heterosis over best checks. These hybrids were also resistant to moderately resistant against Turcicum Leaf Blight (TLB) and Maydis leaf blight (MLB). Besides, AH-7080, AH-7078, AH-8181, AH-8461 and AH-8047 were found to be resistant to TLB, with a disease score of <3.0.

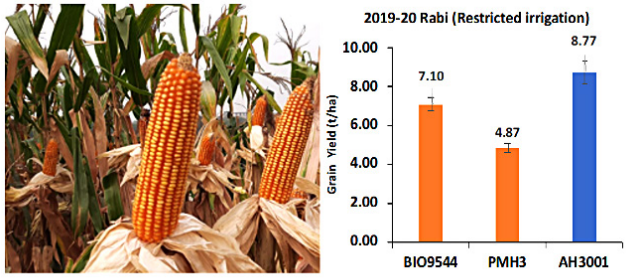
AH-7080 with resistance to TLB

Identification of high yielding disease resistant inbreds: One hundred inbreds were evaluated for yield and resistance to TLB and MLB. PML-93, DIM-337, CDM-318, CDM-350, CDM-304 were promising with a grain yield of more than 3 t/ha and TLB and MLB score of less than 2.5 under natural epiphytotics.

Identification biotic stress tolerant genotypes: A set of 100 newly developed inbreds against TLB and 25 inbreds against MLB and Curcularia Leaf Spot (CLS) were screened under artificial epiphytotics. Promising inbreds, (i) DIM-345, C-11, C-82, C-99, C-153, PML-80, CDM-1318, DIM-310, TC-19 and HSW-1A resistant to TLB (ii) DIM-345, PML-80, C-11, BML-112, PML-6, PML-18, DIM-334, DDM-2309, PML10, PML26, PML28, PML30, PML58, PML102, PML105, PML100, and PML116 resistant to MLB; (iii) PML-64, DIM-334, BLSB-5, DDM-2204, CDM-1101, PML-80 and CDM-1105 resistant to CLS and (iv) PML-80, DIM-345, C-11, DMS-4B, DMS-14A and C-142 resistant to all the three disease (TLB, MLB and CLS) were identified.

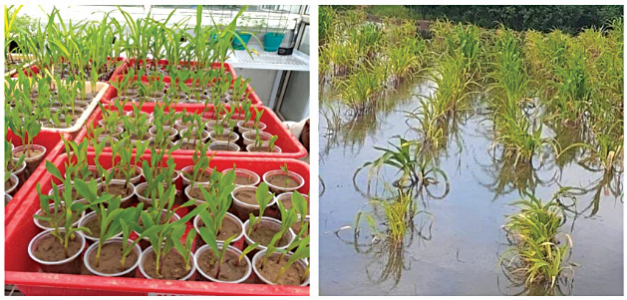
1.1.4.8 Tolerance to abiotic stress

Development of low moisture tolerant maize hybrid: Unavailability of sufficient soil moisture specially during pre-flowering and flowering stages leads to significant loss in grain yield. A medium maturity hybrid, AH3001 was developed with tolerance to low moisture stress conditions. During *rabi* 2019-20, AH3001 produced 8.77 t/ha of grain yield under restricted irrigation conditions, as compared to Bio9544 (7.10 t/ha) and PMH3 (4.87 t/ha). AH3001 also possess stay green trait, thus are also suitable as a source of green fodder.



Ear and grain characteristics of AH3001 and comparison of grain yield under restricted irrigation conditions

Screening maize geneotypes under excess soil moisture: Five hundred accessions were screened under pot conditions for excess soil moisture (ESM) at seedling stage. Twenty four lines differing for agro-morphological, phenological and yield component traits was selected for the development of new populations for grain filling under ESM. One hundred and fifteen crosses were developed for evaluation under ESM during *Kharif* 2020.



Screening technique used for assessing the responses of maize genotypes under excess soil moisture conditions

1.2 MILLETS

1.2.1 Pearl Millet

1.2.1.1 Hybrid Development

Intermediate Station Hybrid Trial (Fe): In intermediate station trial (Fe), thirty five hybrids were tested in Randomized Complete Block design with two replications at Delhi during *kharif* 2020. Hybrids tested as 4002 (ICMA 98222 x 9809/D-19), 4016 (ICMA 98222 x TPRLT-16/10), 4020 (ICMA 98222 x 9733/D-19), 4029 (ICMA 02333 x ICMR 15777), 4030 (ICMA 02333 x PPMI 1012) and 4051 (ICMA 98222 x PPMI 1181) were found promising on the basis of grain yield and related traits.

Initial Station Hybrid Trial (Early and Medium maturity): In initial station trial (E/M), 98 hybrids were tested in alpha lattice design with two replications at Delhi during *kharif* 2020. Hybrids 4662 (ICMA 13222 x PPMI 952), 4677 (ICMA 99111 x ICMR 13888), 4684 (ICMA 99111 x ICMR 15999), 4687 (ICMA 99111 x PPMI 952), 4691 (ICMA 99111 x CHI-19/48), 4694 (ICMA 99111 x ICMR 15777), 4699 (ICMA 96666 x CHI 19/43), 4703 (ICMA 01555 x PPMI 1003), 4712 (ICMA 99111 x CTPRLT-17/34), 4724 (ICMA 99111 x CHI-19/48), 4733 (ICMA 13222 x CHI-19/43), 4740 (ICMA 08666 x CTPRLT-17/17), 4772 (ICMA 13222 x PPMI 952), 4781 (ICMA 01555 x CHI-19/28), 4787 (ICMA 99111 x HFeIT 17/7) and 4790 (ICMA 99111 x ICMR 13888) were found promising on the basis of grain yield and related traits.

Intermediate Station Hybrid Trial (Early and Medium maturity): In intermediate station trial (E/M), 151 hybrids were tested in alpha lattice design with two replications at Delhi during *kharif* 2020. Hybrids 4160 (ICMA 01555 x ICMR 14222), 4191 (ICMA 99111 x CTPRLT-17/17), 4212 (ICMA 99111 x EIJBT-17/6), 4213 (ICMA 99111 x TPRLT-16/10), 4241 (ICMA 08666 x CTPRLT-17/10), 4304 (ICMA 96666 x 9733/D-19), 4307 (ICMA 01555 x CHI 19/48), 4313 (ICMA 01555 x ICMR 14222), 4315 (ICMA 99111 x 9733/D-19), 4333 (ICMA 08666 x CHI-19/48), 4334 (ICMA 99111 x ICMR 15333), 4354 (ICMA 99111 x 9748/D-19), 4356 (ICMA 13222 x J 2563), 4365 (ICMA 13222 x HFeIT-17/24) and 4380 (ICMA 01555 x CHI-19/22) were found promising on the basis of yield and related traits.

Grain view of hybrid (ICMA 99111 x TPRLT-16/10)

Maintenance breeding of cytoplasmic male sterile lines: Thirty six CMS lines were maintained by attempting 3327 paired crosses. Nucleus seed multiplication of 19 promising CMS lines (411A/411B, 431A/431B, ICMA 843-22/ICMB 843-22, ICMA 841A/B, ICMA 92777A/B, 576A/B, ICMA 96222/B, ICMA 96666 /B, ICMA 97111/B, ICMA 99111/B, ICMA 01222/B, ICMA 01555/B, ICMA 04111/B, ICMA 04999/B, ICMA 08666/B, ICMA 11222/B, and ICMA 13222/B) was undertaken by crossing of 6123 panicles.

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

1.3 GRAIN LUGUMES

1.3.1 Chickpea

1.3.1.1 Variety released

Pusa Chickpea 20211 (Manav): *Fusarium* wilt resistant chickpea introgression line (Pusa Chickpea 20211) developed through molecular breeding, has been released and notified for commercial cultivation in Central India comprising states of MP, Maharashtra, Gujarat, Chhattisgarh, and parts of Rajasthan and Bundelkhand region of UP. It has been developed through introgression of "QTL region" for wilt resistance on LG 2 having QTLs 1,3,4 & 5 from WR 315. Its average seed yield is 2.39 t/ha and it matures in 108 days. It has 100-seeds weight of 19.5 g.

Grain characteristics of Pusa Chickpea 20211

1.3.1.2 Entries in AICRP trials

Two drought tolerant introgression lines (BG 4005 & BGM 10218) were promoted to AVT-2 for final year of testing. 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 nominated for multi-location testing in five different IVTs during 2019-20. Four genotypes, one kabuli (BG 3057) and three desi (BG 3088, BG 4002, BG 4004), 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.

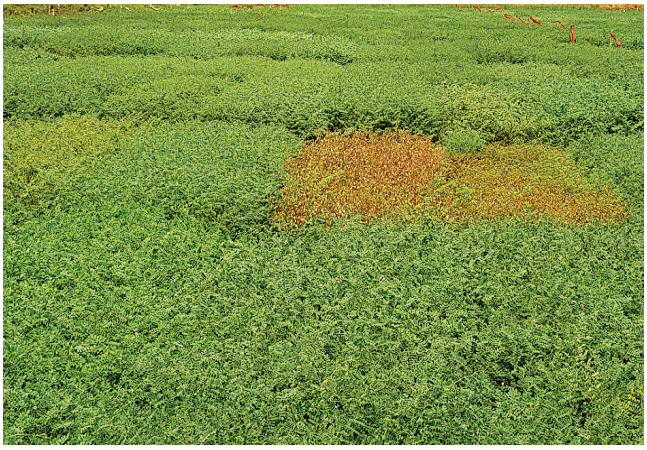
1.3.1.3 Promising genotypes evaluated in multi-location trials in Karnataka and UP states

From Dharwad Centre, six promising entries (BGD 1501, BGD 1536, BG 1510, BG 1524, BG 1534, and BG 3059) were contributed for evaluation in Karnataka state multi-location trials during *rabi* 2019-20.

1.3.1.4 Selection of chickpea genotypes for early flowering and maturity, stem growth habit, lodging resistance and seed yield

Seven early flowering and maturing (120 to 125 days duration) breeding lines having high seed yield potential (2.38 to 3.35 t/ha) were selected from replicated station trials in *rabi* 2019-20. The highest yielding extra-early maturing genotype produced 3.35 t/ha in 123 days, which is about 17% higher than the control variety, GNG 1581 (2.86 t/ha). Seventy-five semi-determinate breeding lines were evaluated along with parents for seed yield during *rabi* 2019-20 and selected eight of them with seed yield potential of 3.13 to 3.66 t/ha. Eleven lodging resistant breeding lines were evaluated along with parents for seed yield

and selected few of them showed yield potential up to 3.32 t/ha. These semi-determinate genotypes produced 14-22% more grain yield than the indeterminate parent BGD 72 (2.99 t/ha). The lodging resistant breeding lines yielded 20-21% higher than the lodging susceptible parent, Pusa 362 (2.74 t/ha).



An extra-early maturing high yielding genotype

1.3.1.5 Evaluation of global chickpea germplasm

A global chickpea core collection of 1950 genotypes was evaluated along with 8 controls in augmented design. The observations on 16 agro-morphological traits including number of nodules, days to flowering, days to maturity and plant height were recorded. Number of nodules formed 45 days after sowing varied significantly. A panel of 300 germplasm showing significant variability for nodulation was developed from the core for mapping studies.

1.3.1.6 Characterization of a RIL population for early flowering, per day productivity and seed yield

Two hundred and fifty six recombinant inbred lines derived from Pusa 362 (Late) x BGD 132 (Early, *efl-3*) were characterized for seed yield and per day productivity. ToFRIL-214 that matured in 125 days produced seed yield (2.99 t/ha) with per day productivity of 23.3 kg/ha which is similar and comparable to that of the highest yielding late parent, Pusa 362 (yield 3.25 t/ha; per day productivity 23.8 kg/ha).

1.3.2 Pigeonpea

1.3.2.1 Breeding of new semi-dwarf semi-erect compact plant types with bold seed size and early maturity

Pigeonpea lines *viz.*, PAE 17-54, PAE 17-64 and PAE 17-39 with semi-dwarf, semi-erect, compact plant type, bold seed (9-10 g/100 seeds) and early maturity (around 135 days), suitable for high density planting have been developed. These plant types are suitable for high density planting with row to row spacing of 45 cm. As these lines mature in about 135 days thus providing scope for timely seeding of wheat crop or mustard and chickpea crop with late sown varieties. These genotypes have bold seed size around 9 to 10 g/100 seeds. During two years of evaluation *viz.*, 2018-19, 2019-20 and also in the current season of *Kharif* 2020, PAE 17-54 has given consistently high grain yield (15.47 and 14.17 g/plant) along with reduced plant height of 100.8 and 115.41 cm and early flowering (64 days during *kharif* 2020). PAE 17-64 with plant height of 106.5 and 92.6 cm, and days to 50 % flowering of 70 and 69 respectively during 2019-20 and 2020 had yielded 23.88 g/plant in 2019-20. PAE 17-39 had yield of 38.7 g/plant in 2019-20 with plant height of 119 and 114 cm, and days to 50% flowering of 81 and 63 days, respectively during 2019-20 and 2020.

Field view of PAE 17-54

1.3.3 Mungbean & lentil

1.3.3.1 Varieties notified and released in lentil

L 4729: It is a bold-seeded short duration variety released for Central Zone. L 4729 has exhibited high yield ranging from 1.7-1.8 t/ha. It is an extra early maturing variety (103 days). Earliness helps in escaping terminal moisture and heat stress in Central India. It is moderately resistant to wilt.

PDL-1 (Pusa Avantika): PDL-1 is released for Haryana and Uttar Pradesh for salinity stress situation (ECe 6.0 dS/m). It has an average seed yield of 0.983 t/ha under salt stress condition and matures in 111 days under salt stress and 140 days under normal conditions. PDL-1 is also rich in iron (93.0 mg/kg) and zinc (52.5 mg/kg) contents.

PSL-9 (Pusa Yuvraj): PSL-9 is released for Haryana and Uttar Pradesh for salinity stress situation (ECe 6.0 dS/m). It has average seed yield of 0.95 t/ha under salt stress condition and matures in 112 days under salt stress and 130 days under normal conditions.

1.3.3.2 Entries contributed in coordinated trials

Mungbean: Spring and Summer - AVT I+II: Pusa1831, IVT Pusa M 1931 and Pusa1932; *kharif*- Pusa M 2071 and Pusa M 2072; *rabi*: Pusa M 20111; UP- AVT II: Pusa 1831, Pusa 1832 and Pusa 1872; AVT I: Pusa M 1771, IVT Pusa 1831 and Pusa M 1931.

Lentil: IVT: PLSS 1901, PLSS 1902, PLLS 1901, PLLS 1902, PLEE 1901 and PLEE1902; UP: L 4772, L 4774, L 4777, PLR 1802 and L 4731; JK: AVT I: L 4773, L 4757, IVT PLS 1802 and PLS 1801; Bihar: AVTI: L 4731, L4757, L 4772, L4773 and L 4774; IVT: PLS 1801, PLS 1802 PLL 1801 and PLL1802.

1.3.3.3 Breeding material evaluated and advanced

Mungbean: Twenty two crosses were made involving trait specific donors. Seventy nine F_1s were raised. Two thousand seven hundred and fifty five single plants in different generations from 196 crosses were raised and evaluated. Lentil: Eighty five crosses were made involving trait specific donors. Eighty eight F_1s were raised. Three thousand three hundred and twenty two single plants in different generations from 345 crosses were raised and evaluated.

1.3.3.4 Maintenance/evaluation of germplasm

Mungbean: Two hundred and sixty germplasm lines were raised/multiplied; Lentil**:** Eight hundred and sixty four germplasm lines were raised/multiplied. Two ICARDA nurseries LSPSNLS and LSPSNSS of 25 entries each were evaluated. The entries in these exotic nurseries were low in biomass.

1.4 OILSEED CROPS

1.4.1 Mustard

1.4.1.1 Variety released

Pusa Mustard 32 (LES 54): Low erucic acid (1.32 % in oil) mustard variety was released for North Western Plain Zone including Rajasthan (Northern and Western parts), Punjab, Haryana, Delhi, Western Uttar Pradesh, plains of Jammu & Kashmir and Himachal Pradesh under timely sown irrigated conditions. Average seed yield of this variety is 2.71 t/ha with 38% oil content. It matures in 145 days.

Low erucic acid LES 54

1.4.1.2 Entries in AICRP trials

Twenty entries were contributed in different AICRP-Rapeseed mustard trials for evaluation in different zones of the country which include six entries promoted to various Advance Varietal Trials *viz.*, PDZ 11 and PDZ 12 (AVT-II Quality), LES 60 (AVT I Quality), NPJ 229 and NPJ 230 (AVT-I Early sown) and NPJ 231 (AVT-I Timely sown). New entries contributed

for their evaluation in initial varietal/hybrid trials were IVT-Early (NPJ-239, NPJ-240); IVT timely sown (NPJ 241, NPJ 242); IVT-Rainfed (NPJ-243, NPJ-244), IHT (Pusa MH 57, Pusa MH 61), IVT Late Sown (NPJ 245, NPJ 246) and IVT-Quality (LES 62, LES 63, PDZ 14 and PDZ 2015). In addition, three entries (NPJ 237, NPJ 238 and PMW 18) were contributed for their testing in National Disease Nursery.

1.4.1.3 Elite genotypes evaluated in station trials

One hundred and thirteen pure lines and 23 CGMS based hybrids were evaluated in six mustard station trials along with the latest released varieties/ hybrids as check. Promising entries will be contributed in different coordinated trials. In addition, five CRP Hybrid Common Trials were also conducted and total 200 hybrids contributed by IARI, DRMR, HAU and PAU were evaluated.

1.4.1.4 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, 2267 single plants/bulks were analysed of which 2226 were having <2% erucic acid. Single plants/bulks, 1809 in number, from double low quality material/progenies were also analysed for total glucosinolates content of which 660 plants/bulks were possessing <30 ppm.

1.4.1.5 Hybridization and pre-breeding

To create selectable genetic variability, a total of 417 crosses were attempted using diverse parents for traits like yield (seed and oil), yield component traits, disease resistance and quality. To infuse genetic variability, 247 progenies from *B. juncea* x *B. carinata* derived from F_6, and BC_1F_4 were raised under rain fed conditions and 218 single plants were selected. Plants of these progenies were variable for drought tolerance and WUE. Well adapted genotypes were crossed with white rust resistance donors like Bio-YSR, BEC-144, BEC-286, Heera and EC-399299 and 44 progenies in F_8, BC_1F_7, F_4 and BC_2F_2 generations were raised at IARI RS, Wellington, and 12 single plants were selected.

1.4.1.6 Restorer development and maintenance

Backcrosses were attempted with pollen tested heterozygous plants, in three pairs each, to transfer the *Rf* gene in 8 nuclear backgrounds. Heterozygous plants in 50 nuclear backgrounds, representing BC_5F_1 or BC_6F_1 generations, were selfed for raising next generation (BC_5F_2/BC_6F_2) and identification of homozygous individuals for their use as fertility restorers. Sixty six progenies of homozygous dominant plants of restorers (in BC_4F_7 and BC_5F_6 generations) developed by transferring *Rf* gene in five genetic backgrounds, were evaluated and selfed for their further utilization. These were also used in generating new hybrids for testing. Eighty eight progenies representing restorers in 22 genetic backgrounds were raised, evaluated and purified following pure line selection. These were also used in generating new hybrids for testing.

Backcross with pollen tested heterozygous plants

1.4.1.7 Breeding material evaluated

Breeding material generated for improvement of various traits was evaluated under different sowing situations and total 1599 single plants (SPs) and 115 bulks were selected which include timely sown (SPs 451, bulks 20), early sown (SPs 313, bulks 34), late sown (SPs 185, bulks 44) and quality (SPs 550, bulks 17) including 303 F_1s which were also evaluated for yield and other important traits. In addition, 253 backcrosses (BC_1-BC_6) for disease resistance and quality were also

evaluated and desirable single plants were selected/ backcrossed. The selected single plants have been analysed for erucic acid and total glucosinolates content for generation advancement.

1.4.2 Soybean

1.4.2.1 Variety Identified

Pusa Soybean 6 (DS 3106): It has identified for release in Delhi NCR region. It has an average yield of 2.10 t/ha. DS 3106 has resistance against yellow mosaic virus (YMV), *Rhizoctonia* Arial Blight (RAB) and Bacterial Pustule (BP). It has high oil content (20.08%) and matures in 120-125 days.

1.4.2.2 Entries in AICRP trial

Following entries are in different stages in AICRP trials. DS 3105, DS 3144, DS 3152 and DS 1312 (NIVT); DS 9421 (Kunitz trypsin inhibitor free) (AVT-I).

1.4.2.3 Development of KTI-free soybean genotype

A specialty soybean genotype (DS9421) was developed through marker-assisted backcross breeding (MABB) and contributed to AICRP soybean trials in North Western Plain Zone.

1.4.2.4 Development of KTI and lipoxygenase-free soybean genotype

Through MABB program, soybean lines are being developed which are free from KTI and lipoxygenase. The lines will be free from off-flavour producing compound lipoxygenase and anti-nutritional factor KTI. The BC_2F_3 plants have been grown during *Kharif* 2020 and plants with desirable traits have been selected. Further process is going on.

1.4.2.5 Tolerance to water logging

Water logging tolerance is required for annual *kharif* crops like soybean to allow effective cropping in major soybean growing tracts of India. Initial stages of crop growth are prone to water logging due rainfall in initial months of monsoon. The complete soybean germplasm collection available (970) were screened for pre-germination tolerance to water logging using the key trait, the percent germination along with respective control (well drained) in soil plot. Five entries were found tolerant based on its ability to tolerate eight days of continuous water logging. Unlike artificial conditions where tolerance was ten days, in soil plot, the level of tolerance was less at eight days. Seed test weight and seed colour may be reasonable indicators of pre-germination tolerance to water logging in soybean seeds. Efforts are being made to identify tolerant entries in initial stages of crop growth namely Ve (emergence) to V4 (four leaf stage). Tolerance was assessed based on ability of genotype to move to next stage and thereby survive stress. Same set of genotypes were screened in each stage for water logging tolerance consequently. New crosses and advancement of pedigree generation was also carried out. Cross combinations were attempted based on water logging tolerance, yield, seed colour and mosaic resistance. Morphological characterization of screened soybean genotypes was done to study the field performance and diversity.

1.4.2.6 Collection and breeding for improved aromatic vegetable soybean

A set of 15 vegetable soybean genotypes has been obtained from the World Vegetable Centre, Taiwan. The genotypes comprise both aromatic and non-aromatic vegetable soybean with various duration of maturity. The seeds of the vegetable genotypes are larger than the common soybean seeds and sweeter in taste. In order to develop early maturing, aromatic vegetable soybean, crosses have been attempted in 4 different combinations. More than 542 F_2 seeds have been harvested during *kharif* 2020. Characterization of the segregating seeds for aroma is in progress.

1.5 SEED SCIENCE AND TECHNOLOGY

1.5.1 Studies on seed quality traits

1.5.1.1 Studies on seed dormancy in rice

Seed dormancy in rice varieties has been studied in the F_4 generation in 3 crosses involving varieties with fresh seed dormancy (Basmati 370) and relatively non-dormant varieties (Annada, IR 64 and Jaya). Fresh seed dormancy was observed in some of the F_4 plant

progenies. Selected F_4 seeds with fresh seed dormancy were grown in 4 lines for each F_3 plant. After harvesting the seeds were evaluated for fresh seed dormancy and at 3 months after harvesting, keeping the seeds at ambient conditions. Most of the selected F_4 derived F_5 progenies showed fresh seed dormancy indicating the transfer of dormancy trait from the donor parent to the recipient parents and the positive effect of selection for the trait.

1.5.1.2 Seed dormancy in mungbean varieties

Studies were taken up to know the dormancy mechanism of mungbean cultivars. The identified varieties with strong (TM 93-25) and weak dormancy (Pusa 1331) were screened for dormancy by soaking the seed for 24 h for two consecutive years .The identified lines were crossed and the F_1 was generated. The genetic basis of hard seededness will be studied in $F_{2:3}$ as it is dependent on maternally originated seed coat. The gibberellic acid content at different stages of seed development was positively correlated with germination. The GA content increased in both the varieties at stage 4 indicating that the dormancy may be exclusively due to seed coat.

1.5.1.3 Seed vigour studies in pearl millet

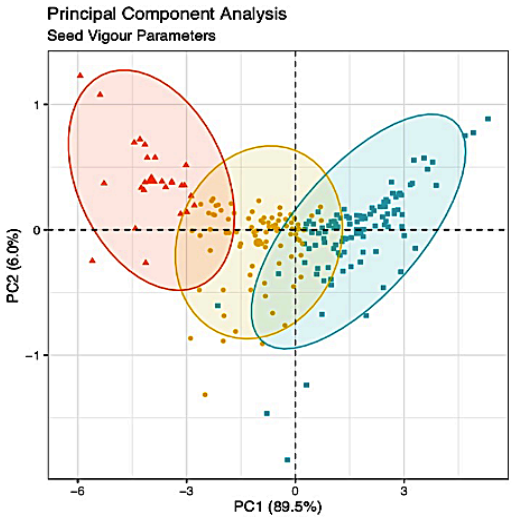
The radicle emergence test was developed for pearl millet based on the studies of 26 genotypes and on accelerated ageing data. The suitable time period for radicle emergence was identified as 50 h after imbibing the seed on moist paper. The test was developed at 25°C controlled condition. The seed vigour enhancement by priming with silver nano particles (AgNP) was studied in pearl millet 13222A, 13222B and Pusa composite 701 genotypes. The AgNP at 50 µg/ml showed significant increase in germination (9%) and vigour traits. This can be attributed to the decrease in EC and increase in amylase and antioxidant enzyme (CAT & POX) activities.

1.5.1.4 Effect of storage on ROS and antioxidant system affecting seed vigour in Indian quality mustard

The effects of genotype, storage period and their interaction on seed vigour and deterioration in Indian quality mustard were investigated. Among the different types of Indian mustard, both conventional type and single zero genotypes have significantly higher mean germination percentage *i.e.*, 95.11% and 90.7% respectively. Significantly lower germination percentage was observed for double zero genotypes (81.5%) of Indian mustard**.** The experiment revealed that as the storage period increases ROS accumulation also increases and enzymatic antioxidants goes on decreasing. Both germination percentage as well as seed vigour indices were negatively correlated with ROS and positively correlated with enzymatic antioxidants. The reduced vigour in quality genotypes could be due to extensive damage caused by ROS during storage and inefficient anti-oxidative system in comparison to conventional genotypes.

1.5.1.5 Early seed vigour in rice

One hundred and ninety two diverse rice genotypes for which 70K SNP chip data is available was collected from Division of plant physiology and phenotyped for early seed vigour characters like time to 50 per cent lemma rupture (LR), Mean LR time, Velocity of LR, Uncertainty of LR Rate, Coefficient of variation of LR time, Modified LR Value, LR Rate Index, Mean LR Rate, Coefficient of velocity of LR, Coefficient of Uniformity of LR and Synchrony of LR process. In PCA analysis, the rice genotypes were grouped in to three groups with high, intermediate and low seed

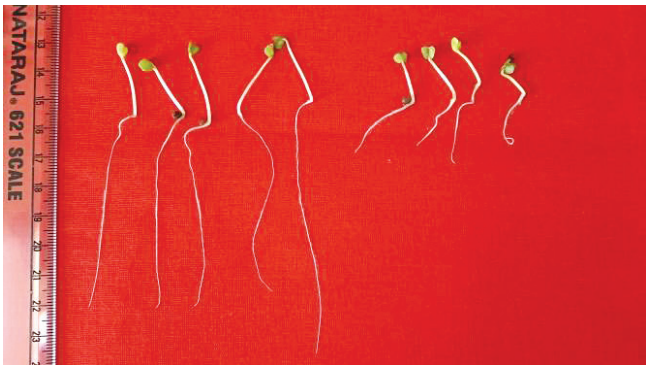


PCA analysis of 192 rice genotypes

vigour categories. The first three PCAs accounted for 94.5% of phenotypic variance.

1.5.1.6 Effect of NADPH oxidase inhibitor on seed germination and seedling development in Indian mustard (*Brassica juncea*)

The experiment was conducted to study the effect on seed germination and seedling development by inhibiting NADPH oxidase activity with different concentrations of diphenylene iodonium chloride which is a potent inhibitor of NADPH oxidase. There was no effect on physiological seed germination up to 0.4 mM DPI treatment after which the seeds failed to germinate. The root growth was mainly affected whereas shoot growth was not affected as much as root growth. As a result total seedling length was reduced in treated seeds which in turn reduced the seed vigour index-I (SVI-I). So it can be concluded that NADPH oxidase play important role in controlling root growth during post germinative period and which is associated with seed vigour.



Effect of DPI (0.01mM) application on root and shoot differentiation

1.5.1.7 Effect of seed vigour on seed yield parameters in rice varieties

One, 2 and 4 year- old seed of five varieties showed loss of germination in two varieties (at 4 years: 28-41%) and other three maintained the seed germination (> 85%). The seed lots also showed a significant difference in seed vigour index-I and seed vigour index-II. A field experiment was conducted to evaluate the effect of seed quality deterioration under natural conditions on the seed yield parameters. The results showed that seed yield and number of tiller per plant were influenced by the low germinating/vigour seed lot in a variety. About 1.5 to 2 g seed yield reduction per plant in low germinating seed lot of varieties consequently reduced productivity by 3-6 q/ha. Hence, seed lots with low germination are not preferred in crop/seed production.

1.5.1.8 Basis of phenol colour variation in rice seeds

In order to address the problem of non-uniformity of phenol colour reaction to seeds of paddy varieties, to help variety identification and to understand biochemical basis of this character, experiments were conducted to evaluate sixty rice varieties for phenol color reaction (rapid chemical test) during 2019-20. Difference in phenol colour in seeds within a plant *i.e* inter-panicle and intra-panicle in a variety was studied revealing some intra-panicle variation than inter-panicle. The phenol content in different panicles in a plant and seeds at different portions of a panicle in a variety indicated non-significant differences. Further, polyphenol oxidase activity in the seed coat governed by tyrosinase enzyme and other substrates like pyro-catechol and L-DOPA were studied. The poly-phenol activity and phenol content along with phenol color per cent have shown higher values in old seed lots of varieties than that in fresh seed lots. A distinct difference in phenol content, L-DOPA, tyrosinase and pyrocatechol activities were found among the varieties belonging to different phenol colour groups. The results of the study indicated that rice varieties showed a very high level of phenol colour reaction to its seeds corresponding to the phenol content and poly phenol oxidase activity. This information would be useful in clearly characterizing a rice variety for phenol colour reaction and in determining varietal admixture.

1.5.1.9 Onion seed storability

Onion seeds are short-lived and exhibit an orthodox storage behaviour. A study was undertaken to assess seed quality and storability of onion varieties. Fresh seeds of 17 onion varieties were accelerated aged at 42°C, 100% relative humidity for 144 h and

seed quality was assessed with conventional approach and parameters extracted from a mathematic model 4-Parameter Hill Function test (4-PHF). The results showed that 4-PHF provided a realistic assessment of seed storability and characterization of onion varieties into different storability groups and area under curve (*AUC*) was the most critical parameter contributing towards clustering of varieties based on their performance potential. Onion varieties namely; Bhima Kiran, Bhima Shakti, Bhima Shwetha, Bhima Super, Pusa Riddhi, Pusa Red, Agrifound Light Red, Arka Bheem, and Arka Kalyan were identified as good storers (AUC: 1182.25±26.02 and vigour: 481.55±24.58); Arka Ujjwal, Agrifound Dark Red, Pusa Madhavi, NHRDF Red and Bhima Shubhra were medium storers (AUC:1045.64±36.27 and vigour: 400.98±34.04) and Pusa Early Grano, Arka Pragati and Arka Niketan were classified as poor storer (AUC: 850.61±79.29 and vigour: 368.90±37.72). The study concluded that 4-PHF provided realistic assessment of onion seed quality.

1.5.2 Studies on seed priming

1.5.2.1 Priming technologies for enhancing planting value of mustard seed under optimal and sub-optimal conditions

Studies were conducted to evaluate the effect of different priming treatments on Indian Mustard. Among the genotypes Pusa Vijay showed better seed quality as compared to all others. Among the different treatments, quality mustard showed significantly higher SVI-I in seed hydropriming with drought Alleviating Bacteria + Bio Grow while significantly higher SVI-II was seen in soaking seed in $ZnSO_4$ @ 0.3% + $MnSO_4$ @ 0.5% solution and drying.

1.5.2.2 Effect of standardized priming treatments on GA (ppm) and ABA (µg/ml) content in pigeon pea

The analysis of GA and ABA revealed that the Pusa 992 variety had significantly higher GA and ABA contents (0.372 ppm & 21.762 µg/ml) than the Pusa 991 variety (0.190 ppm & 13.625 µg/ml). All the treatments had significantly higher GA and ABA contents than the untreated control (0.252 ppm & 13.965 µg/ml). The exposure of seeds at 40ºC for 24 h resulted in highest GA and ABA contents (0.614 ppm & 28.212 µg/ml). The interaction between variety and treatment also resulted in significant differences in GA and ABA contents.

1.5.2.3 Effect of standardized priming treatments on content of GA (ppm) and ABA (µg/ml) in soybean

The analysis of GA and ABA data revealed that the SL-958 variety had significantly higher GA content (0.608 ppm) than the Pusa-12-5 variety (0.532 ppm), whereas the Pusa-12-5 variety had significantly higher ABA content (13.56 µg/ml) than the SL-958 variety (11.40 µg/ml). Significant differences among treatments and interaction between variety and treatments were observed for GA and ABA content. All the treatments, except hydropriming (T2), had significantly higher GA content; however GA content in halo-primed (T5) seeds (0.451 ppm) was significantly lower than the untreated control (0.499 ppm). ABA content, except osmo-primed (T4) seeds (11.53 µg/ml) and halo-primed (T5) seeds (05.37 µg/ml), had significantly higher than the untreated control (12.92 µg/ml) seeds. The exposure of seeds at 40ºC for 24 hrs resulted in highest GA and ABA contents (0.851 ppm & 18.64 µg/ml).

1.5.2.4 Use of nano-particles for enhancing seed quality and storability of soybean seeds

Two soybean varieties *viz.* DS 2614 and PS 9712 were used for the present study. Soybean seeds were dry dressed with each of the nano particles and bulk formulations of zinc oxide, titanium dioxide, silicon dioxide @ 100, 250, 500, 750 and 1000 ppm along with control. After dry dressing with the nanoparticles, the seeds were analyzed for seed quality parameters along with control and selected best treatments were evaluated at field level to study the effect on seed yield and contributing traits. The study revealed that for both the varieties, highest germination percentage, better seedling vigour indices and maximum seedling length was recorded for seeds treated with ZnO NPs @500 ppm followed by SiO_2 NP @ 750 ppm and TiO_2 NPs @ 500 ppm. With respect to bulk formulations,

better seed quality parameters were recorded for ZnO BPs @ 750 - 1000 ppm followed by SiO_2 BPs@ 750 - 1000 ppm and TiO_2 BPs @ 500 ppm.

1.5.2.5 Seed longevity studies on primed pearl millet seeds

The longevity of AgNP primed seed was compared with hydro-primed and un-primed seed in the Pusa composite 701 of pearl millet.The longevity based on accelerated ageing (2-5 days) test showed the superiority of AgNP primed seed compared to hydro primed and un-primed seed up to three days of accelerated ageing. The decrease in EC, WSS and lipid peroxidation (MDA content) in AgNP primed seed up to 3 days indicated the lower level of deterioration in them compared to un-primed seed. The increase in H_2O_2 due to ageing in primed seed was due to decrease in antioxidant enzymes in the later stages. After 3 days of accelerated ageing, the superiority of AgNP primed seed over un-primed seed in terms of germination and vigour disappeared indicating that with extended period of ageing/ storage the priming benefits will be lost.

1.5.2.6 Effect on storability of standardized priming treatments on soybean and pigeonpea seeds

After 10 months of storage, significantly higher germination was maintained in thermo-primed seeds of Pusa 21-5 (83.33%) and SL 958 (74.67%). Significantly higher germination in Pusa12-5 (90.00%) and SL 958 (81.33%) was observed in thermo-primed seeds stored for 10 months at 4°C as compared to untreated seeds stored at ambient condition. In pigeon pea also seeds exposed at 40°C for 24 h resulted in higher values than all other treatments for various quality parameters studied and maintained germination above IMSCS after 10 months of storage. The variety Pusa 991 was found better than the variety Pusa 992 with respect to storability.

1.5.2.7 Effect of nanoparticles in enhancing planting value of onion seed

The efficacy of zinc oxide (ZnO) and graphene oxide (GO) nanoparticles was investigated to enhance the seed quality and antifungal potential against *Alternaria porri*, causing purple blotch in onion through nano-priming. The seed of varieties, Pusa Red and Pusa Madhavi were subjected to seed treatments at different concentrations of ZnO (25, 50, 100, 250 and 500 ppm) and GO (50, 100, 250, 500 and 1000 ppm). The results revealed that the ZnO @ 100 ppm and GO @ 500 ppm significantly improved the germination, mean germination time and vigour indices. ZnO and GO nano-primed seeds also resulted in enhanced activity of antioxidant enzymes; catalase, peroxidase and ROS (H_2O_2) as well as reduced lipid peroxidation (MDA) as compared to control. Further, antifungal potential of NPs was evaluated *vis-à-vis* two commercial fungicides, SAAF and carbendazim through mycelial reduction method and agar well diffusion method; ZnO NPs significantly reduced the growth of pathogen *in vitro* at 250 ppm. The seeds were artificially inoculated with spores of *A. porri*, followed by nano-priming to examine the antifungal activity of NPs. It was observed that the ZnO @ 250 ppm inhibited the establishment of the pathogen on the seeds. Hence it was concluded that ZnO nano-priming is an effective technique to enhance seed quality and provide protection against seed borne pathogen, *Alternaria porri* in onion.

1.5.3 Seed production technology

1.5.3.1 Effect of planting geometry on seed yield and quality of Pakchoi

Four plant spacings *viz.*, 60 x 45 cm, 60 x 30 cm, 45 x 30 cm and 30 x 30 cm were compared to assess the effect on the growth, yield and seed quality attributes of pakchoi (*Brassica rapa* L. subsp. *chinensis* L.) during *rabi* 2019-20. The result exhibited that seed yield and yield attributes, namely, plant height (88.8 cm), number of primary branches per plant (6.3), number of secondary branches per plant (9.1), number of tertiary branches per plant (8.2), number of silique per secondary branches per plant (110.4) and tertiary branches per plant (45.2), number of seeds per silique (26.5), seed yield per plant (45.1 g) seed yield per secondary branch per plant (37 g) and per tertiary branch per plant (8.1 g) were found highest in spacing of 60 x 45 cm, but seed yield per hectare (2.14 t/ha) was found highest in spacing

of 60 x 30 cm mainly due to higher plant population per hectare and optimum resource utilization in field per unit area. The seed quality attributes, such as 1000 seed weight (1.81 g), germination percentage (96%), seedling vigour index I (663) and seedling vigour index II (18.9) were found highest in spacing of 60 x 30 cm. Thus, it can be concluded that pakchoi should be planted with a spacing of 60 x 30 cm for higher seed yield and quality.

1.5.3.2 Effect of abiotic stress on seed yield and quality

Effect of high temperature on seed yield and quality in wheat varieties: Heat tolerance of eleven wheat varieties HD 2967, HD 2985, HD 2987, HD 3043, HD 3059, HD 3086, HD 3117, HD 3118, HD 3171, WR 544 and WH 1105 was evaluated through phenological, seed yield and its contributing characters, quality parameters, membrane thermo-stability (MTS) test, and chlorophyll content in leaves. Heat stress was found to have a significant influence on all these parameters. Thus, on the basis of morphological traits, yield and its contributing traits, physiological, biochemical and seed quality parameters, varieties namely, HD 3086, HD 3171, HD 3117, and HD 3118 were found heat tolerant. With respect to physiological parameters; MSI, chlorophyll content and RWC; and with respect to biochemical parameters; free amino acids, proline content and glycine betaine were identified as potential heat tolerance indicators.

Development of technologies to mitigate the effect of elevated temperatures on seed, yield and quality in wheat: Six mitigation treatments *viz.* salicylic acid (400 ppm), salicylic acid (200 ppm), ascorbic acid (10 ppm), KCl (1%), thiourea (400 ppm) and cycocel (1000 ppm) were evaluated on three wheat varieties *viz.* HD 3171 (timely sown), HD3117 (late sown) and PBW 757 (very late sown). The material was raised under three different sowing dates so as to expose the material to different temperatures. Spraying was done at two different stages, *viz.* vegetative and seed filling stage. Significant differences were recorded between the normal sown crop and the crop exposed to heat stress environments for only two characters, namely, 1000 seed weight and germination percentage. Among the various mitigation treatments, KCl @ 1% and ascorbic acid @ 10 ppm were found to be the most effective treatments for heat stress mitigation.

Sweet corn performance under low temperature: Sweet corn is predominantly grown in winter season wherein seed germination and early seedling growth is adversely affected due to prevailing sub-optimal temperatures. An investigation was undertaken to study the performance of parental lines under sub optimum temperatures and its mitigation through seed enhancement treatments. Shrunken2 based sweet corn hybrids, namply, CMVL Sweet Corn-1 and Pusa Super Sweet Corn-2 along with their respective parental lines VSL16, VSL4, SWT16 and SWT17 were sown under low (15°C), suboptimum (20°C) and optimum (25°C) temperatures in growth chambers. Genotypic variability existed for seedling vigour traits under low temperature conditions. Among genotypes, hybrids (CMVL sweet corn-1 and Pusa Super Sweet corn-2) performed better for seedling emergence and vigour traits as compared to their parental lines under suboptimum conditions. Seedling emergence, GI, MGT, vigour indices and field emergence, were adversely affected by low temperature. Under 15 and 20°C temperature, seed germination, MGT, vigour indices and electrical conductivity were significantly affected and highly correlated with field emergence. Seed enhancement treatments, had pronounced effect on improvement of emergence percent and seedling vigour parameters wherein hydropriming (17h/25°C + Thiram @ 2.5 g/kg) and magnetic treatment (200 mT for 1h)] significantly improved seedling emergence, vigour indices and root growth in terms of root length, surface area, volume and number of forks over control.

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 seeds production of different varieties of IARI which include nucleus, breeder and truthfully labelled seed. The details of the seed produced during 2020 are as follows:

Seed production (t)				
Crop Group	**Nucleus Seed**	**Breeder Seed**	**IARI Seed**	**Total Seed**
SPU, IARI, New Delhi				
Cereals	3.460	144.665	307.685	455.810
Pulses	0.190	4.193	15.973	20.356
Oilseeds	--	2.381	6.075	8.456
Regional station, Karnal				
Cereals	2.750	195.349	371.712	569.811
Pulses	0.005	0.822	0.000	0.827
Oilseeds	0.000	0.462	0.926	1.388
Others	0.000	0.000	1.200	1.200
Regional station, Indore				
Cereals	--	233.100	--	233.100
Regional station, Pusa, Bihar*				
Cereals	--	77.702	60.730	138.432
Pulses	--	--	1.602	1.602
Oilseeds	--	--	3.195	3.195
Others (Tobacco)	--	--	0.125	0.125

*Seed produced (unprocessed)

2. HORTICULTURAL SCIENCES

Horticulture sector in the country has shown phenomenal increase in cultivation area and production since 2013-14 maintaining an annual growth of about 4%. Due to this changed trends, the country is growing towards nutritional security, besides providing livelihood security as outlined in SDGs. The School of Horticultural Sciences was created in 2013 by reorganizing the School of Crop Improvement. Presently, focused attention is being made on genetic improvement; efficient and cost saving production and resource management strategies and diverse value addition. A number of improved varieties/ rootstocks in different horticultural crops have been identified and notified at State and Central levels for different agro-ecological zones. These improved genotypes have high yields, besides better biotic and or abiotic stress tolerance, high nutraceautical properties and processing attributes have also been developed. Emphasis, is also on use of wild and related species in pre-breeding for evolving desired genotypes. New genotypes have been identified in several crops for their release by the 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

Variety notified by Central Sub-committee on crop standard, notification and release of varieties for horticultural crops

Brinjal: Pusa Vaibhav (DBPR-23): This variety was identified for release in the XXXVII AICRP (VC) group meeting held at TNAU, Coimbatore June, 22-25, 2019 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 in colour with non-spiny green calyx and borne in solitary. The average fruit weight is 250 g and average yield is 41 t/ha with a potential yield of 58 t/ha. This variety has resistance to *Fusarium* wilt, virus complex and little leaf under field conditions. The notification is under process by CVRC.

Cucumber: Pusa Gynoecious Cucumber Hybrid-18 (DGCH-18): It is recommended for cultivation in Zone I [Humid Western Himalayan Region, *i.e.* Jammu & Kashmir (J&K), Himachal Pradesh and Uttarakhand] by AICRP (VC). It is a gynoecy based hybrid with earliness and desirable horticultural traits for spring summer and *kharif* season cultivation. Fruits are attractive and green in colour with mild whitish-green stripes originating from the blossom end and

Pusa Vaibhav (DBPR-23)

DGCH-18

brownish-green blotchy patches present near the stem end. Fruits are 18-20 cm long having soft skin, crispy and tender flesh with average fruit weight of 200-210 g. Fruits become ready for first harvest in 40-45 days after sowing during spring-summer and *kharif* season. Average yield is 24.52 t/ha, which is 31.44% higher than National check PCUCH-3. The notification is under process by CVRC.

Varieties identified by AICRP (VC)

Brinjal: DBR-03: The variety was identified in the XXXVIII Annual Group Meeting AICRP (VC) online held during Sept 25-27, 2020 for cultivation in zone IV (Punjab, UP, Bihar, Jharkhand). It is an early variety suitable for growing in *kharif* season. Fruits are round, shiny purple in colour with light purple stripes towards calyx end. The average yield is 31 t/ha. This variety has resistance to *Fusarium* wilt, virus complex and little leaf phytoplasma under field conditions.

DBR-03

Cauliflower: DCEH-1467: It is the first CMS based high yielding hybrid of early maturity group (20-25@) of Indian cauliflower. The variety was developed by IARI, New Delhi and identified for Zone IV during by XXXVIII Annual Group Meeting of AICRP (VC) Sept 25-27, 2020. It is suitable for sowing in June-July and harvesting in October. Curds are white, compact and plants are semi-erect. Average marketable curd weight is 600-650 g and yield in the range of 22-24 t/ha (41% higher over Pusa Kartik Sankar). Besides the above varieties, two more varieties one each in tropical carrot IPC3 for zone VI and VIII and dolichous bean DB 5 for zone V have been identified byXXXVIII Annual Group Meeting of AICRP (VC).

DCEH-1467

Varieties identified by IARI variety identification committee

Tomato (F_1): Pusa Rakshit (DTPH-60): It is a hybrid variety suitable for cultivation under protected condition. Fruits are round, deep red in colour with average fruit weight of 108 g. The ripe red fruits have high TSS (5.1°Brix) and lycopene content (6.0 mg/100 g). It gives an average yield of 10-12 kg/plant in 7-8 months crop duration. Fruit has thick flesh (8 mm) and it is suitable for long distance transportation. The average yield potential is 20 t/1000 m^2 area under polyhouse.

Pusa Rakshit

Brinjal: Pusa Unnat (DBHL-211): Plants are non-spiny having semi-erect branches with light purple pigmentation on younger leaves, mid-rib and veins. Fruits are long, shiny dark purple, weighing 120-125 g with non-spiny green calyx. Maturity period is between 50-55 days (days to first fruit harvest from transplanting). Average yield is 50 t/ha. It contains higher flavonols (6.98 mg/100 g) and ODH phenols (7.89 mg/100 g).

Pusa Unnat

Pusa Cauliflower Hybrid 3: It is the first cytoplasmic male sterility (CMS) based hybrid in mid maturity group (12-16°C) of Indian cauliflower developed by IARI, New Delhi. Plants are medium in size with short stem and compact white curd. It is suitable for sowing in August end – mid September and harvesting in December under North Indian plains. The PCH-3 is also suitable for sowing in July-August and harvesting in October-December in mid-hill region. Average marketable curd weight is 1150-1250 g and marketable curd yield is 37-39 t/ha (31% higher over Pusa Hybrid 2).

Pusa Cauliflower Hybrid-3

Cucumber-8 (DG-8): Pusa Pickling Cucumber-8: It is the first improved variety of parthenocarpic gynoecious pickling cucumber suitable for cultivation in protected conditions developed for North Indian plains. Fruits become ready for first harvest in 40-45 days after sowing during winter season (off-season, November-March) under low cost polyhouse. Fruits are attractive, uniform, dark green, glossy, cylindrical, straight, ribbed, warty with prickles, and has tender skin and crispy flesh. Average fruit weight is 18-20 g. Average fruit yield 84.9 t/ha (849 kg/100 m^2) during winter season (off-season, November-March) under low cost polyhouse.

Pusa Pickling Cucumber-8

Satputia: DSat-4 (Pusa Tripti): It is an early high yielding variety for spring summer and *kharif* season for North Indian plains. Fruits become ready for first harvesting in 48-50 and 42-45 days after sowing during spring summer and *kharif* season, respectively. Fruits

Pusa Tripti

are elliptical elongated, dark green and have soft flesh at edible maturity stage. Number of fruits/cluster is 5 to 6. Average fruit weight is 20-22 g at marketable stage. Due to its hermaphrodite sex form, it can be successfully grown under insect-proof net house and open conditions during spring summer (March-May) and *kharif* season (July-October). The average fruit yield is 15.5 t/ha.

Summer squash: DS-17 (Pusa Shreyash): It is an early, high yielding flattish-round shaped large fruited (370-420 g) variety of summer squash for winter season (off-season) under protected cultivation for North Indian plains. Fruits become ready for first harvesting in 45-50 days after sowing during winter season (Mid December - Mid February) and in early spring summer season (March-April). Fruits are flattish-round, 370-420 g, main colour of skin is green and mottled like pumpkin, and has tender flesh at edible maturity stage. The average fruit yield is 21.6 t/ha.

Pusa Shreyash

Muskmelon: Pusa Kazri (DMM-148): It is an early maturing muskmelon variety with an average yield of 22.73 t/ha and tolerance to *Fusarium* wilt. Fruit flesh is thick, green, juicy and crispy with medium musky flavour and high sweetness (TSS 12^{0}Brix).

Pusa Kazri

Muskmelon: Pusa Sunehari (DHM-39): It is a speciality melon (C. *melo* var. *inodorous)* and fruit is oblong shape with average weight of about 1.5 kg. Fruit flesh is thick, light orange, juicy and very crispy with no typical musky flavour and high sweetness (13.8^{o}Brix). Its average yield is 5.5 t/1000 m^2 under protected cultivation.

Pusa Sunehari

Spinach: Pusa Vilayati Palak: It is a prickly seeded variety having succulent stem and leaves. Plant is vigorous having completely green stem and leaves. Leaves are smooth, soft having pointed apex with slightly serrated margin. It is a short duration crop

Pusa Vilayati Palak

suitable for 2 cuttings. It recorded high contents of ascorbic acid, iron and calcium (65, 8 and 186 mg/ 100 g, respectively). It is suitable for autumn winter season for both plain and hilly areas. It gives an average green leaf yield of 12 t/ha.

2.1.1 Solanaceous crops

2.1.1.1 Tomato

Development of new promising materials: MAS breeding lines (>25) derived from Pusa Sadabahar, Pusa-120, Pusa Gaurab, Pusa Rohini, and Pusa Ruby as recurrent parents were found promising for ToLCV tolerance, short duration, better resilience to high as well low temperature w.r.t. fruit set.

In station trials, during *rabi* season, 45 breeding lines including F_1s were evaluated for yield and quality traits and during *kharif* season, 35 F_1s were evaluated for ToLCV resistance, yield and quality traits. MAS TOLCV-2 is suitable for growing without stacking, reducing the cost of production and the introgression of *Ty-3* gene was confirmed through linked molecular marker. MAS TOLCV-2 was evaluated using both under natural epiphytotic conditions as well as under controlled conditions, was found promising for ToLCV tolerance. This will be potential genetic stock for resistance breeding programme for rainy and autumn-winter seasons.

Development of ToLCV Hybrid-7 from ToLCV tolerant MAS derived line (ToLCV MAS-1) : Genetic enhancement of IARI released tomato varieties using *Solanum habrochaites* (LA1777) as source of resistance, F_2 population (>200) were screened for ToLCV tolerance during *kharif* 2019. The plants promising for ToLCV tolerance in $F_{2:3}$ population, were evaluated for yield and quality traits during *rabi* 2020. Selected $F_{3:4}$ progenies (20) are being evaluated during *kharif* 2020 for ToLCV tolerance, yield and quality attributes. The genotyping and phenotyping of progenies for *Ty* genes as well as ToLCV tolerance was done at 90 DAT. Two ToLCV resistance promising lines were promoted to AVT-I in AICRP (VC) trials. Two promising lines for ToLCV resistance were promoted to AICRP (VC) ToLCV resistance AVT-II trials.

Evaluation of tomato hybrids for protected condition: Twenty one hybrids along with commercial hybrid GS-600 were evaluated under protected condition. Hybrid DTPH-60 was superior for yield (16.5 q/ 100 $m^{2)}$, with average fruit weight of 105 g, good TSS (5.1°Brix) and lycopene (6.0 mg/100 g) under protected conditions. Hybrid DTPH-60 was also evaluated at farmer's fields/ stations and recorded better performance. Five cherry tomato selections and three hybrids were also evaluated. Selection-1 recorded prolific bearing with fruit yield of 10.5 q/100 m^2 with high TSS (10° Brix). Cherry Selection-3 an orange colour fruits with average yield of 8 q/100 m^2 and desirable TSS (8.5°Brix).

Cherry Selection-1 under protected condition

2.1.1.2 Brinjal

***Promising lines*:** Among the long fruited lines, DBWL-22-1-11 (white long, 350 q/ha), DBGL-187-6-12 (green long, 380 q/ha), and DBPiL-186-3-13-3 (dark pink, 375 q/ha) were found superior for yield, whereas in round fruited lines, DBR-99-3-12-3-4 (black purple, 55.48 t/ha) and DBR-92 (purple round 44 t/ha) were found very promising for fruit yield over check. A white fruited phenolics rich brinjal line DBWR-190-44-3-2-5 was

developed through inter-specific hybridization. The plants are semi-vigorous, fruits oval round, shiny white with green calyx having average fruit weight of 100-110 g. The line had the potential yield of 46.78 t/ha. It is also rich in total phenolics (46.58 mg GAE per 100 g FW), which can serve as a potential antioxidant in human health.

DBWR-190-44-3-2-5

Promising hybrids: In long fruited hybrids, DBHL-112 (72.7 t/ha) and DBHL-101 (63.50 t/ha) were found to be superior over the check Navina (50.50 t/ha). Two long fruited hybrids DBHL-2110 and DBHL-2100; and two round fruited hybrids DBHR-25 and DBR-2340 were promoted to AVT-II, respectively.

DBHL-101

Genetic analysis of fruit bearing habit: Genetic analysis of fruit bearing habit was carried out using 217 F_2 plants of Pusa Safed Baingan 1 (cluster bearing) and Pusa Hara Baingan 1 (solitary bearing). The plants in F_2 generation were segregated into 130 solitary: 31 mixed: 54 cluster habit suggesting recessive epistasis in ratio of 9:3:4. The B_1 (backcross with the recessive parent) plants also showed the expected ratio of 1:1: 2 with 25 solitary, 15 mixed and 33 cluster bearing plants, respectively. The individuals of B_2 (backcross with the dominant parent) had solitary bearing habit.

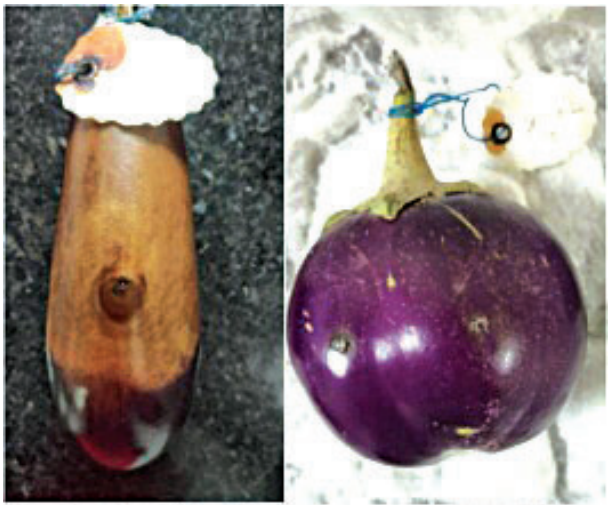
Screening for *Fusarium* wilt resistance: Brinjal lines and hybrids were evaluated in sick plot (spore population of 6.0 x 10^4 CFU/g of soil) for resistance to *Fusarium* wilt. Among the lines, DBR-160-2-3-1-3 and DBR-40-7-10-5 were found highly resistant with DI of 0. The hybrids DBHL-1407, DBHL-112407 and DBHR-4070 were found highly resistant. Among the wild accessions *S. sysimbrifolium* (EC-390352), *S. macrocarpum* (874750022 and EC790354), and *S. torvum* were found highly resistant to wilt.

DBR-160-2-3-1-3

Screening for virus resistance: Among the lines screened for virus resistance (PVY, PVX, ctarlavirus), DB-65, DB-31 expressed resistance to all viruses under field conditions.

Identification of novel heat tolerant lines: Brinjal lines were evaluated under heat stress conditions (March-July). The lines DBL-21 (1.2 kg/plant) and DBL-8 (1.35 kg/plant) were found to be heat tolerant (>40°C day temp) with higher proline content (1.87, 1.57 µmol/g FW, respectively).

Screening for Phomopsis blight resistance: Twenty lines were screened for phomopsis blight resistance after artificial inoculation with *P. vexans*. The lines DB-175 and DBR-112-14 were found to be resistant.



Pusa Kranti DBR-112-1

Promising lines for bioactive compounds: A total of 25 lines were evaluated for biochemical contents. Line DBR-03 was found with highest (221.30 mg/100 g GAE FW) total phenolics. The antioxidant content, CUPRAC was maximum in DBGL-225-2-5-17 (129.65 mg/100 g GAE FW) and FRAP was found to be highest in DB-10 (163.17 mg/100 g GAE FW). The total flavonoids were highest in DBOR-94 (38.91 mg/100 g GAE FW).

2.1.1.3 Chilli

Development of breeding lines: 152 F_3 families and 24 F_4 families were raised during *kharif* 2020 to evaluate for yield and yield related parameters and response to leaf curl disease. Out of these, 56 plants were selected which had good yield as well as tolerance to leaf curl disease.

Trial of promising breeding lines: Five new promising breeding lines (DChV-92, DChV-231, DChV-270, DChV-274 and DChV-295), isolated in the process of population development were evaluated for yield and yield attributing traits. National check used was LCA-334 along with local check Pusa Jawala. Lines DChV-274, DChV-92 and DChV-295 were found promising with yields of 650, 634 and 535 g/plant, respectively in comparison to the national check (515 g/plant).

Fruit bearing in chilli lines DChV-92 and DChV-274

Identification of cold tolerant lines: Several cold tolerant genotypes were identified from three segregating populations, *viz*., Gouri Bidanur × WBC-Sel-5 (F_3), Pusa Sadabahar × Phule Mukta (F_4) and PSH-L & PSH-P (F_3). The cold tolerant genotypes identified were DLS-CT-IR2-1, DLS-P-1R-3, DLS-L-2R-5, and DLS-CT-IR2-2. These lines had green foliage, normal flowering and some fruit set during December to January compared to susceptible genotypes.

2.1.1.4 Capsicum

Identification of high temperature resistant lines: Lines KTC-152, KTC-120 and KTC-130 were found promising with good fruit set at high temperature. F_1 hybrids KTC-130 × YW, KTC-142 × YW and KTC-152 × KTC-131 were also found promising for fruit set. Three CMS lines, namely, KCS-1A, KCS-2A and KCS-3A along with their maintainer lines are being maintained, which are having desirable fruit shape and size along with other horticultural traits. *Phytopthora* resistant line KTC-152 is being maintained for its further use. Total 16 promising advance lines and 37 F_1 hybrids were evaluated under net house conditions during October 2019 to March, 2020. Among the lines KTC-144 (850 g/plant) followed by KTC-130 (810 g/plant) and CW (check) 790 g/plant. In hybrids, KTC-130 × CW (950 g/plant) was found promising followed by KTC-142 × KTC-145 (910 g/plant) and KTC-130 × YW (890 g/plant). Lines KTC-152, KTC-120 and KTC-130 had fruit set at high temperature (40°/28°C day and night) during May.

Development of coloured capsicum: Lines KTC-130 and KTC-145-1 were found promising as coloured capsicum having orange colour fruits having good horticultural traits. The maximum fruit size (8.33 cm length and 5.5 cm width) was obtained in KTC-152 followed by Yellow Wonder (7.0 ×5.5 cm). Maximum average fruit weight was noted in Hybrid-6-3 (105 g) followed by KTC-145 (92.66 g) and KTC-130 (90.66 g). Among the lines, KTC-145 (1100 g/plant), KTC-142 (850 g/plant) and KTC-130 (800 g/plant) were found promising for fruit yield. Three hybrids, *i.e.* KTC-152 × YW, KTC-152 × CW and KTC- 152 × KTC-133 took 80 days to flower after transplanting. Total 24 hybrids were also evaluated for fruit set at low temperature, out of which KTC 142 × YW, KTC-142 × KTC-145 and KTC 142 × CW were found promising for flowering and set during December under net house conditions.

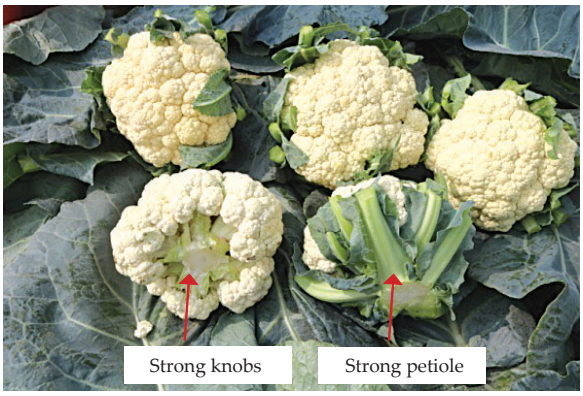
Evaluation capsicum hybrids: Thirty hybrids including one standard check (Asha) were evaluated for yield and its attributing traits at IARI Regional Station, Katrain. Among them, KTCH-27 (36.00 t/ha), KTCH-28 (34.64 t/ha), KTCH-26 (31.53 t/ha), KTCH-8 (30.25 t/ha) and KTCH-17 (29.87 t/ha) performed better over the check cultivar, *viz.* Asha (28.55 t/ha).

Assessment of yellow gypsum in capsicum: During summer/*kharif*, 2020, the effect of application of yellow gypsum was studied on yield and quality traits of var. California Wonder. In first experiment, treatment 100% NPK (recommended dose for the crop) + 20 t/ha FYM+ 60 kg/ha sulphur through yellow gypsum was found best based on yield and quality traits. While, in second experiment, treatment T_6 (Farmers' practice on nutrient management (FP) + sulphur @ 30 kg/ha + Yellow gypsum @ 30 kg/ha) followed by T_5 (Farmers' practice on nutrient management (FP) + lime @ 1/10th LR + Yellow gypsum @ 30 kg/ha) were found best based on yield and quality traits. Besides this, incidence of blossom end rot was reported nil with the application of gypsum in the soil.

2.1.2 Cole crops

2.1.2.1 Cauliflower

Development of new promising lines/hybrids for early and mid-maturity: In total, 160 CMS based F_1 hybrids of early group were evaluated during September-November maturity. None of the hybrid showed harvestable curd maturity in September, but 11 F_1 hybrids were promising for October maturity with marketable curd yield (20 t/ha) and six for November month (25 t/ha). Five F_1 hybrids (DCEH-2171, DCEH-8415, DCEH-1527, DCEH-4167 and DCEH-7523) for October maturity, 4 hybrids (DCEH-9403, DCEH-9923, DCEH-4158 and DCEH-9467) for November maturity were most promising. In mid-early group, 58 CMS based F_1 hybrids were evaluated and promising hybrids (>35 t/ha) were DCMEH-4902, DCMEH-8405, DCMEH 9325, DCMEH 5161, DCMEH 9202 and DCEH 8404. Furthermore, four F_1 hybrids (DCH 312397, DCH 1527 of early group; DCMH 1544, DCMH 8405 of mid-group) advanced to AVT-1 and two F_1 hybrids of early (DCEH 31503, DCEH 7523) and two of mid group (DCMH-8404, DCMH-8476) contributed in AICRP (VC). Twenty five hybrids were evaluated for february-march maturity and the most promising hybrids were KTCFH-5, KTCFH-15, KTCFH-2 and KTCFH-1 for marketable curd yield (>38 t/ha) and other horticultural traits.



DECH 9403

DCEH 2171

DCMH 8404

Screenings of cauliflower lines against black rot (race-1 and 4) and development of mapping population: Ten Indian cauliflower lines were evaluated for resistance to black rot disease (*Xcc* race 1) after artificial inoculation. The lines BR-207, BR 161 were found to be resistant with PDI value of 0.2 and 0.1, respectively. 185 cauliflower collections from India and five other countries were screened for resistance against race-1 and race- 4 through artificial inoculation. Two genotypes (EC-617744 and Kt-301) were identified with credible resistance against race-1 and race- 4, respectively. Genotyping of F_2 population through GBS and phenotyping of the $F_{2:3}$ populations for black rot resistance and other important agronomic traits are going on.

Phenotypic screening of advanced lines for resistance to downy mildew disease: A total of 20 advanced breeding lines were screened for resistance to downy mildew disease through artificial inoculation. Among them, DMR-2-0-7 (progeny of 3-5-1-1 × DC-466), DMR 3-0-8 (advanced progeny of 3-5-1-1 × Improved Japanese), DMR-6-2-2-6-2 (advanced progeny of 309 × BR-2 × BR-2), and DMR-8-4-8-1 (advanced progeny of Pusa Himjyoti × BR-2) were found resistant with DI values of 1.85, 5.926, 0.37%, respectively.

Screening against *Alternaria* leaf blight: Total 327 lines (256 local germplasm; 71 accessions from NBPGR) of cauliflower and related crops were screened against *Alternaria brassicicola* through detached leaf method. Nine lines were identified as resistant (DS: 0≤1) (DC-3003-1, DC-3030-7, DC 351, BR-207, DC-5, DC N392, DC-N386, DC-N345, DC-N214, DCN324 and DC-N270), 36 lines as moderate resistant (DS: 1≤2), 60 lines as moderate susceptible (DS: 2≤3), 118 lines susceptible (DS: 3≤4), and 36 as highly susceptible (DS: 4≤5) F_2 population (190) from DC 67 (ALSS) x vv17 (ASLR) was phenotyped against *Alternaria brassicicola* by detached leaf method and identified quantitative inheritance with recessive nature of resistance. Using detached leaf method, were 133 accessions of *Brassica oleracea* (source: NBPGR, New Delhi) for *Alternaria* leaf spot (*Alternaria brassicicola*) and identified two as resistant and 22 as moderately resistant. Five wild *Brassica* species, namely, *Capsella bursa pastoris* (late), *Capsella bursa pastoris* (early), *Camelina sativa*, *Diplotaxis asergence*, *D. gomezcampoi*, and *D. muralis* were resistant.

Disease scale for *Alternaria* leaf spot for cauliflower genotypes

Introgression of multiple disease resistances in cauliflower: Introgression of *Alternaria* leaf spot resistance was advanced to BC_2F_1 in Pusa Meghna and Pusa Ashwini. Black rot resistance in both varieties was also advanced to BC_3F_1 and BC_2F_2. A genetic stock 'BR-2' was registered for downy mildew resistance with ICAR-NBPGR, New Delhi.

Development of mapping population: 25 F_1 crosses were made using diverse fertile lines and raised for developing double cross for NAM population. Further, F_1 crosses between Purple × White and Orange × White colour genotypes were generated for introgression of *Pr* and *Or* genes, respectively. Both traits showed dominant pattern in F_1s, however, influence of modifiers in recipient parents' background was also visible.

Segregation of orange curd trait in $F_{2:3}$ progenies: The F_2 population for *or* gene segregated in 1 (orange deformed curds): 2 (orange full size curds): 1(white full size) indicating strong penalty on curd development. Further, all the deformed curds had curd rotting symptoms due to *Fusarium equiseti*. 127 $F_{2:3}$ progenies segregated into orange normal to deformed curds (102; *OrOr* or *Oror*) and white normal curd (25; *oror*). One progeny (*Or*-95) produced all medium orange normal size curds, while *Or*-120 produced normal orange and white curds but multiple with shoots. In orange

Deformed orange (Parental type) | Deformed orange | Multi-shoot orange | Ricey orange | Normal size orange | Normal size white (Parental type)

progenies, 28 progenies had single stem plants along with rudimentary/deformed curd, similar to *OrOr* genotype.

Dietary minerals in cauliflower genotypes: Nine dietary minerals namely copper, iron, zinc, potassium, magnesium, manganese, calcium, sodium and sulphur were analysed in leaf and curd fraction of 101 genotypes cauliflower, broccoli (26) and wild Brassicas (49). Genotypes showed wide range for iron (6.5-480.7 ppm), zinc (0.1-526.5 ppm), potassium (5058.8-9975.7 ppm) and sulphur (14.5-137.7 mg/100 g) in curd.

Genetics of black rot resistance in *Brassica napus* and introgression of a genome specific single dominant gene: Two populations, namely, F_2 population (198 plants), *B. napus* in GSL-1 × BN-2, and 106 RILs (F_8) of *Brassica carinata* (NPC-17 × NPC-9) were artificially inoculated with *Xcc* race 1, 4, 6. On the basis of χ square analysis, single dominant gene was found for *Xcc* race 1, 4 and 6 with segregation in 3 R:1 S ratio in *B. napus* and 1 R: 1 S in *B. carinata*. It is feasible to transfer in *B. oleracea via* distant hybridization due to close relationship at sub-genomic level (AC/C). Interspecific hybridization between cauliflower variety Pusa Meghna, Pusa Sharad (susceptible) × *B. napus* "BN-2" was attempted and very less quantity F_1 seed rescued (~40 seeds). Twenty F_1 inter-specific plants were raised, characterized on the basis of morphology and floral traits backcrossed with cauliflower variety "Pusa Meghna" to produce first back cross generation.

Development of pre-breeding genetic stock(s) for black rot resistance: The plants of BC_3F_2 stage of (cauliflower 'Pusa Sharad' × *B. carinata* 'NPC-9') and BC_3F_2 stage of (cauliflower 'DC 401' × *B. juncea* 'Pusa Vijaya') and (cauliflower 'DC 401' × *B. nigra*) were inoculated with *Xcc* race 1, 4 and 6 and resistant plants with cauliflower leaf resembling, dwarf and late bolting were selected for backcrossing to recipient parent of cauliflower and selfing to produce advance stage. Morphological characterization was done for vegetative and reproductive traits. Identified resistant three genetic stocks of *B. napus* (AACC) and one genetic stock of *B.carinata* (BBCC) from segregating population (BC_1F_3) derived from inter-specific hybridization between cauliflower (CC) × *B. juncea* (AABB). Selfed seeds were harvested for achieving stability of the genetic stock and backcrossed with cauliflower for the recovery of C genome specific traits along with *Xcc* resistance.

***B. juncea* derived black rot resistance in cauliflower background carrying *Xcc* 1,4 & 6 BC_2F_3 stage**

Snowball cauliflower

Evaluation of CMS and inbred parental lines-based hybrids: At IARI Regional Station, Kattrain, 120 F_1 hybrids were evaluated during winter season

of 2019-20. The marketable yield of top five hybrids *viz*., KTCFH-50 (41.09 t/ha), KTCFH-16 (40.30 t/ha), KTCFH-57 (39.13 t/ha), KTCFH-101 (38.87 t/ha) and KTCFH-55 (38.44 t/ha) were found higher than the check cultivar 'Pusa Snowball Hybrid-1 (33.38 t/ha)' with the heterosis range of 13.16-18.76 per cent. These promising hybrids need to be tested at multi-locations for stability analysis.


KTCFH-50


KTCFH-57


KTCFH-16


Pusa Snowball Hybrid-1

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

Evaluation of CMS and DH parental lines-based hybrids: Newly developed 90 F_1 hybrids (CMS and DH parental lines based) were evaluated at Baragan Farm, Katrain during winter season of 2019-20. The marketable yield of top five hybrids, *viz*., KTCFDH-28 (47.80 t/ha), KTCFDH-120 (46.70 t/ha), KTCFDH-104 (45.83 t/ha), KTCFDH-22 (45.43 t/ha) and KTCFDH-46 (43.06 t/ha) were found higher than the check cultivar 'Pusa Snowball Hybrid-1 (34.37 t/ha)' with the heterosis ranging 20.18-28.10 per cent. These promising hybrids would be tested at multi-locations for stability analysis.


KTCF-DH-H-28


KTCF-DH-H-104

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

Evaluation of promising snowball cauliflower hybrids in multi-location yield trials: Twenty-five promising F_1 hybrids developed and already tested by ICAR-IARI Regional Station, Katrain were evaluated at three different locations, *viz*., ICAR-IARI Regional Station, Katrain, ICAR-IARI, New Delhi and Dr YS Parmar UHF, Nauni, Solan. At ICAR-IARI Regional Station, Katrain, marketable yield of top five hybrids *viz*., KTCFH-9 (41.15 t/ha), KTCFH-7 (37.89 t/ha), KTCFH-2 (37.14 t/ha), KTCFH-16 (36.74 t/ha) and KTCFH-6 (36.66 t/ha) were found higher than the check cultivar 'Pusa Snowball Hybrid-1 (32.39 t/ha)' with the heterosis ranging from 11.65-21.28 per cent. These hybrids performed well during this year too. Therefore, these hybrids could be carried forward for multi-location trials throughout India and their identification at national level.


KTCFH-9


KTCFH-7


KTCFH-2


Pusa Snowball Hybrid-1

Promising snowball cauliflower hybrids in multilocation yield trials

Introgression of *Diplotaxi scatholica* and *Trachysto maballii* male sterile cytoplasm: During summer season of 2020, 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 *or* and *Pr* genes into different genotypes (Pusa Snowball K-1 and Pusa Snowball K-25) was evaluated during winter, 2019-20. The plants carrying both the above genes will be advanced to the next generation through marker-assisted backcross selection.

Introgression of fertility restorer gene (*Rfo*) into *Brassica oleracea* through inter-specific hybridization: The BC_2 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_2 plants carrying *Rfo* gene will be backcrossed with their respective recurrent parents to get BC_3 progenies.

Utilization of yellow gypsum in cauliflower: During winter, 2019-20, the effect of application of yellow gypsum was studied on yield and quality traits of snowball cauliflower var. Pusa Snowball K-1. Under first experiment, treatment 100% NPK (recommended dose for the crop) + 20 t/ha FYM + 30 kg/ha sulphur through yellow gypsum followed by 100% NPK (Recommended dose of the crop) + 20 t/ha FYM + 45 kg/ha sulphur through yellow gypsum were found best based on yield and quality traits. On the other hand, in second experiment, treatment Farmers' practice on nutrient management (FP) + sulphur @ 30 kg/ha + Yellow gypsum @ 30 kg/ha was found best based on yield and quality traits. The effect of application of yellow gypsum was also studied on yield and quality traits of mid-season cauliflower var. Pusa Hybrid-301 during summer, 2020. In first experiment, treatment 100% NPK (recommended dose of the crop) + 20 t/ha FYM + 30 kg/ha sulphur through yellow gypsum was found best based on yield and quality traits. Whereas, in second experiment, treatment T_6 (Farmers' practice on nutrient management (FP) + sulphur @ 30 kg/ha + Yellow gypsum @ 30 kg/ha) was found best based on yield and quality traits.

Entries contributed in AICRP (VC) trials: During the year 2020, two open-pollinated genotypes of mid-season cauliflower (KTCF-14 and KTCF-25) and two CMS based hybrids of mid-season cauliflower (KTCF-11 and KTCF-22) were contributed in AICRP (VC) IET trials. Besides this, two entries each of open pollinated snowball cauliflower (KTCF-30 and KTCF-33) and mid-season cauliflower (KTCF-2 and KTCF-4) were advanced to AVT-I and AVT-II trials, respectively.

2.1.2.2 Broccoli

Promising lines: Out of ten tropical lines, the promising entries (November end to December maturity) for marketable head yield (>13 t/ha) identified were DC-Brocco-13, DC-Brocco-20-8 and DC-Brocco-15-4 in green colour and Delhi Purple Broccoli-1 (DPB-1) in purple colour. Two promising lines Pusa Purple Broccoli-1 (or DPB-1) and DC-Brocco-13 were advanced to AVT-I in AICRP (VC).

Broccoli 'DC-Brocco-13'

2.1.2.3 Cabbage

Promising lines: 'No-chill type' cabbage genotype 'PA-2' was promising for head yield (31 t/ha) and

PA-2

December maturity (60-65 DAT) and advanced to AVT-II in AICRP (VC). Besides, 15 F_1 hybrids were evaluated at IARI, New Delhi and the best performing entries were KTCBH-2, KTCBH 1 and KTCBH 5 (>40 t/ha) in white cabbage and KTCBRH-7, KTCBRH-12 and KTCBRH-15 in red (>30 t/ha) were promising.

Evaluation of CMS based F_1 hybrids of white cabbage: Five CMS lines were utilized for crossing with 10 EC lines to develop 50 F_1 hybrids and evaluate them for their performance for yield and biochemical traits. Hybrid 6A × EC-686766 recorded significantly the highest marketable yield (66.7 t/ha) followed by 2A × EC-840890 (66.2 t/ha) over the best standard check Pusa Hybrid-81 (47.9 t/ha). Positive and significant heterosis over SC was observed in 6A × EC-686766 (38.9%) and 2A × EC-840890 (37.9%). For nutritional quality traits, hybrid 5A × 686713 (4.93 µ mol trolox/g) recorded the highest CUPRAC value, while hybrid 6A × 686718 (5.52 µ mol trolox/g) recorded maximum FRAP value. Hybrid 208A × EC-840890 recorded to maximum total carotenoids and β-carotene (2.97 mg/100g and 3.82 µg/100 g, respectively) and 2A × 686718 (1.69 mg/100g) recorded maximum lycopene content. Hybrid 208 A × EC-840948 (43.47 mg/100 g) recorded highest ascorbic acid content. Hybrid 2A × 616602 (41.63 µg gallic acid/gfw) exhibited maximum total phenolics. Hybrid 836A × EC-697371 (3.00 mg/100 g) recorded the highest anthocyanin content and surpassed the standard check varieties Pusa Hybrid-81 and Royal Vintage.

Estimation of heterosis over standard check Pusa Hybrid-81 and Royal Vintage for quality traits revealed that 9, 2, 2, 1, 24, 4, 13 and 1 hybrids showed significant positive heterosis over standard check for CUPRAC, FRAP, total carotenoids, β-carotene, lycopene, ascorbic acid, total phenolics and total anthocyanins, respectively.

Evaluation of DH based F_1 hybrids of white cabbage: Among the 57 DH based hybrids evaluated, 5A × 50-1 recorded significantly the highest marketable yield (65.3 t/ha) over the best standard check Pusa Hybrid-81 (47.9 t/ha) followed by 208A × 51-1 (64.9 t/ha) and 208A × 51-19 (63.1 t/ha). The top performing three hybrids showed 36.1, 35.4 and 31.5 per cent increase over the best standard check, respectively. Cross combinations 1A × 51-11, 1A × 51-6, 5A × 51-1, and 5A × 51-11 were observed to be the earliest in maturity (75.5 days) and at par with the earliest check Pusa Cabbage-1 (77.7 days).

Evaluation of promising hybrids of white cabbage: Out of 23 promising hybrids, 5A × Sel-5-83-5 (63.4 t/ha), 6A × Sel-5-KIRC-10 (62.9 t/ha) and 5A × 83-5-83-6-204 (61.0 t/ha) were found superior than the best standard check for yield. These hybrids showed 32.2, 31.2 and 27.2 per cent increase over best standard check, respectively. Hybrid 5A × Sel-5-83-5 (74.0 days) was at par with earliest check Pusa Cabbage-1 (77.7 days) for harvesting days.

Evaluation of F_1 hybrids of red cabbage: Among the 46 CMS based red cabbage hybrid combinations evaluated, hybrids PMA × Sel-5-83-5 (56.2 t/ha) and RCGA × PM (54.7 t/ha) exhibited significantly higher yield over the check Ruby Ball F_1 (39.7 t/ha). Per cent increase over

5A × 50-1 208A × 51-1 5A × 51-7

Promising DH based F_1 hybrids of white cabbage

standard check of these promising hybrids for yield was 41.6 and 37.8 per cent, respectively. Hybrids RCGA × RC (101.2 days) and PMA × Sel-5-83-5 (111.5 days) were significantly earliest in harvesting days than the check (138.7 days).

RCGA × RC hybrid

RCGA × PM hybrid

Promising F_1 hybrids of red cabbage

Diversification of CMS system: BC_5 and BC_6 generations with *Diplotaxi scatholica* and *Trachysto maballii* male sterile cytoplasms are being further backcrossed with cabbage variety Golden Acre as recurrent parent.

Introgression of β-carotene rich '*Or*' gene into cabbage and broccoli: BC_2 populations of the introgressed β-carotene rich gene (*Or*) in cabbage and broccoli genotypes were evaluated in winter, 2019-20. The plants carrying β-carotene rich '*Or*' gene will be advanced to next generation through marker assisted backcross selection.

Two entries of cabbage, *viz.*, KTCB-52 and KTCB-121 were tested in AVT-I (varietal) and advanced to AVT-II. In red cabbage two entries (KTCBR-3 and KTCBR-5) were evaluated in IET and advanced to AVT-I from IARI regional station, Katrain.

2.1.3 Cucurbitaceous crops

2.1.3.1 Bitter gourd

Promising hybrids: Two hybrids, namely, DBGH 246 and DBGH 163 and two hybrids, namely, DBGH 11 and DBGH 26 were prompted to AVT-I and AVT II trials of AICRP (VC), respectively. Twenty eight hybrids were evaluated for yield and related traits and two best performing hybrids were G 48 × Pusa Vishesh (DBGH-4863; 31.23 t/ha), and G 52 × PDM (DBGH-5201; 30.50 t/ha). These two hybrids were entered in IET trials of AICRP (VC).

Susceptible genotype

Virus tolerant genotype: Selection 2

Promising genotypes: One long fruited genotype, *i.e.* Sel 2 was found promising for yield (23.5 t/ha). Its fruits are green, 22-28 cm long, 4.0-4.5 cm diameter with broken ridges, curved at harvesting stage and individual fruit weight 85-95 g. It is tolerant to virus complex including ToLCNDV with the vulnerability index of 18.25% under August sowing in *kharif*.

Seventeen genotypes were under station trial and two genotypes, namely, DBGS 21-06 and DBGS 53-59 were recorded higher yield (24.50 t/ha) followed by DBGS 21-06 (23.66 t/ha) under open field conditions. The fruits of DBGS 21-06 are light green, 21.50 cm long, 14.50 cm girth with pointed tubercles, discontinuous ridges with individual fruit weight of 115 g.

Two selections DBGS 32-1 and DBGS 57 were found promising under polyhouse growing condition and produced fruit yield of 4.10 and 3.85 q/100 m^2 with

DBGS 21-06

individual fruit weight of 95 and 120 g, respectively. The fruits of DBGS 32-1 are light green, smooth; fruit matures after 57 days of planting. The fruits of DBGS 32-1 are light green, smooth; fruit matures after 56 days of planting, where as the fruits of DBGS 57 are dark and glossy green with blunt tubercles and fruit matures at 65 days of planting.

2.1.3.2 Cucumber

Development and evaluation of promising genotypes: During spring summer 2020, 119 germplasm/advance breeding lines including 14 new collections and 15 tropical gynoecious lines were evaluated and promising lines were maintained. Lines DGC-102 and DGC-103 had stable performance at average day temperature of 40-45^{0}C. Out of 23 new collections evaluated under replicated trial, DC-39 and DC-43 showed consistently good performance with respect to fruit size, quality traits and yield (18.3 and 17.9 t/ha) showing an increase of 17.3 and 14.7% higher over national check Pant Khira-1 (15.6 t/ha), respectively.

Promising hybrids: Out of 43 F_1 hybrids evaluated, gynoecious hybrids DGCH-31 and DGCH-40 yielded 25.4 and 27.7 t/ha, respectively. Introgression of gynoecious parthenocarpic traits to our promising indigenous lines having desirable horticultural traits was carried out taking DC-83, DC-43 and DC-48 as recurrent parent and crosses were made with the promising line and Pusa Seedless Cucumber-6 as non-recurrent parent (male parent) and F_2, B_1 and B_2 generations were developed.

Promising gynoecious parthenocarpic lines: Fourteen lines were evaluated of which DPaC-41 and DPaC-59 were found promising for yield (1250 kg and 1321 kg per 100 m^2) in polyhouse, respectively. Two new gynoecious parthenocarpic F_1 hybrids were broken by using silver thiosulphate for induction of male flowers and simultaneously selfing and individual plant selection were carried out on the basis of true gynoecious and parthenocarpic trait. Further, eight gynoecious hybrids broken last year were advanced to F_3 generation. Twelve gynoecious parthenocarpic hybrids, which were evaluated and DPaCH-7 was found most promising for yield, earliness and other desirables horticultural traits showing an yield of 1450 kg per 100 m^2 polyhouse.

Screening for downy mildew and development of mapping population: During *kharif* 2020, 145 lines were screened for downy mildew resistance under natural and challenged inoculation conditions. DC-77 (16.3 t/ha) and DC-70 (17.9 t/ha) showed highly resistant disease reaction against downy mildew having high yield, earliness and other desirable horticultural traits as compared to local resistant check Barsati (14.2 t/ha), Pahari Barsati (12.8 t/ha) and Panipat Local (15.6 t/ha). Out of 112 F_1 hybrids evaluated DCH-16 (22.3 t/ha) and DCH-19 (19.8 t/ha) were promising with high yield and tolerant to downy mildew disease. The genotypes, DC-77 and DC-70 were also found resistant through artificial inoculation among the 51 genotypes.

Identification of *Cucumis* sp. and accessions with resistance to leaf curl and development of mapping population: A large collection *Cucumis* genotypes including 172 *C. sativus* var. *sativus* and 54 wide accessions of *Cucumis* (*C. sativus* var. *hardwickii*, *C. callosus* and *C. metuliferous*) were evaluated for resistance against leaf curl disease in cucumber, which predominantly caused by ToLCNDV both under natural field conditions and forced white fly inoculation. Majority of the accessions were found to be highly susceptible, while one genotype of *C. hardwickii* (H-16) and one genotype of cultivated cucumber (DC-61) showed effective resistance against leaf curl disease with a score of less than 2.0 on a scale of 0-9. F_1 and F_2 and back-cross progenies were developed involving DC-48 × H-16 and DC-83 × DC-61. These populations will be used for inheritance study and development of mapping population for leaf curl resistance.

Identification of *Cucumis sativus* var. Hardwickii with ToLCNDV resistance and development of mapping population: Among *C. 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 on a 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). These F_1 populations will be further evaluated and utilized in developing F_2

and back-cross population. The presence of ToLCNDV was confirmed in all the infected leaf samples through ToLCNDV specific primers.

Identification of cucumber genotypes with resistance to downy mildew and development of mapping population: One hundred and fifty-four genotypes were evaluated against resistance to downey mildew caused by *Pseudoperenospora cubensis* both under natural field conditions in the time with maximum disease appearance (September-November) and through artificial inoculation. Two genotypes, DC-70 and DC-77 showed credible resistance under both conditions. They were used to develop F_1 population with two highly susceptible genotypes, DC-748 and DC-749 for development of F_2, BC and RILs for studying the inheritance and development of mapping population for DM resistance genes.

Development of mapping population for extended shelf-life and high β-carotene content: Four F_2 and back-cross progenies were developed by utilizing novelgeno types, DC-48 (staygreen trait with extended shelf-life) and AZMC-1 (high β-carotene content with orange flesh). The progenies will be used for development of recombinant inbred lines (RILs) for fine mapping of genes/QTLs for extended shelf-life and high β-carotenoids in cucumber.

2.1.3.3 Sponge gourd

Development of promising selections and F_1 hybrids: A total of 47 germplasm including 2 accessions of wild species *Luffa echinata*, 3 accessions of *L. graveolens* and 20 accessions of *L. hermophrodita* (*Satputia*) were evaluated and maintained. Out of 28 selections evaluated in replicated trial during spring summer season, DSG-511 (15.2 t/ha) and DSG-43 (14.7 t/ha) were found to be very promising with respect to yield and superior fruit quality traits as compared to national check Kalyanpur Hari Chikni (12.1 t/ha). DSG-33 (14.4 t/ha) was advanced to AVT-II in AICRP (VC). Out of 59 sponge gourd F_1 hybrids evaluated, DSGH-132 (24.5 t/ha) and DSGH-134 (22.1 t/ha) were found to be very promising as compared to national check Kalyanpur Hari Chikni (12.1 t/ha). The promising lines DSGH-38 and DSGH-95 was advanced to AVT-I and AVT-II of AICRP (VC) trial, respectively.

During *kharif* season 46 advanced breeding lines were screened for *Tomato leaf curl New Delhi virus* the promising line DSG-29(17.8 t/ha) showed highly resistant reaction to Tomato leaf curl New Delhi virus with other desirable horticultural traits. The DSG-29 was submitted for multi-location testing for its release for Delhi NCR.

Genotypes with resistance against ToLCNDV: DSG-7, a sponge gourd genetic stock having high resistance to *Tomato leaf curl New Delhi virus* during *kharif* season has been submitted for registration to ICAR-NBPGR, New Delhi. Its fruits are elongated (15-20 cm), straight, light green with thin skin and tender flesh. Average fruit weight is 110 g. It is ready for first harvesting in 45-50 days during *kharif* season and 50-55 days in the spring summer season. Average fruit yield is 16 t/ha. The results were further confirmed through challenge inoculation with purified strain of the virus under insect proof green house at Virology Unit, Division of Plant Pathology, IARI, New Delhi.

DSG-7

2.1.3.4 Ridge gourd

Promising selections: In ridge gourd, out of 35 selections, DRG-20 was found to be very promising showing a yield of 17.5 t/ha as compared to Pusa Nutan (16.6 t/ha). Eight true breeding gynoecious lines

were evaluated on the basis of colour, shape and size. DRGGL-8 had light green attractive colour, long fruit (20-25 cm) and true gynoecious character and found to be most promising and maintained by spraying sliver thiosulphate and simultaneously utilized for hybrid development. Out of 18 F_1 hybrids evaluated gynoecious based F_1 hybrid DRGGH-12 (18.8 t/ha) and DRGH-8 (18.5 t/ha) were found promising and were advanced to AVT-I and AVT-II of AICRP (VC) trials, respectively.

2.1.3.5 Muskmelon

Novel source of resistance for ToLCNDV resistance: Fifty-six germplasm from different horticultural groups were screened in field under natural conditions as well as under challenged inoculation with viruliferous white flies under controlled conditions for identification of ToLCNDV resistance in Indian melon germplasm. Novel source of ToLCNDV resistance from Indian melon germplasm was identified in *Cucumis melo* var. *momordica* accessions DSM-132 & DSM-19. The most susceptible genotypes were found as oriental melon genotype DOM-118 (*C. melo* var. *conomon*), Pusa Sarda and Pusa Sunehari (*C. melo* var. *inodorous).* They have been utilized for population development for study of inheritance of resistance gene(s).

2.1.3.6 Pumpkin

Promising genotypes: Fifty-five genotypes were evaluated for yield and yield related traits, out of which five genotypes (DPU-150, DPU-136, DPU-14, DPU-41 and DPU-165) were found promising. The plants of DPU-150 was medium viny with spherical fruits, light ribs, orange flesh, average fruit weight 2.8 kg and flesh thickness 3.5 cm. The fruits of DPU-136 and DPU-41 were flattish-round having average fruit weight of 2.4 and 2.1 kg, dark yellow orange flesh with thickness of 2.9 and 2.7 cm, respectively. The plants of DPU-14 was medium viny with flattish round fruits, medium ribs, orange flesh, average fruit weight 2.5 kg and flesh thickness 2.9 cm. The fruits of DPU-165 were flattish-round having average fruit weight of 1.6 kg and flesh thickness of 2.4 cm, respectively. The genotypes DPU-41 and DPU-43 showed field resistance against begomovirus (ToLCNDV) and potyvirus (PRSV) causing leaf curl disease.

With the objective of improving plant ideotype, carotenoids content and flesh quality in pumpkin, promising plants were selected in the F_3 progenies of 15 crosses of pumpkin × butternut squash, 25 crosses of butternut squash × pumpkin hybrids and 5 crosses of butternut squash × butternut squash hybrids. Twenty segregating generations (8 F_4, 6 F_5 and 6 F_6) of pumpkin were further advanced and promising individual plants were selected in each generation.

Promising hybrids: Fifty-five F_1 hybrids were developed and evaluated for yield and related traits in the spring-summer season. The best performing F_1 hybrids in small fruit segment were DPUH-6414 (average fruit weight 2.75 kg, flesh thickness 4.0 cm), DPUH-4529 (average fruit weight 2.90 kg, flesh thickness 3.5 cm) and DPUH-4550 (average fruit weight 2.30 kg, flesh thickness 3.0 cm). In the medium fruit size segment, DPUH-1417 (average fruit weight 4.10 kg, flesh thickness 4.1 cm) and DPUH-4114 (average fruit weight 4.00 kg, flesh thickness 3.1 cm) were found promising.

DPUH-6414

2.1.3.7 Bottle gourd

Quality evaluation of bottle gourd hybrids: Twenty-one F_1 hybrids were evaluated for different quality parameter of fruits, *viz.* dry matter, ash content, total phenols, antioxidants (CUPRAC and FRAP), total proteins, calcium, magnesium, phosphorous, potash, sodium, manganese, iron, zinc and copper. The cross

IC 588084 × Narendra Rashmi recorded maximum ash content (22.37%), while minimum total phenols was observed in Pusa Santushti×Pusa Sandesh (0.33% DW). Among the hybrids, maximum antioxidants (CUPRAC and FRAP) were recorded by the cross Pusa Santushti × Narendra Rashmi (0.19% DW) and Pusa Naveen × Pusa Santushti (0.40% DW), respectively. Maximum total proteins were recorded for the cross Pusa Sandesh x IC 415716 (14.04% DW). The average calcium content among F_1 hybrids ranged from 4.02 to 9.22 mg/g DW with an overall mean of 5.87 mg/g DW. Hybrid Pusa Naveen × Narendra Rashmi recorded the highest calcium content of 9.22 mg/g DW. The magnesium content in F_1 hybrids was ranged from 9.04 to 12.29 (Pusa Sandesh × IC 415716) mg/g DW, phosphorous from 2.41 to 8.34 mg/g DW. The cross IC 415716 x IC 588084 recorded highest (8.34 mg/g DW) phosphorous content; average potash content from 6.27 to 30.48 mg/g DW; sodium content ranged from 0.29 to 1.40 (Pusa Naveen × Narendra Rashmi) mg/g DW. The average manganese ranged from 13.60 to 87.67 µg/g DW with an overall mean of 51.46 µg/g DW (Pusa Sandesh × IC 415716), while iron content ranged from 87.82 to 231.75 µg/g DW (Pusa Naveen × IC 588084); average zinc content from 24.08 to 44.68 µg/g DW with an overall mean of 32.96 µg/g DW. The cross Pusa Naveen × IC 415716 recorded the highest (44.68 µg/g DW) zinc content, while average copper content ranged from 5.73 to 15.43 µg/g DW and cross Pusa Naveen × IC 588084 recorded the highest (15.43 µg/g DW) copper content.

2.1.4 Malvaceous crop

2.1.4.1 Okra

Promising hybrids and yield and YVMV & ELCV resistance: Forty-eight F_1 hybrids were evaluated alongwith 26 private sector hybrids for yield, quality and disease resistance. DOH-3, DOH-7, DOH-9 was found highly resistant to bhendi yellow vein mosaic virus (BYVMV) and enation leaf curl virus resistance (ELCV) both under field conditions and through PCR reaction. DOH-3 recorded maximum yield 275 q/ha followed by DOH-9 (273 q/ha) and DOH-7 (270 q/ha).

Promising lines YVMV & ELCV resistance: Forty-four parental lines and 17 advance lines (F_4-F_9) were evaluated and DOV-92 was found most promising for yield (231 q/ha), resistant to YVMV and ELCV diseases. DOV-69 recorded good yield 203 q/ha, YVMV and ELCV resistance both under field conditions. Fruiting starts at lower nodes (4th node) and pods tender up to 10 days with pod length of 12 cm even 7 days after anthesis. Individual plant selection was made from advance lines, namely, DOV-6490, DOV-6126, DOV-6128 and DOV-6496 (>25 long fruits), which were found high yielding; dark green fruited with resistance to YVMV and ELCV diseases. Among lines and hybrids evaluated, private hybrid Shakti and US-8063 recorded 100% ELCV incidence and IC-685583 and Pusa Sawani recorded 92 and 88% YVMV incidence.

Among the one red fruited okra line and hybrids evaluated, the hybrid DOH-68 was resistant to both the diseases under field condition and recorded 243 q/ha fruit yield with anthocyanin content of 415 ppm. More than 25 fruits/plant were recorded in DOV-69 and DOV-92. Fruiting at shorter internodes was recorded in DOV-69 (3.5cm), DOV-6490 (4.0 cm), DOV-6126(4.2 cm) and DOV-6492(4.5cm).Among 15 genotypes evaluated for insect resistance, DOV-92 was found highly resistant, 4 genotypes (IC-090491, DOV-17, Pusa Sawani and DOV-69) moderately resistant, while wild genotype *Abelmoschus caillei* was found highly susceptible to red spider mites. One okra variety DOV-

Fruiting at shorter internodes in YVMV and ELCV resistant line DOV-69

Promising high yielding okra hybrid DOH-7 having resistance to YVMV and ELCV disease

9 promoted to AVT-I trial during 2020. The breeder seed of newly notified variety Pusa Bhindi-5 was supplied to National Seeds Corporation for large scale seed production.

2.1.5 Root and bulbous crops

2.1.5.1 Carrot

Promising genotypes: Fifty-five genotypes/breeding lines were assessed for quantitative and quality traits. Based on the quality for root shape, surface, external & internal colour and external appearance, the promising genotypes identified were DCat-13, DCat-53, DCat-122 and DCat-7.

Promising hybrids: In normal season, 30 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 and internal colour, self-core and external appearance, the promising F_1 hybrids were DCatH 9848, DCatH 531, DCatH 5313 and DCatH 981. Sixty CMS based F_1 hybrids were assessed for mineral nutrients. The promising hybrids for various nutrients were, DCatH 9139 for potassium (441.72 mg/100 g DW), DCatH 533for calcium (120.57 mg/100 g DW), DCatH 9800 for iron (512.62 µg/g DW) and DCatH 739 for zinc and copper (43.71 & 12.06 µg/g DW).

DCatH 9848

Hybrid evaluation temperate carrot: Fifty-five F_1 hybrids of temperate carrot developed by using 10 CMS lines were evaluated for yield and its contributing traits against Pusa Nayanjyoti as check. A total of 5 hybrids, *viz*. KT-48 A × New Kuroda (34.89 t/ha), KT-28 A × KS-21 (32.98 t/ha), KT-10 A × KS-21 (31.97 t/ha), KT-80A × KS-59 (30.26 t/ha) and KT-10A × New Kuroda (29.40 t/ha) were found superior than the check cultivar (24.2 t/ha).

Entries contributed in AICRP (VC) trials: Two open pollinated varieties, *viz*. KTTC-50 and KTTC-59 were advanced to AVT-I testing under AICRP (VC) trials.

2.1.5.2 Onion and garlic

Breeding for higher yield in onion and garlic during *rabi* season: In onion, 40 accessions were evaluated for yield and other horticultural traits. Pusa Shobha had recorded the highest yield (30.3 t/ha) followed by NHRDF Red-4 (29.9 t/ha) and Early Grano (29.8 t/ha). Six commercial hybrids alongwith local open-pollinated varieties were also evaluated. Hybrid T821 recorded significantly higher yield (41.3 t/ha) as compared to others. In garlic, 30 accessions were evaluated for yield and other horticultural traits. G282 recorded the highest yield (10.4 t/ha), which was

a. KT-48 A × New Kuroda b. KT-28 A × KS-21 c. KT-10 A × KS-21 d. KT-80A × KS-59 e. KT-10A × New Kuroda

Promising CMS based hybrids of temperate carrot

significantly at par with PGS207 (10.0 t/ha) followed by G386 (10.0 t/ha), G41 (9.7 t/ha) and Bhima Omkar (9.7 t/ha). The lowest yield was recorded in Yamuna Safed (1.4 t/ha).

Breeding for *kharif* season: Two promising elite breeding lines, 20PKOSW (2020HORT) and 20PKOSR (2020ENTO) alongwith six *kharif* varieties were evaluated for bulbing under *kharif* season. It was observed that highest plant survival (35.8%) was observed in 20PKOSW followed by 20PKOSR (33.4%).

Promising breeding lines for *kharif* season under Delhi conditions

All the recommended varieties for *kharif* season had survival rate of less than 25%. The highest bulb forming ability was observed in 20PKOSW (51%) followed by 20PKOSR (46.8%). Both the lines have higher yield potential as compared to the recommended varieties.

Breeding for bolting tolerance: Fifty-five breeding lines were evaluated for bolting tolerance and transplanted on 22nd October. None of the material was found to be tolerant to bolting and the bolting percentage was observed to be more than 80% in all the evaluated genotypes.

Breeding for Stemphylium blight resistance: A total of 110 onion and allied species were screened for *Stemphylium* blight resistance under artificial inoculation conditions. Conidial suspension of $1x10^6$ was sprayed and based on the percent disease index (PDI), one *Allium* species, *viz.*, Leek (*A. ampeloprasum* L.) was found to be immune. Highly susceptible onion lines were AVON1021, OREA-19-48, OWTA-19-94 and OWTA-19-96. The marketable yield ranged from 4.0-26.7 t/ha. Based on the yield data, Early Grano, Hisar3, PC2019RB021, Phursungi Local, VL Pyaz, PC2019RB026, Bhima Red and PC2019RB055 recorded marketable yield of more than 20 t/ha. Thirty-five genotypes were evaluated for bulb production though seedlings. In the marketable bulb, the proportion of bulb was higher than the foliage suggesting lower leaf volume at harvesting is a desired trait for improving *kharif* onion yield. Six genotypes yielded more than 20.0 t/ha marketable yield. The most promising genotypes were KP-62 (24.35 t/ha), followed by KP-127(23.34 t/ha) and KP-41 (22.81 t/ha).

Screening of onion genotypes against *Alternaria alternata*: High mortality of *kharif* onion seedlings upon transplanting during first week of September were due to *Alternaria alternata* and *Stemphyllium vesicarium*. The inoculum in terms of conidia was found high for *A. alternata*. Pure culture of *A. alternate* was used for challenge inoculation of onion genotypes in late *kharif* using spore suspension (2×10^4/ml). The initial symptoms suggest presence of resistance in the allied species, namely, *A. galanthum* and *A. fistulosum*.

2.1.6. Leguminous crops

2.1.6.1 Garden Pea

Assessment of promising lines in station trials: Among new bulks, GP 1501, GP 1502, GP 1503, GP 1504, GP 1505, GP 1701, GP 1703 and GP 1705 were found promising. Entries evaluated under AICRP (VC)

KP 62 | KP 127 | KP 41

Onion Genotypes

trials were, GP 1001 (early AVT-II), GP 1102 (AVT-I) and GP 1101 (early IET) and GP 1505 (PMR IET).

Screening for resistance to *Fusarium* wilt disease: Thirty-two germplasm and 94 crosses (39 F_2, 37 F_3, 18 F_4) were evaluated in wilt sick plot for screening and selection wilt resistance. The genotypes GP6, GP17, GP48, GP 55, GP473, EC 927771, GP17x 2015/ PEV-3, GP 48x 2011/PEV-3-1, GP 48x 2011/PEV-3-2, GP55 x 2011/PEV-2-1, E-6 x EC677214-1 and GP 6 x GP55/GP 55-2 showed high degree of wilt resistance.

Screening for resistance to powdery mildew disease: Highly resistant genotypes were identified as GP6, GP 473, GP 1001, GP 1101, GP 1102, GP 1505, GPE 1, GPE 3 and GPE4.

Development of new lines and handling of segregating materials: A total of 435 crosses (18F_1, 46 BC_1, 26F_2, 102F_3, 23F4, 22F_5, 35F_6) were retained for further evaluation/selection. Thirty-six new crosses were developed, besides, 20 progenies of a cross of edible podded lines were retained for further selection.

Screening for heat tolerance: Out of 70 genotypes, GP 55, GP 57, EC 598638, GP916, GP473, GP 912-II, VP 233, VP438-2, and EC 598646, showed the pod set at high temperature.

The F_2 population derived from VRP-6 × N-8 were raised in artificially inoculated *Fusarium* sick pot exhibiting resistant and susceptible plants in segregating population

Genetics of *Fusarium* wilt in wild pea: The F_2 population derived from VRP-6 × N-8 were raised in artificially inoculated *Fusarium* sick pots. On the basis of chi square analysis a single dominant gene (*Fw*) was found carrying resistance in *P. sativum* ssp. *elatius* (N-8) for *Fusarium* wilt with 3 R:1S segregation. This gene will be used for introgressing *Fusarium* wilt resistance in early maturing garden pea varieties.

Identification of host plant resistance against *Fusarium* wilt in *Pisum* species: Total 100 *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, those were developed by inoculating four virulent *Fop* isolates during Oct-January 2020. Total 12 accessions were found highly resistant against all four virulent *Fop* isolates in which two of *P. fulvum* (N-3, N13), one of *P. elatius* (M2), four of *P. sativum* var. *elatius* (N-6, N8, N11, N14) and five of *P. sativum* (M13, Hyd32-sel-2, Hyd26, Hyd51-sel-1, and Hyd42 sel-1).

Advancement and development of breeding population for *Fusarium* wilt resistance: Twenty two F_2 populations, namely, Arkel × N-8, VRP-5 × N-8, VRP-6× N-8, MA-7 × N-8, Pusa Pragati × N-8, PB-89× N-8, Arkel × N-14, VRP-5 × N-14, VRP-6× N-14), MA-7 × N-14, Pusa Pragati × N-14, PB-89× N-14, MA-7 × NB-4, Pusa Pragati × M1, Arkel × M2 VRP-5 × M1 Pusa Pragati × M5, VRP-5 × NB3, Arkel × NB-5, Arkel ×NB4, VRP-6× NB3, MA-7 × M1 and fifteen backcross introgression populations (BC_1/BC_2) were raised and advanced to F_3. Single plant selections were made for early maturing with *Fusarium* wilt resistance and good transgressive segregates.

2.1.6.2 Other legumes

Development of New lines: Dolichos bean entries DB 3 and DB 5 were tested in AVT-II, DB-23 in AVT-I and DB-24, DB-27 in IET and DB 10 as National check. Cowpea entry CP-60 was tested in cowpea (Bush) IET.

2.1.7 Lettuce

Promising genotypes: Thirty one lines were evaluated and promising lines were maintained. DLS 134 (green leafy type), DL 128 (green leafy type) and

DLS 110 (butterhead red type) showed consistently good performance and yielded 41.7, 39.1 and 35.4 t/ha showing an increase of 29.9, 21.8 and 10.2%, respectively over check Chinese Yellow (32.1 t/ha). Selection DLS-101 (heading type) was found to be promising with an average yield of 32.4 t/ha having uniform reddish colour head.

2.2 FRUIT CROPS

2.2.1 Mango

Identification of new mango hybrids: The two mango hybrids, namely, Pusa Deepshikha (H-11-2) and Pusa Manohari (H-8-11) have been identified by Institute Variety Identification Committee for their release from the Delhi State Seed Sub-Committee for National Capital Region. The salient features of these varieties are given below:

Pusa Deepshikha (Hybrid 11-2): It is a cross between 'Amrapali' x 'Sensation' having regularity in bearing and uniform sized fruits. Fruits are oblong in shape, bright red peel with orange-yellow pulp, moderate TSS (18.67° Brix), high pulp content (70%) and ascorbic acid (35.34 mg/100 g pulp), β-carotene (9.48 mg per kg pulp), good shelf-life (7 to 8 days) at room temperature. It is semi-dwarf and suitable for medium density planting (6 m x 6 m).

Pusa Deepshikha (H-11-2)

Pusa Manohari (Hybrid 8-11): It is a cross between 'Amrapali' x 'Lal Sundari', regular bearing and having field tolerance to mango malformation (10-15%). Trees are semi-vigorous and suitable for medium density planting (6 m x 6 m). Medium-sized (223 g) fruits have greenish-yellow peel with red tinge on shoulders, yellowish-orange pulp, fibreless, good TSS (20.38°Brix), acidity (0.27%), ascorbic acid (39.78 mg/100 g pulp) and β-carotene content (9.73 mg per kg pulp).

Pusa Manohari (H-8-11)

Mango hybridization and hybrid evaluation: During March 2020, five cross combinations were attempted on 473 panicles having 3,203 flowers employing Amrapali as female parent and Sensation, Vanraj, Tommy Atkins, Pusa Arunima and Janardan Pasand as male parents. From these crosses, a total of 66 hybrid fruits have been obtained out of which 48 germinated. In addition, 176 panicles having 453 flowers were crossed using Olour, Kurukkan, Bappakai, 13-1 and Amrapali genotypes for rootstock improvement. Out of these, 27 seedlings were recovered for further evaluation.

Mango hybrids (87) were evaluated for 20 physico-chemical traits. Amongst hybrids, the maximum fruit weight (269.07 g) was observed in Pusa Deepshikha followed by H-1-11, H-1-5, H-1-1, NH-7-2 and H-3-2. Significant variation has also been observed for the fruit shape and stone parameters. The pulp content in hybrid progenies varied from 46 to 75 per cent and total soluble solids content ranged from 14 to 27°Brix. Fruits of hybrids H-11-2, H-12-5, H-12-6, H-22-2, H-17-4 and H-3-2 had red colouration on fruit shoulder, while Pusa Manohari (H-8-11) showed field tolerance to floral mango malformation. Score for fruit blush ranged between -5.62 (H-3-7) to 3.77 (H-1-1).

H-1-5

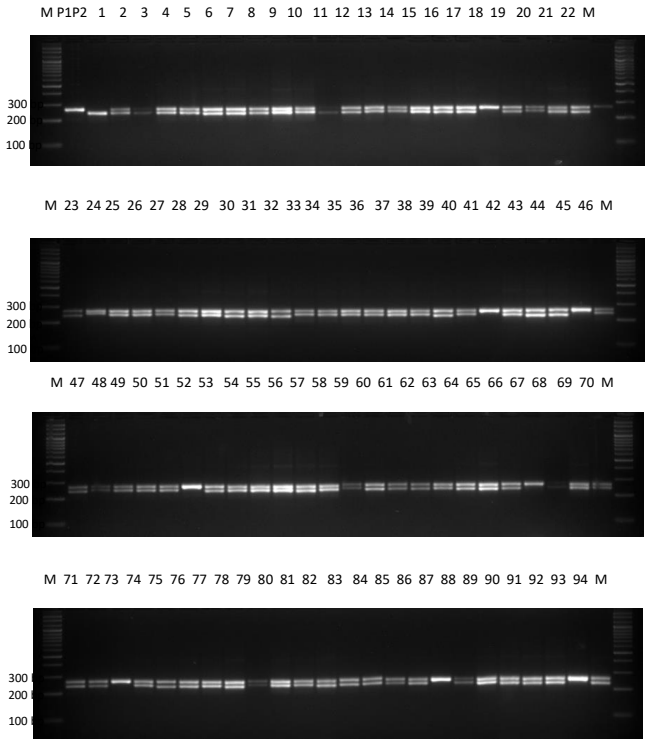
H-1-11

H-12-6

H-22-2

Three-year-old progenies of rootstock Olour x Amrapali were evaluated for plant height, number of leaves, inter-nodal length, total phenolic and flavonoid contents in the leaves. Significant variation was recorded for plant height (53.5 to 146 cm) with a mean of 94.82 cm and the coefficient of variation was 22.19. The number of leaves ranged from 18 to 98 with a mean value of 43.6. The internode length also varied from 2.5 to 9.7 cm with a mean of 5.95 cm. Total leaf phenolics and flavonoids content significantly varied in the progeny population, *i.e.*, 870 to 3,370 mg/100 g and 680 to 2,960 mg/100 g, respectively. The coefficient of variation of the total phenolics (27.17) and flavonoids (25.36) were within the acceptable limit.

Identification of mango SSRs for parentage (Amrapali x Sensation) confirmation: Mango SSRs (MSSRs) designed from Amrapali genome sequences were screened against Amrapali and Sensation parental genotypes. Out of 212 polymorphic MRRs, only one, *i.e.* 8 MSSRs showed polymorphism in terms of homozygous for '*a*' allele in Amrapali and homozygous '*b*' allele for Sensation and *vice versa*. These MSSRs were used for assignment of parentage of hand-pollinated Amrapali x Sensation hybrids and open-pollinated Amrapali seedlings. The MSSRs were mapped backed to the Amrapali genome version 3.0



MSSR-M109 profile of Amrapali (P1), Sensation (P2) and 94 hybrid progenies

NCBI GenBank database, of which, M109, P125, M15 and M73 assigned parentage to more than 88.0% of hand-pollinated bi-parental progenies. P125 confirmed parentage in 93.61% progenies followed by M109 (90.43%), M15 (89.36%), M73 (88.29%). Markers M109, P125 and M73 were further used for assignment of parentage of open-pollinated seedlings of Amrapali. Out of 22 OP seedlings, only two seedlings showed the identical heterozygous allelic pattern and thus their hybrid origin was confirmed. It is concluded that MSSRs (P125, M109, M15 and M73) from Amrapali genome have immense value in MAS in mango and can be utilized for early-stage selection of true hybrids. MSSR-M109 profile of Amrapali (P1), Sensation (P2) and 94 hybrid progenies.

2.2.2 Citrus

New sweet citrus scion hybrids: During 2020, 17 sweet citrus scion hybrids (Pummelo x sweet orange) were examined for growth, yield and fruit quality parameters. Hybrids SCSH-7-2/12, SCSH-11-9/13 and SCSH-11-15/12 were found promising with regard to moderate fruit weight (380-535 g), higher juice content (40.01% for SCSH-11-9/13 and 45.33% for SCSH-11-15/12). This orangelo also exhibited lower acidity content (0.86 to 1.12%) with low seeds (<34 seeds/fruit) compared to pummelo (female parent).

SCSH-11-15/12

SCSH-11-15/12

New acid citrus scion hybrids: Growth performance of 23 limmo hybrids of acid lime x lemon have been observed for growth, fruiting and yield parameters. One hybrid (Pusa Abhinav x Konkan Seedless) was found to be highly precocious and flowered within three years of *in vitro* culture. Compared to commercial acid lime cultivars, hybrid ASCH-3-2/2018 produced > 6% bigger fruits with better (>7%) acidity and tolerant to citrus canker. This hybrid had tendency of round the year fruiting with the peak during September-October.

Bearing in acid citrus hybrid ACSH-3-2/18

Clonal selection in lemon: Of the ten lemon collections evaluated the highest fruit weight was recorded in LS-5 (55.98 g) but was statistically at par with most of the collections except Lucknow Seedless (47.30 g). The lemon collections were found to have thin peel (0.73-0.91 mm) except LS-1 and LS-4 (1.05 mm), while LS-7 was found absolutely seedless. LS-7 had the highest juice content (41.87%), followed by LS-1, LS-3, LS-4, LS-5 and Lucknow Seedless, lowest was in Jammu Local (30.00%). The juice TSS was registered highest in LS-1 (8.42°B), followed non-significantly in LS-5, LS-7 and Lucknow Seedless, though LS-1, LS-7 and Kagzi Kalan had a significantly higher amount of acidity (4.66-4.94%).

Evaluation of new citrus fruits: W-Murcott tangerine produced the highest number of fruits (386.00/ tree) and was ready to harvest by 7th November (47 days earlier than Kinnow) with aborted seeds. Fruit weight a was highest in Kinnow (218.62 g). The highest juice TSS content was recorded in W-Murcott (10.14°B), which was statistically at par with Kinnow. The fruits of W-Murcott had thin peel (2.20 mm) and titratable acidity (0.64%) too, although acidity was lowest in Minneola (0.56%). Both W-Murcott and Minneloa were

statistically similar with respect to juice content (59.69-59.87%), while ascorbic acid was highest in Daisy (58.61 mg/ 100 ml juice).

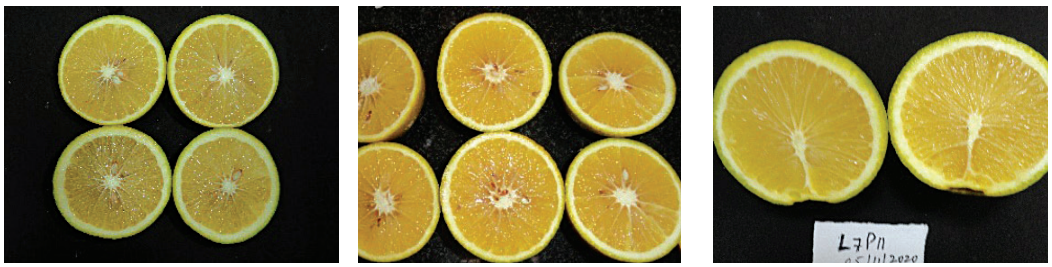
Evaluation of citrus rootstock hybrids against salinity and drought: Of the 20 citrus rootstock hybrids (Pummelo x Troyer citrange) screened against 50 mM NaCl induced salinity (upto $EC_{(1:2)}$ 2.60 mS), nine hybrids (PxT-229, PxT-280, PxT-286, PxT-294, PxT-313, PxT-318, PxT-319 and PxT-321) showed tolerance. Fifty rootstock hybrids and four checks were exposed to normal irrigation, drought and rewatering for four weeks. Hybrid H11, H12, H13, H22, H24, H27, H31 and check Soh Sarkar exhibited lower wilt score (≤1.5/5). These hybrids exhibited higher relative water content (RWC) (>65 and 73%) in drought and rewatering. Some genotypes with high starch contents, proline levels and lower malondialdehyde (MDA) content were recorded under induced drought.

Hybridization : During 2020, 270 flowers were crossed for development of citrus canker tolerant hybrids in acid citrus using Konkan SL x Pusa Abhinav, LS-1 x Pusa Abhnav, Pusa Abhinav x Konkan SL, Pusa Udit x Konkan SL and ALC-2 x Konkan SL. In sweet citrus scion improvement, Kinnow was crossed with Nagpur mandarin, PM-4 (pummelo mutant), sweet orange cultivar Mosambi has been hybridized with Sunkonkan (deep red fleshed pummelo), and PM-4. In rootstock breeding, a total of 186 flowers were crossed for development of Na^+ and Cl^- excluder as well phytophthora tolerant rootstock hybrids.

Mutagenesis in Kinnow and sweet orange: *In vitro* mutagenesis using physical (gamma rays) and chemical (EMS) mutagens as well as characterization and identification of putative/solid mutants using molecular markers is being attempted in Kinnow mandarin and sweet orange. Based on the observations recorded in the mutated population developed over the years (2011-2020), six putative mutants were identified for traits of interest. For dwarfism mutant G-20-5 developed through irradiation and EMS-M-3 developed through chemical mutagen, Ethylene methane Sulphonate have been identified. Among the colchi mutants, Col-1 and Col-2 were found to be extremely dwarf. The sought trait of interest, i.e. reduced the number of seed (<10 seeds/fruit) and better juice recovery per cent (>50%) was witnessed in the mutants G-6-1, G-9-4 and G-39-3.

Characterization of colchiploids based on morphological and reproductive characters: Forty-three colchiploids of Kinnow and 22 of Mosambi were characterized for plant growth, morphological and physiological characteristics and 31 colchiploids of Kinnow mandarin and 22 of Mosambi were characterized for reproductive characteristics.

Variation in fruit surface, seeds and rind thickness in second generation Kinnow colchiploids



Variation in seeds and rind thickness in second generation Mosambi sweet orange colchiploids

Additionally, 19 colchiploids of Kinnow mandarin and 11 of Mosambi were also characterized using molecular analysis (SSR markers). Ten putative tetraploids of Kinnow and 7 of Mosambi sweet orange were identified. The flow cytometric analysis conducted on colchiploids and three putative tetraploids could be identified in Kinnow mandarin and one in Mosambi.

Twenty-one second generation colchiploids each in Kinnow mandarin and Mosambi were also characterized based on reproductive characteristics for assessing their stability. Traits like rind roughness, thickness, reduced seediness and less juiciness indicated the presence of tetraploidy in these colchiploids of Kinnow mandarin and Mosambi sweet orange were identified.

Morpho-biochemical characterization of identified superior Darjeeling mandarin selections: At IARI, Regional Station, Kalimpong, Darjeeling mandarin genotypes were collected and evaluated. On the basis of fruit morphological characterization collection from YK Barbot recorded the fruit quantitative traits. Antioxidant activity through ABTS assay ranged from 87.92 to 82.34 µg VCE/ml. The highest value was measured in ThapaGoan (DS) collection and while lowest was measured in IARI regional satation Kalimpong.

2.2.3 Grape

Hybridization: Hybridization was attempted for achieving extra-early maturity, seedless berries, and improved fruit quality using five cross combinations. A total of 51 panicles having 4,379 flowers were crossed during March 2020. In rootstock breeding crossing among the *Vitis* genotypes, *V. parviflora* × Dogridge (*V. champini*), *V. parviflora* × Salt Creek (*V. champini*) was attempted.

Evaluation of hybrids and germplasm: Grape hybrids (66) resulting from different cross combinations and germplasm (31) were evaluated for 23 physico-chemical traits. Among grape hybrids from 'Pearl of Csaba' and 'Beauty Seedless' cross, the earliest maturity (last week of May, 2020) of berry was noted in 'ER-R2-P36 (Pusa Purple Seedless) followed by ER-R1-P16, and ER-R2-16 as compared to check varieties, *i.e.*, 'Perlette', 'Beauty Seedless' and 'Flame Seedless'. Two new hybrids, *viz.*, Hy-R1-P9 and Hy-R1-P14 have been found promising in terms of having loose bunch, early maturity, bold berry, and acceptable total soluble soilds content at maturity. The maximum total soluble solids (21.90° Brix) was estimated in Pusa Purple Seedless followed by ER-R1-P16 (19.52° Brix), while the minimum was in Anab-e-Shahi (10.5°Brix). The maximum juice content (71.19%) was found in Hy-72-151 followed by 16/2A-R1-P9 (70.61%), 16/2A-R2-P12 (70.35%), 16/2A-R3P10 69.44%) and Pusa Purple Seedless (68.48%). Based on seedlessness, few genotypes found seedless/ minor seed traces, *viz.*, ER-R2-P19, ER-R1-P16, Hy-72-151, 16/2A-R1-P15 and 15/2A-R1-P15. The maximum total monomeric anthocyanins content was noted in Pusa Navrang (892.04 mg kg^{-1}) followed by 16/2A-R1-P18 (678.74 mg kg^{-1}), 16/2A-R4-P7 (645.25 mg kg^{-1}), 16/2A-R4-P14 (568.84 mg kg^{-1}) and 16/2A-R3-P10 (588.25 mg kg^{-1}). Four hybrids have been identified as potential for juice making purpose, *viz.*, 16/2A-R2-P7, 16/2A-R4-P9, 16/2A-R4-P7 and 16/2A-R3-P3.

Evaluation of new hybrids on Bower system: Different commercial grape varieties, namely, Flame Seedless, Perlette, Pusa Seedless, Beauty Seedless and IARI hybrids, namely, Pusa Aditi, Pusa Trishar, Pusa Swarnika, Pusa Urvashi and Pusa Puple Seedless were evaluated on Bower system of training. The maximum yield was recorded in Flame Seedless (22.0 kg/vine) followed by Pusa Aditi (21.7 kg/vine) and

16/2A-R2-P7

16/2A-R4-P7

Pusa Swarnika (18.1 kg/vine). The bunch weight was maximum (368.7 g) in Pusa Trishar followed by Pusa Aditi (342.40 g) and Pusa Urvashi (340.0 g).

Evaluation of wine grape varieties on different rootstocks: 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 the maximum number of bunches (48) per vine and also the highest yield (6.54 kg/vine) followed by SO4 (5.69 kg/vine), while the maximum average bunch weight (164 g/bunch) was obtained on SO4 rootstock.

2.2.4 Guava

Hybridization: Hybridization was undertaken in 30 cross combinations involving ten best combiner genotypes with desirable traits, namely, Allahabad Safeda, Punjab Pink, Hisar Surkha, Shweta, Pant Prabhat, Pant Prabhat, Thai Guava, Hisar Safeda, Lalit, L-49, Arka Kiran and Black Guava using 300 flowers. Fruit set were noticed in only 12 cross combinations, which gave 300 hybrid populations.

Characterization of genotypes: The guava genotypes and hybrids showed significant variation for different traits. A total of 20 genotypes new hybrids were evaluated for morpho-physico-chemical traits. Among the new hybrids which came into maiden fruiting some promising ones have been identified, Among the white pulped soft seeded hybrids, GH-2017-7A (Hisar Safeda x Purple guava) found very potential having excellent flavour, fruit weight (155-190 g), ascorbic acid (169.6-211.32 mg/100 g of pulp), total soluble solids (12.30 to 14.04°Brix), phenolic content (151.43-180.00 mg/100 g GAE of FW), titratable acidity (0.45-0.51%), and potential yield of 35-40 t/ha. In the pink pulped and soft seeded type, GH-2016-6D (Shweta x Punjab Pink) was found promising with smooth fruit surface having excellent nutritional quality and yield potential. Fruit weight ranged from 190-210 g, antioxidant activity (3.7-4.5 mg/100 g of FW), total flavonoids (55.45-81.45 µM TE/g FW), ascorbic acid (158.97-175.6 mg/100 g of pulp), total soluble solids (11.21-13.5°Brix), total phenolics (125.73-140.00 mg/100 g GAE of FW), titratable acidity (0.41-0.45) and potential yield of (50-55 t/ha). Among the red pulped hybrids, GH-2017-8E (Thai Variant x Lalit) had excellent nutritional qualities. The fruit weight ranged from 160-175 g, high antioxidant activity (6.4-7.5 mg/100 g of FW), total flavonoids (84.53-110.22 µM TE/g FW), ascorbic acid (157.22-190.16 mg/100 g of pulp), total soluble solids (12.50 to 13.6°Brix), total phenolics (121.57-142.00 mg/100 g GAE of FW), titrable acidity (0.41-0.45) and potential average yield of 40 t/ha.

Development of genomic resources : Thirty-eight novel genomic SSRs developed through microsatellite enriched libraries in guava cv. Allahabad Safeda. These SSRs were synthesized and validated among the 40 guava genotypes including the wild *Psidium* species, cultivars and cultigens of which 26 SSRs were found polymorphic.

Seven guava parents and 35 hybrids were characterized for pulp colour. During the winter season, maximum lycopene content (22.56 mg/100 g) was found in hybrid PP x T-14-2-8 followed by PP x AS-14-1-14 (18.32 mg/100 g) and Punjab Pink (17.29 mg/100 g), while minimum (0.160 mg/100 g) was in Black guava. The guava genotypes were grouped into six groups on the basis of presence or absence of lycopene, β-carotene,

GH-2017-7A

GH-2016-6D

GH-2017-8E

lutein and zeaxanthin. Segregation of pulp colour among hybrid progenies indicated that pulp colour is not governed monogenically but is also dependent on environmental factors. Based on the segregation pattern of the hybrids resulting from different cross combinations, it was evident that white pulp colour is homozygous recessive in nature. Sanger-sequencing and subsequent analysis of the amplified products revealed 12 SNPs at nucleotide positions 377, 387, 389, 392, 397, 438, 444, 447, 468, 492, 495, and 510 between pink and white pulped guava parents of which eight were found to result in non-synonymous substitutions.

2.2.5 Papaya

Intergeneric hybridization: Six wild relatives of cultivated papaya, *viz*., *Vasconcellea parviflora, V. monoica, V. quercifolia*, *V. goudotiana*, *V. stipulata* and *V. pubescens* were introduced from USDA with the help of ICAR-NBPGR, New Delhi. Out of six *Vasconcellea* species seed germination was recorded in *V. parviflora*, *V. quercifolia*, *V. goudotiana* and *V. pubescens* only. The plants are maintained in the National Phytotron Facility for their further utilization in inter-generic hybridization. Considering the cross-compatibility of the *V. parviflora* with varieties of *Carica papaya* and *V. cundinamarcensis*, the *V. parviflora* was used as bridge species for hybridization. The crosses were attempted with *V. parviflora* x P-7-2, *V. parviflora* x P-9-5 and *V. parviflora* x *V. cundinamrcensis* to develop intermediate population. Besides, *V. parviflora* as maternal plants, *V. goudotiana* was also exploited as donor parent with an advance gynodioecious line P-9-5. Fruit set was recorded in each cross combination except *V. goudotiana* x P-9-5. Subsequently, fruits were harvested at maturity and seeds were extracted from all successful cross combinations.

***Vasconcellea* spp. I plants maintained in Phytotron**

***V. parviflora* plants in flowering and bearing crossed fruits**

Identification of gynodioecious variety: Among the promising advance papaya lines, namely, P-9-5, P-7-2, P-7-14, P-7-9 and P-9-12, P-7-2 was identified for promotion as gynodioecious variety. The plants of P-7-2 are semi-dwarf (187-201 cm), early flowering (68 DAP), light green colour of stem and petiole, petiole length 85-97 cm, fruiting zone 95-135 cm, fruit weight ranged from 725-1115 g, total soluble solids ranged from 9.0-12.1°Brix, pulp colour deep yellow, fruit

P-7-2 in fruiting

maturity after 132-145 days, yield 32-48 kg/plant, fairly rich in antioxidants, with better fruit shelf-life than Pusa Nanha. It is suitable for high density planting with a spacing of 1.5 m x 1.5 m and is moderately tolerant to papaya ring spot virus (PRSV) under field growing conditions. The per plant fruit yield is 64 per cent higher compared to Pusa Nanha.

Seed quality analysis: Full diallel papaya crosses were made using six parents (dioecious and gynodioecious) namely, Pusa Nanha, Pune Sel. 3 (PS 3), P-7-2, P-7-9, P-9-5 and P-9-12. Total 30 cross combinations were attempted and mature fruits were harvested for seed extraction. Thereafter, seed parameters were recorded and seed quality was assessed. There were significant differences among the genotypes and various cross combinations on seed length, diameter and 100-seed weight. The maximum seed length (97.637 mm) was recorded in P-9-12 x Pusa Nanha followed by Pusa Nanha x P-9-5 (7.263 mm) and P-9-12 x P-7-2 (7.190 mm), whereas minimum (3.383 mm) was noticed in P-7-2 X PS 3. Seed diameter (5.117 mm) was significantly higher in P-7-9 over other genotypes followed by P-7-9 x Pusa Nanha (5.017 mm) and Pusa Nanha x P-9-5 (4.79 mm),while minimum (2.603 mm) was in P-7-2 x PS 3. Similarly, 100-seed weight (1.596 g) was highest in P-9-12 x P-7-2 followed by P-9-12 x Pusa Nanha (1.548). Based on seed boldness parameters, it was evident that seed size was reduced due to hybridization, when PS 3 was utilized as maternal or donor parent.

Mutation breeding: Five mutant plants, *viz*. PM 04, PM 09, PM 22, PM 28 and PM 33 were selected from two lower doses, *i.e.* 0.1 and 0.15 kGy gamma rays, which particularly affected the vigour giving rise to dwarf stature and low bearing height in M6 population. Minimum height at first fruiting (64.24 cm), plant girth (68.56 mm), nodes to first flowering (48.36), days to flower initiation (80.64), middle internode length (4.4 cm), and petiole length (86.12 cm) were noted in PM 04 plant and minimum plant spread in East-West (142.8 cm) in PM 04 and North-South (148.4 cm) was recorded in PM 28, while maximum plant height at first fruiting (88.00 cm), plant girth (78.25 mm), node to first flowering (62.44), days to flower initiation (95.52), middle internode length (6.4 cm), petiole length (105.74 cm) and plant spread in East-West (168.4 cm) and North-South (170.4 cm) were registered in P-7-2 line (control).

Characterization of Pune papaya selections: At IARI Regional Station, Pune the overall PRSV intensity was 50% in all the gynodioecious lines as against 57% in dioecious lines during second year, however, it was lower in all the PS lines compared to that of Red Lady (98%).

Temperate fruits: Ten walnut genotypes were evaluated to determine phenotypic diversity and to detect superior trees. "Pusa Khor" -a walnut selection is being evaluated at IARI Regional Station, Shimla. This accession is precocious and started bearing in the second year of its grafting compared to other walnut varieties which take 12-15 years. The fruit are borne on lateral position as well as terminally. This is the unique traits amongst all newly evolved early and heavy bearing walnut varieties. It is semi-vigorous in growth habit, the fruit weight with husk is 49.5 g; whereas, without husk (nut) it is 23.7 g. The fruit length with husk is 55.45 mm whereas, without husk (fresh nut) it is 43.13 cm. The nut is thin-shelled and dry weight is 12-13 g. Kernel colour is light yellow and good in taste. The kernel weight varied from 5.5-6.5 g. The oil and shelling were 55.6 and 50.1%, respectively. It is suitable for high density.

Precocity in Posa Khor

Exploration of Sirmour district of Himachal Pradesh was conducted and six elite walnut germplasm were identified and fruit samples were collected. Fresh fruit weight varied from 30.07 to 49.45 g and dried

kernel weight ranged from 10.33-11.41 g. Different *Malus* species (*M. baccata Jalma, M. baccata Lahaul*) genotypes (collected from Lahaul & Spiti dist. of H.P.) were evaluated for plant height, branching pattern, sucker production potential, biotic stress resistance *etc*. Evaluation of different crab apple (*Malus baccata*) genotypes of their suitability as pollinizer and rootstock for commercial cultivars is underway. Newly introduced plum varieties, Fariar, Red Beauty, Black Amber and prune variety Green Gauge were evaluated. Fruit weight in plum varieties varied from 45.21-47.39 g with maximum in Red Beaute (47.39), TSS varied from 11.2-14.3%. Fruit weight of Green Gauge (prune) was 36.95 g. In pomegranate, there was fruiting in 9 Russian type/temperate type accessions, namely, Boskalinisi, GR Pink, Spin Sakaharin, Shirin Anar, Kayaki Anar, AHPGC-3, Gulsha Red, Surkh Anar, and Splender. Fruit weight varied from 117-181 g, TSS varied from 16.5-20.8^{0}Brix in different genotypes. Amongst new apricot collections (Baiti, Cneff-A, Himri Sel, Karsog Sel, CITH Sel, Moorpark, Chindi Sel and Local Sel) were evaluated and fruit weight varied from 27.2-90.1 g, TSS (^{0} brix) ranges from 16.05-19.35. Six strawberry genotypes collected from Jalpaiguri, W.B. (J1, J2,J3, J4, J5, J6) and were evaluated under glasshouse conditions for off-season fruiting, Fruit weight varied from 15.21-25.5 g and TSS from 9.4-12.1^{0}Brix, and vitamin-C28.2-39.8 mg/100 g. New peaches (Sarahanpur, Gujrati, Glow Heaven, EC 174084) were evaluated for growth and different horticultural traits. Fruit weight varied from 42.5-95.2 g, pulp thickness varied from 15.12- 18.31 mm.

2.2.6 Production technologies of fruit crops

2.2.6.1 Mango

Effect of polyembryonic rootstocks on semi-vigorous mango varieties: Tree growth in terms of canopy diameter, tree volume and height varied significantly individually and combinedly with varieties and rootstocks. Among varieties, 'Pusa Arunima' exhibited highest tree growth, while lower values were found in 'Pusa Surya'. Considering rootstock individually, 'K-5' and 'K-2' had an inhibitory effect on tree growth. Interaction showed that in Pusa Arunima, significantly smaller trees were found either on K-5 or 'K-2'. Yield per tree, yield efficiency, fruiting density and yield/ metre canopy also impacted significantly by rootstock and scion genotypes. Fruiting density (FD) was higher for 'Amrapali, while both 'Pusa Surya' and 'Amrapali' had parallel yield efficiency (YE). 'Pusa Arunima' exhibited the highest yield per tree basis, but both 'Pusa Arunima' and 'Amrapali' performed equally with regard to yield/ metre canopy cover (YPCD). Considering the effect of rootstock alone showed, the superiority of 'K-5' for FD, YE, while both Olour and 'K-5' performed excellent for yield /tree, but 'K-5', 'Olour' and 'K-3' were found better for YPCD. The combined effect showed the highest FD for Amrapali-'K-5' 'Amrapali-'K-3' and 'Amrapali- 'K-2', Pusa Surya'-'K-5' combinations. For 'Amrapali, except 'trees on 'Kurakkan', rest had equal performance. 'Pusa Arunima-Kurakkan' (8.13 kg/m CD), 'Pusa Surya'-'K-5' (5.55 kg/m CD), Pusa Surya-'K-3' (5.04 kg/m CD), 'Amrapali-'K-3' (7.77 kg/m CD) produced higher YPCD.

Fruit quality traits also influenced significantly by rootstock and scion genotypes individually and jointly. Amongst scion varieties, 'Pusa Arunima' and Pusa Surya' had higher fruit weight, while pulp content and pulp: stone ratio was found higher for 'Pusa Surya' and 'Amrapali'. Rootstock, 'K-2' had positive effect on weight irrespective of scion varieties, through there was not much effect on pulp content and pulp: stone ratio. Rootstock K-3 induced lowest stone weight for all the scion varieties. Pulp acidity and TSS were affected by scion varieties and their interaction with rootstocks but rootstocks didnot affect the TSS significantly. Vitamin C was not much influenced but 'K-5' and 'Olour' rootstocks induced higher photosynthetic rate.

Effect of polyembryonic rootstocks on vigorous varieties: Canopy diameter (CD), tree volume (TV) and height varied significantly due to varieties, rootstock and their interactions. Regard to varieties both CD and TV were found higher for 'Mallika'. Considering the rootstock effect alone, 'K-5' and 'Kurakkan had comparatively lower growth than 'Olour'. Interaction effect showed 'Mallika-'Olour', 'Dushehari-'K-5', Dushehari-Kurakkan had an inhibitory effect on CD, plant height and TV. Dushehari had higher FD (0.89 fruits/m^3 CV), YE (0.17 kg/m^3 CV), yield on per tree

basis (23.01 kg/tree) and YPCD (5.09 kg/m canopy diameter). Overall, 'Dushehari'-'K-5' had the highest FD, YE, yield/tree and YPCD. For Mallika, both 'K-5; and Olour' appeared to be promising for inducing higher FD, YE, yield/tree and YPCD. There was not much effect on fruit quality traits. 'Mallika' had higher fruit weight, on K-5 (311.33 g), while it was 'Kurakkan' for and 'Dushehari' (209.92 g).

Development of INM schedules on newly developed mango hybrids: There was a significant effect of different INM treatments on mango cultivars with respect to plant height and canopy volume. Maximum height (4.69 m) was recorded in treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 4.22 m in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g). Among cultivars, maximum height (4.16 m) was recorded in Pusa Arunima and minimum (3.68 m) in Pusa Pratibha. Maximum canopy volume (71.22 m^3) was recorded in treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 47.04 m^3 in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g), while minimum (40.08 m^3) in control (T1). Amongst cultivars, maximum canopy volume (67.72 m^3) was recorded in Pusa Arunima with minimum (24.38 m^3) in Pusa Pratibha. Maximum number of fruits per tree (18.61) irrespective of cultivar was recorded in treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 16.91 in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g). Among cultivars, the maximum number of fruit (16.75) was registered in Pusa Arunima, while minimum (13.62) in Pusa Pratibha. Maximum fruit weight (185.54 g) was recorded in the treatment NPK 100% + AMF (250 g) + *Azotobacter* (250 g) followed by 177.82 g in treatment NPK 75% + AMF (250 g) + *Azotobacter* (250 g).

Effect of organic nutrient sources in mango: Twelve treatments comprising of different organic nutrient sources were used for enhancing Kurukkan mango seed germination and growth. Seeds with removed seed coat produced the earliest germination (14.56 days), higher germination (84.03%), better seedling survival (68.06%), and higher polyembryony (2.66) compared to the seeds with an intact seed coat. Among all the treatments, vermicompost + microbial consortia produced the higher seedling fresh weight, dry weight, root length and shoot: root ratio in both in intact and removed seed coat treatments. It also resulted in the significantly highest vigour index I (8504.17 cm; 11,083.33 cm), vigour index II (4020.00 g; 5165.42 g) and thus exhibited the maximum leaf net photosynthesis (6.54 and 6.79 μmol CO_2 $m^{-2}s^{-1}$), stomatal conductance (0.68 and 0.73 mmol $m^{-2}s^{-1}$), intrinsic water use efficiency of seedling (8.62 & 9.30 μmol $mmol^{-1}$) and relative leaf water content (87.06 & 88.81%).

In another experiment, 12 organic nutrient treatments along with control having recommended dose of fertilizers were used in Amrapali grafted on Kurukkan rootstock. The microbial consortia comprising of *Azotobacter* (50 g/tree) + arbuscular mycorrhiza fungi (AMF, 250 g/tree) + phosphate solubilising bacteria (PSB, 50 g/tree) + potash solubilizing bacteria (KSB, 50 g/tree). The treatment with vermicompost (40 kg/tree) + microbial consortia improved soil physical, chemical and biological properties as well as leaf nutrient status. It also produced significantly higher activities of dehydrogenase, acid phosphatase and leaf nitrogen (1.21%), potassium (1.52%), copper (24.23 ppm), iron (299.10 ppm), Mn (48.44 ppm) and Zn (63.67 ppm) contents compared to other treatments. Better yield and quality of fruit as well as net return per ha was realized with the application of vermicompost 40 kg/tree + microbial consortia, which also gave higher cost: benefit ratio.

2.2.6.2 Citrus

Performance of Kinnow mandarin on different rootstocks: Nine-year-old Kinnow mandarin grown on different rootstocks was evaluated with respect to their fruit yield and quality. Amongst the root-scion combination, fruit weight (220 g) was recorded maximum on *Jatti khatti* rootstock followed by rough lemon (195.0 g) and *Karna khatta* (172.5 g). The juice recovery percentage (48.25%) and TSS (12.58°Brix) were recorded maximum in Kinnow budded on Rangpur lime. Fruits of few promising rootstocks NRCC 1-4 developed from ICAR-CCRI, Nagpur were collected and rootstock has been raised for further evaluation with other rootstocks such as X-639, Alemow *etc*.

Performance of sweet orange cultivars on different rootstocks: The tree vigour, fruit yield and quality of two newly released cultivars of sweet orange (Pusa Sharad and Pusa Round) were significantly influenced due to different rootstocks. The tallest trees of Pusa Sharad (3.63 m) were observed on RLC-6 followed by Soh Sarkar rootstock, while most dwarf trees were found on Yama Mikan (2.25 m). While, RLC-7 resulted in the tallest trees of Pusa Round (3.58 m). The lowest tree vigour of Pusa Sharad (23.93 m^3 CV) was recorded on Yama Mikan closely followed by RLC-7. In Pusa Round, the similar vigour was recorded on RLC-6 and X-639 rootstocks. However, yield was higher on Soh Sarkar for Pusa Sharad (39.77 g/tree), while for Pusa Round (37.81 Kg/tree) it was recorded on *Jatti khatti* rootstock. The heavier fruits of Pusa Sharad (197.41-215.70 g) were yielded, while grown on RLC-6, C-35, X-639, RLC-7 and *Jatti khatti*, without any significant influence, however, the similar response in case of Pusa Round (201.66-212.96 g) was noticed on RLC-6, RLC-7 and *Jatti khatti* rootstocks. Except for *Jatti khatti*, all the rootstocks behaved similarly for inducing high juice content in Pusa Sharad (46.78-51.60%) and Pusa Round (48.00-50.23%). Yama Mikan excelled for higher TSS and lower acidity contents for the two cultivars. Minimum juice acid content was recorded on RLC-6 rootstock.

Evaluation of Darjeeling mandarin and Assam Lemon on different rootstocks: At IARI RS kalinpong Rough lemon proved vigorous rootstock for Darjeeling mandarin, while sour orange showed high budding success rate (95.00%), which was found to be on par with rough lemon. The total chlorophyll content was found to be highest on trifoliate orange (1.14 mg/g FW).

2.2.6.3 Grape

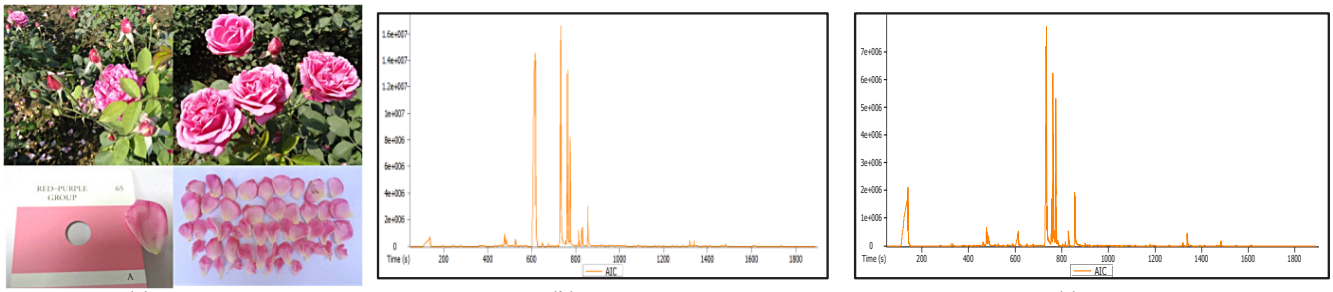
Evaluation of bio-regulators for grape production: Four grape varieties, namely, Flame Seedless, Beauty Seedless (seedless, coloured), Pusa Aditi (Seedless, white) and Pusa Swarnika (seeded, golden yellow) were subjected to bio-regulators and micronutrients treatments for quality improvement. Ethephon (400) ppm was found the best for Flame Seedless and Beauty Seedless in improving berry colour and quality, while ethephon (300 ppm) for Pusa Aditi and boric acid (0.4%) for Pusa Swarnika were found better. RNA sequence analysis of Flame Seedless berries treated with ethephon (400 ppm) had highly up-regulated genes such as UFGT (VIT_16s0039g02230) and GST (VIT_04s0079g00690) associated with anthocyanin biosynthesis pathway.

Production technologies in temperate fruit crops: Studies on top working in pear with different rootstocks (*Pyrus pashia*, *P. pashia* Kumaoni, *P. calleriyana*, *P. serotina*) and different varieties (Max Red Bartlette, Conference, Canal Red, Star Krimson, Pakham, Moti Dandi) were evaluated The highest graft success (94.5%) was recorded for Max Red Bartlette on *P. calleriyana* rootstock. In kiwifruit, medium comprising of cocopit (70%) + perlite (15%) + vermiculite (15%) showed the highest success with better root volume. Studies on pruning severity and time in kiwi was conducted, pruning at 35 cm (6 bud stage) in 3rd week of January gave better yield and fruit quality. Management of fruit cracking in pomegranate through application of micronutrients and different mulches was studied. Grass mulch with 0.4% B+Zn+Ca mixture gave better results. Evaluation of different rootstocks (*Prunus japonica*, wild peaches, *Chuli*, *Behmi* and bitter almond) for different stone fruits were studied and planted at different spacings.

2.3 ORNAMENTAL CROPS

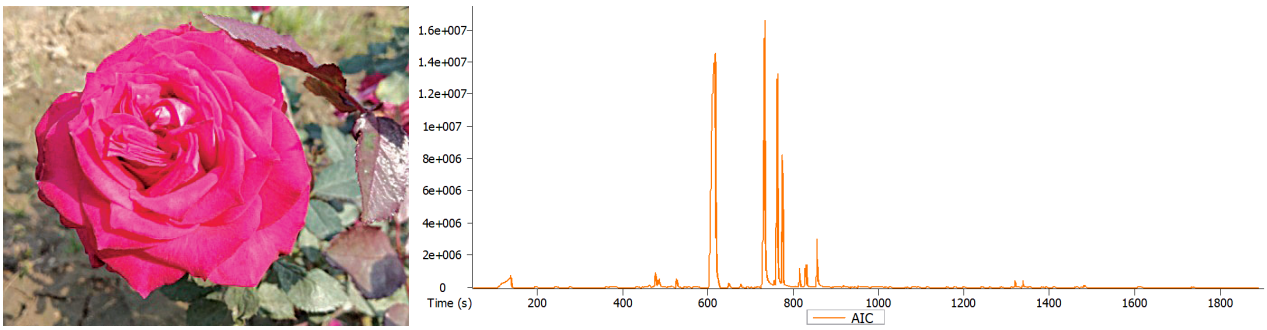
2.3.1 Rose

Profiling of floral volatiles of promising selections by HS-SPME-GC X GC-TOFMS: R-SD-6-2015 is a selection from open-pollinated seedlings of var. Rose Sherbet belonging to Floribunda type and has fragrant, compact and pink coloured flowers. It produces recurrent and floriferous semi-double flowers. The promising seedling is suitable for fragrant loose flower purpose. The major volatile compound in R-SD-6-2015 and its seed parent var. Rose sherbet is phenyl ethyl alcohol (per cent Peak area: 44.26 and 38.48, respectively). SD-3 is another selection from open-pollinated seedlings of cv. Preyasi, which is thornless, highly floriferous and has recurrent flowering, compact flowers with more petals and fragrance. It is suitable for loose flower purpose, garland preparation and garden display.



(a) (b) (c)

Promising seedling 'R-SD-6-2015' (a); Chromatogram showing headspace volatiles in promising fragrant rose selection 'R-SD-6-2015'(b) and its seed parent 'Rose Sherbet' (c)



(a) (b)

Promising seedling 'SD-3' (a); Chromatogram showing headspace volatiles in promising fragrant rose selection 'SD-3'(b)

Hybridization in rose for loose and fragrant flower purposes: Crosses were made among promising rose varieties to develop new genotypes for loose and fragrant flower production. The parent genotypes utilized in the crossing programme were Rose Sherbet, Pusa Mahak, Jantar Mantar, Krishina, Surabhi, Pusa Virangana, Shola, Pusa Baramasi, Pink Queen Elizabeth, Delhi Princess, SD-3, Pusa Urmil, Surdas, Oklahoma, Jadis and Midas Touch. The cross combinations such as Pusa Virangana x Midas Touch (50%), Pusa Virangana x Delhi Princess (75%), Jantar Mantar x Krishna (57%) and Surabhi x Rose Sherbet (66%) exhibited good hip set.

Hybridization in rose for cut flower purpose: Crosses were made among promising varieties, namely, Pusa Virangana, Pusa Mahak, Moon Drop, Happiness, Bewitched, Upper Class, High Sparkling, Lenny, Top Secret, Tajmahal, Neptune, American Heritage, Bluss, High Magic, Oklahoma, Jadis, Midas Touch *etc*. These crosses exhibited variable hip set.

Hybridization in climbing roses: Fifteen cross combinations were made among promising rose varieties to develop new varieties of climbing roses. The cross combinations exhibited differential hip set abilities. Maximum hip set was observed in Summer Time x Shola (80%).

Promising mutants for garden display purpose: A promising mutant RM-1-2018, which arose as a natural mutant (bud sport) of cv. Folklore, produced light orange coloured large sized blooms having white coloured stripes. The plants are medium in height and bushy. It belongs to Hybrid Tea type. The promising seedling is suitable for garden display purpose.

Promising mutant 'RM-1-2018' (a); its parent cv. 'Folklore' (b)

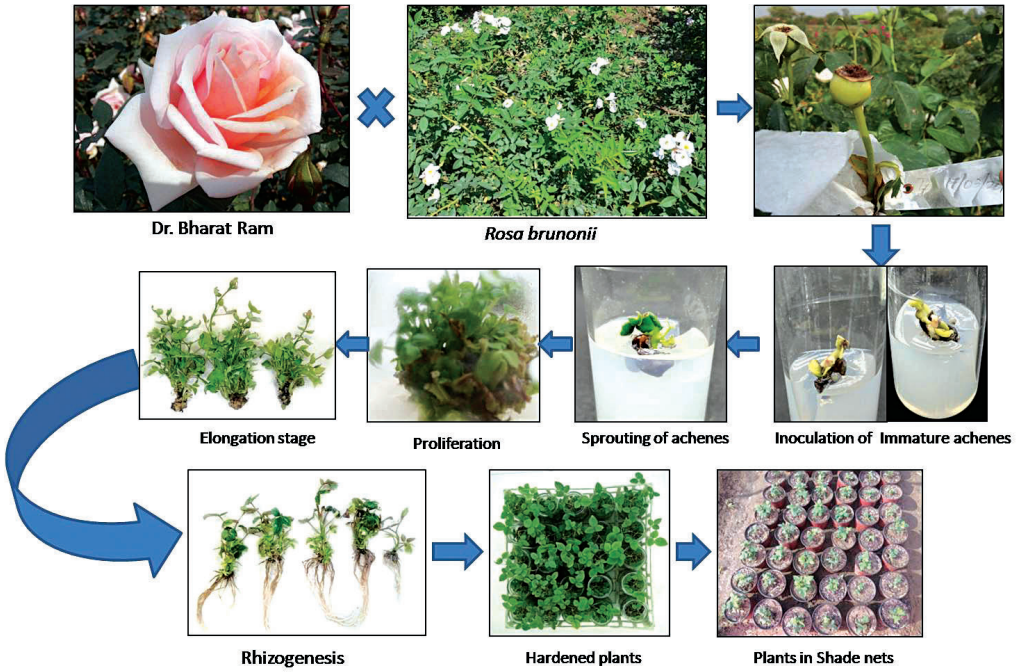
Identification of '*Candidatus* Phytoplasma *australasia*' in rose: '*Candidatus* Phytoplasma *australasia*' was identified in three rose varieties,

Phytoplasma symptoms in rose varieties: a) "Delhi Princess" showing flat stem B) "Pusa Arun" showing phyllody, and c) Rose variety "MS Randhawa" showing flower malformation

namely, Delhi Princess, Pusa Arun and M.S. Randhawa causing flat stem, phyllody and flower malformation symptoms. Disease incidence of 37.5, 50 and 87.5 t% were recorded, respectively. Amplifications of ~1.25, ~480 and ~1.3 kb products using primer pair P1/P7, R16F2n/R16R2 for *16SrRNA* gene, *sec*Afor1/*sec*Arev3, *sec*Afor2/*sec*Arev3 for *sec*A gene and *rp*(II)F1/*rp*(I) R1A, *rp*(II)F2/*rp*(I)R1A for *rp* gene confirmed the phytoplasma association in all the three symptomatic rose varieties in nested PCR assays. Pair-wise sequence comparison, phylogenetic analysis and virtual RFLP comparison of the *16S rRNA* gene sequences of rose varieties confirmed the association of 16SrII-D phytoplasma subgroup in all the three rose varieties.

Screening of pre-breeding lines for powdery mildew tolerance: Pre-breeding lines such as PBL-R-PM -1-2016, PBL-R-PM -5-2016, PBL-R-PM -8-2016, PBL-R-PM -11-2016, PBL-R-PM-12-2016, PBL-R-PM-15-2016, and PBL-R-PM-17-2016 were screened against powdery mildew. Among these, PBL-R-PM-8-2016 and PBL-R-PM-17-2016 pre-breeding lines were found to be moderately resistant. Pollen viability was also studied in promising pre-breeding lines such as PBL-R-PM-8-2016, PBL-R-PM-28-2017, PBL-R-PM -36-2017, PBL-R-PM -17-2016, PBL-R-PM-6-2018, and PBL-R-PM -13-2018. Lines such as PBL-R-PM-8-2016, PBL-R-PM-17-2016 and PBL-R-PM-28-2017 exhibited high percentage of viable pollens.

Standardization of *in-vitro* protocol for regeneration from immature achenes in interspecific hybrids: Immature achenes of inter-specific hybrid of Dr Bharat Ram × *Rosa brunonii* were used for direct shoot



Direct regeneration from immature achenes of interspecific hybrid (Dr Bharat Ram × *Rosa brunonii*) of rose

organogenesis as explant. Cultures were established using enriched MS medium supplemented with BAP (2.5 mg/l), NAA (0.1 mg/l) and GA_3 (2.0 mg/l). Full-strength of MS medium + BAP (5.0 mg/l) + NAA (0.1 mg/l) + GA_3 (0.5 mg/l) was found most effective for shoot proliferation, while half-strength MS medium + NAA (1.0 mg/l) for rooting.

Marigold maintenance of germplasm and evaluation for flower yield: Eighty-two genotypes were maintained in germplasm including varieties, selections and male sterile lines belonging to *Tagetes erecta*, *T. patula* and *T. minuta* species. During *kharif* season, 43 selections/lines of marigold belonging to *T. patula* and *T. erecta* were assessed for various vegetative and flowering traits. Among the selections belonging to *T. patula*, the selections numbered as Fr./R-5-1, Fr./R-5-2, Fr./R-2, Fr./R-3, Fr./R-5, Fr./R-14-6 and among the selections belonging to *T. erecta*, the selections numbered as Af./SR-12, Af./SR-15-1, Af./SR-53, Af./SR-16-1 and Af./SR- 16-2 were found very promising for loose flower production/ bedding purpose and all flower profusely during October-November. During *rabi* season, 22 selections of *T. patula* and *T. erecta* were assessed for various vegetative and flowering traits. Among them, the selections Fr./R-20, Af./w-1, Af./w-2, Af./w-3-2, Af./w-4, Af./w-7 and Af./w-8 were found very promising for loose flower production/ bedding purpose, which flower profusely during February-March.

Development of protocol for production of doubled haploids: With the aim to develop the homozygous lines in African marigold, unfertilized ovary culture was attempted in eight petaloid type marigold F_1 hybrid. The successful regeneration from unfertilized ovaries was obtained in five hybrids, namely, Inca Yellow, Yellow-300, Orange-900, IHS-007 and IHS-303. The regenerated plants are being maintained under *in vitro* conditions and will be evaluated for various flowering traits in the next season. The effects of different temperature pre-treatments on *in vitro* gynogenic response were studied in three African marigold genotypes. The temperature pre-treatment significantly improved the *in vitro* response in all the genotypes. Among the three genotypes, the best *in vitro* response was observed in Arka Bangara-2 (73.7%) followed by BM-2 (65.8%) when the cultures were pretreated at 9°C for 3 days. The effect of different culture media on *in vitro* gynogenesis was assessed, the best *in vitro* response was obtained on B_5 based media supplemented NLN vitamins, 45 gl^{-1} maltose and 2.6 gl^{-1} gelrite™. The germinated shoots were successfully maintained on B5 medium supplemented with 250 mgl^{-1} polyvinyl pyrrolidine, 0.5 mgl^{-1} BAP, 0.1 mgl^{-1} GA_3 and 0.25 mgl^{-1} NAA. The gynogenetically induced shoots were successfully rooted and characterized for important flowering traits. In another study, attempts were made to develop double haploids through anther culture, the regenerants were multiplied *in vitro* and subjected for ploidy analysis through cytological studies and counting of chloroplasts in guard cell of stomata to isolate haploid regenerants.

Development of stable male sterile lines and identification of their maintainers: Twenty-five cross combinations involving two petaloid type male sterile lines and 15 advanced male fertile lines were evaluated for identification of type of male sterility present and potential maintainers in marigold. In most of the crosses, segregation was observed for male sterile (petaloid types), and male fertile (semi-double types) types of flower forms. Backcrossing was attempted in selected crosses. Few promising plants from different crosses were selfed to raise F_2 progenies. The crosses were evaluated for vegetative and flowering traits. The earliest flowering was observed in OM × M10. The cross combinations OM x M3 and OM x M4 were found promising for garden display.

Estimation of carotenoids content in promising lines/ hybrids: Different genotypes were validated for total carotenoids. In rainy season, genotypes, *viz*. Sel. Af./SR-12, Af./SR-17 and Af./SR-1were found rich in total carotenoids on fresh weight basis, while in winter season, genotypes, *viz*. Sel. Af./W-1 and Pusa Narangi Gainda were recorded with high carotenoids content on fresh weight basis. Amongst hybrids, MS-8 x Af./SR-12 had 859.14 mg/100 g total carotenoids followed by MS-8 x Af./SR-17 with 743.04 mg/100 g on fresh weight basis.

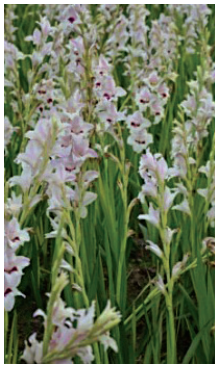
2.3.2 Gladiolus

New variety "Pusa Shanti" identified for release: A new variety 'Pusa Shanti' was identified for release by the IARI Variety Identification Committee for NCR Delhi. This variety is a cross between Yellow Stone x Melody with spikes of more than 120 cm in length and florets ranging from 19-21, medium long sturdy spikes with 15 days in field-life. The vase-life of this variety in normal tap water is 9-10 days. It has rachis length > 67.00 cm. It is very good multiplier and produces 3.33 corms per plant and 67.77 cormels/ mother corm. This is a medium flowering hybrid and takes 100-105 days to first floret opening after planting. Floret colour is attractive and outer three tepals are in whitish group (NN 155B). Out of three inner tepals, two tepals on base are in the red group (51 C) as per R.H.S. Colour Chart. Highly suitable for commercial cut flower production, garden display, floral arrangement and landscaping as well.

Pusa Shanti

Identification of new mutant: A natural novel colour spontaneous mutant was identified and it has been evaluated with its parent Pusa Vidushi for the last four years. It was noticed that it is stable. Mutant/variant and was seen in florets colour. As per RHS Colour Chart, outer tepals are in yellow-orange group 16D and two-three spots on inner tepals are in red group 46C. It was different from its parent variety for floret colour.

Mutant of "Pusa Vidushi"



Parent "Pusa Vidushi"

Evaluation of hybrids: Twelve newly developed gladiolus hybrids along with two check varieties were evaluated under Kullu Valley of Himachal Pradesh. The mean performance of gladiolus hybrids in terms of vegetative and flower traits studied revealed that maximum plant height (163.07 cm), spike length (107.10 cm), internodal length (6.10 cm) and leaf width (4.78 cm) recorded by Sunayana open-seedling. One open-pollinated seedlings each of Suchitra and Sunayana and one hybrid Arka Kesar x Australian Fair were found to be earliest. Hybrid Suchitra x Melody and Peter Pears open-pollinated seedling had higher number of florets (19.67 and 18.50, respectively). The widest flower diameter (13.41 cm) was recorded in hybrid Archana x Arka Kesar. The maximum leaf length (52.20 cm) was registered in Suchitra open-seedling. Urmi open-seedling and Suchitra x Melody hybrids produced greater number of corms per plant (2.67). However, Suchitra open seedling had more number of cormels per plant (26.33). The maximum corm size (57.02 mm) was recorded in Archana x Arka Kesar hybrid.

Archana x Arka Kesar

Sunayana open seedling

Suchitra x Melody

2.3.3 Chrysanthemum

Hybridization: Crosses were made among promising chrysanthemum varieties to develop new spray, pot mum and photo-thermo insensitive varieties. The parents utilized in crossing programme were Lalpari,


No.18 x cv. Belum


No.18 x cv. Belum


No.18 x cv. Belum

Red Spoon, Corcon Small, Haldighati, Sadbhavana, Ajay Orange, Vijay Kiran, Pusa Sona and Discovery. Good seed set was observed with pollen of varieties Ajay Orange and Pusa Sona.

2.3.4 Lilium

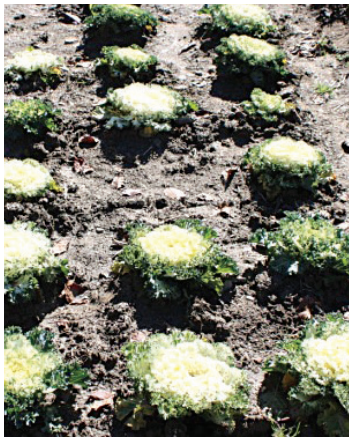
Evaluation of interspecific crosses and Hybrid selections: Non-vernalized bulbs of three inter-specific lilium hybrids were evaluated in pots for growth and flowering traits. A cross between No. 18 x *Lilium speciosum* attained maximum plant height (113.0 cm), No. of flowers (2.0), bud length (13.0 cm) and No. of leaves (80.0). Minimum plant height (70.7 cm) and earliest flowering (240.3 days) were recorded in cross between No. 18 x Belum. Similarly, non-vernalized bulbs of hybrid seedling selections No. 18 were evaluated under polyhouse conditions. Maximum plant height (145.1 cm), and flower size (10.16 cm) were registered in hybrid Sel.-1. Maximum No. of leaves (69.6), bud length (13.12 cm) and bulb size (13.1 cm^2) were recorded in hybrid Sel.-8. Outer tepal length (14.1 cm) and inner tepal length (13.6 cm) was found in hybrid Sel.-4.

2.3.5 Ornamental kale

Evaluation of DH and elite inbred lines: Fifteen DH and eleven inbred lines were evaluated at ICAR-IARI, Regional Station, Katrain for different aesthetic traits. Among the DH lines, maximum plant height (38.7 cm), plant spread (36.2 cm) and stem diameter (1.8 cm) were recorded in KtDH-1-10 followed by KtDH-1-57 and KtDH-1-27 over the standard check Crane Red (F_1 hybrid). These DH lines had early colour development and found suitable for cut flower production. Among other inbred lines, KtOK-2, KtOK-2-1, KtOk-1 and KtOk-11 were found superior for pot culture or


KtDH-1-10


KtDH-1-57


KtOK-2

bedding purpose over the standard check Nagoya Mix (F_1 hybrid). These promising lines will be tested at multi-locations.

Evaluation of DH based hybrids: Preliminary crosses were attempted between three double-haploid lines and the obtained F_1 hybrids along with their parents and check cultivar were evaluated for different traits at ICAR-IARI, Regional Station, Katrain. The hybrids between KtDH-1-29 x KtDH-1-30 and KtDH-1-29 x KtDH-1-27 were found superior with respect to plant height (37.9-34.7 cm) and plant spread (24.9-31.7 cm) over the parental lines with the heterosis of 27.6 and 12.5 per cent, respectively. These hybrids need to be tested at multi-locations for stability analysis.

KtDH-1-29 x KtDH-1-30

KtDH-1-29 x KtDH-1-27

Maintenance of stable CMS line(s) and CMS conversion of doubled haploid and other elite lines: In ornamental kale, two stable CMS lines along with their respective maintainers were planted in the field. These lines are at different stage of backcrossing (BC_1-BC_4) for the introgression of sterile cytoplasm. The CMS lines were maintained with their respective male fertile counter-parts during summer. Besides this, six doubled haploid (DH) and five other elite inbred lines with good agronomic traits were selected for CMS conversion. The CMS system was introgressed into these lines by crossing them with two stable CMS source lines.

2.3.6 Improved production technologies in ornamental crops

2.3.6.1 Chrysanthemum

Effect of mulching on growth and flowering: A field experiment was conducted at IARI, New Delhi to study the effect of various mulching techniques on growth and flowering in chrysanthemum cv. Kundan. The various treatments used were control (No mulching), Black polythene, yellow polythene, silver polythene, brown polythene, transparent polythene, and paddy straw. Maximum plant survival and No. of weeds per plot were observed when no mulch was used (control). The minimum number of weeds per plot and the maximum No. of flowers per plant were observed with yellow polythene.

2.3.6.2 Tuberose

Studies on salt tolerance: A pot experiment was conducted at New Delhi to study the effect of saline irrigation water on growth, flowering, physiological and biochemical parameters in cv. Prajwal. The treatments were-T1- 0.7 dS m^{-1} (control), T2- 2 dS m^{-1}, T3- 3 dS m^{-1}, T4- 4 dS m^{-1} and T5- 5 dS m^{-1}. The pooled data showed that the earliest shoot sprouting after planting of bulbs was observed with T1. The maximum plant height, No. of leaves per plant, spike length, spike diameter, fresh and dry weight of spikes was observed with T1. Membrane Stability Index, and leaf Relative Water Content decreased with increasing salt concentration, while proline content with the increase in salt concentration.

2.3.6.3 Lilium

Application of nutrient spray and GA_3 on flower and bulb production in LA hybrid: A study was carried out at IARI RS Katrain to standardize the optimum dose of NPK (19:19:19) mixture (0, 250, 350, 450 and 550 ppm) and GA_3(0, 150, 200, 250 and 300 ppm) for better quality flower and bulb and bulblet production of LA hybrid cv. Pavia. Treatment NPK @ 550 ppm performed better for most of the vegetative growth parameters, quality flower, bulb & bulblet production and total phosphorous content in opening was recorded with NPK @ 450 ppm, while, GA_3 @ 300 ppm performed better for leaves. Most of the parameters, *viz.*, plant height, leaf length, leaf width, early flowering, stalk length, stalk diameter, bulb and bulblet production, leaf chlorophyll and total nitrogen content.

2.3.6.4 Licoris and Easter Lily

At IARI RS, Kalimpong, West Bengal effort was made for optimisation of nutrient requirement for

bulblet size enlargement. Application of full-strength of Hoagland's solution increased bulb diameter (2.90 cm), bulb height (3.54 cm), fresh (3.55 g) & dry (0.95 g) weight of bulb as compared to ½ and ¼ strengths. Similarly, efforts were made for standardisation of nutrient requirement for flower production in Easter lily. Application of NPK 300:300:300 kg/ha improved plant height (75.45 cm), flower buds (14.5) and spike length (65 cm) as compared to other doses. Tissue analysis indicated that same dose also consisted higher N (3.02%), K (2.85%) and Ca (0.85%).

2.4 SEED PRODUCTION IN HORTICULTURAL CROPS

The production of quality seed in horticultural crops (vegetables, fruits & flowers) at institute farms, and its regional stations and under the farmer participatory seed production programme, respectively) and also 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 fruit crops

Following is the detail of fruit plants multiplied by the IARI, New Delhi and its regional station during 2020.

Propagation of Fruit crop varieties during 2020

Sl. No.	Crop	Cultivar(s)	IARI RS, Karnal	IARI, New Delhi	IARI RS, Samastipur	IARI RS, Kalimpong	IARI RS, Shimla	Total
1	Mango	Amrapali, Mallika, Pusa Arunima, Pusa Surya, Pusa Pratibha, Pusa Lalima, Pusa Shrestha, Pusa Peetamber, Other cultivars	3,706	2,932	1,285	0	0	7,923
2	-do-	Scion sticks	0.0	2,450	0	0	0	2,450
11	Lemon	Kagzi Kalan	1,470	1,950	108	0	0	2,450
12	Acid lime	Abhinav & Udit	0.0	457	0	0	0	3,528
13	Sweet orange	Pusa Round & Pusa Sharad	0.0	1,045	0	0	0	457
14	-do-	Darjeeling mandarin	0.0	0	0	500	0	1,045
	Grape	Pusa varieties	0.0	673	0	0	0	500
15	Guava	Allahabad Safeda	750	0	0	0	0	673
16	Litchi	Sahi	0.0	0	90	0	0	750
17	Temperate fruits	Apple, walnut, pear, plum, apricot, peach, persimmon, pomegranate & kiwifruit	0.0	0	0	0	4,224	90
18	Strawberry	Different varieties	0.0	0	0	0	4,285	4,224
	Large cardamom	Suckers	0.0	0	0	5,000	0	4,285
20	Papaya	Seedlings	55	1,150	10,186	0	0	11,391
		Total	**5,981**	**10,657**	**11,669**	**5,500**	**8,509**	**42,316**

2.4.2 Ornamental Crops

Following is the detail of ornamental crops seed production by the IARI, New Delhi and its regional stations in 2020.

Planting material production in ornamental crops during 2020

Sl. No.	Crop	Variety(ies)	Quantity (kg)	Centre/ Location
1.	Marigold	Pusa Narangi Gainda	27.0	SPU, IARI, New Delhi
2.	Marigold	Pusa Arpita and Pusa Deep	15.0	IARI RS, Karnal
3.	Marigold	Pusa Narangi Gainda	1.0	IARI RS, Katrain
4.	Winter seasonal flowers	Different flowers	2.5	IARI, New Delhi
5.	-do-	-do-	1.5	IARI RS, Katrain
		Total (kg)	**47.0**	
6.	Flower seedlings	Winter Annuals	7,500	IARI, New Delhi
7.	Bougainvillea	All named varieties	2,500	IARI, New Delhi
8.	Rose	All named varieties	850	IARI, New Delhi
9.	Gladiolus	Named Varieties	1550	IARI, New Delhi
10.	Lilium	Named Varieties	250	IARI, New Delhi
11.	Amaryllis	Pusa Suryakiran	300	IARI, New Delhi
12.	Potted plants	Syngonium, Pothos, Aglonema & Dracena	500	IARI, New Delhi
13.	Other bulbous	Touch Lily, Day lily, Iris, Nargis, Daffodil Alestromeria, Lilum, Dahlia etc.	750	IARI RS, Katrain
14.	Licoris	Different varieties	7,000	IARI RS, Kalimpong
15.	Easter lily	Different varieties	300	IARI RS, Kalimpong
		Total (No.)	**21,500**	

2.4.3 Seed production in vegetable crops

The detail of vegetable crops seed production by the IARI and its regional stations and seed production unit in 2020 is given in the following table.

Total seed production of vegetable crops during *rabi* 2019-20 and summer/ *kharif* 2020

Type	No. of Crops	No. of Varieties	Seed Production (kg)			
			Nucleus	Breeder	IARI	Total
IARI, New Delhi	24	36	0.00	232.00	1426.00	1,658.00
SPU, New Delhi	21	29	0.00	293.75	6234.6	6,528.35
IARI RS, Karnal	21	37	3.47	1763.495	1662.20	3,429.165
IARI RS, Katrain	16	32	98.38	166.20	3296.54	3,561.12
		Total	**101.85**	**2,455.445**	**12,619.34**	**15,176.635**

3. GENETIC RESOURCES AND BIOSYSTEMATICS

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

3.1. CROP GENETIC RESOURCES

3.1.1 Wheat

Development of disease resistant genetic stocks from wild relatives of wheat: Yellow rust resistance was recorded in primary gene pool derived introgression lines. Five bread wheat introgression lines derived by crossing with *T. spelta* accessions were identified to show high levels of resistance (0) against yellow rust at adult plant stage. Another introgression line derived by crossing *T. turgidum* with *T. aestivum* cultivar NI5439 was also identified to show resistance (10MS) against yellow rust at adult plant stage. It was cytologically stable and showed perfect pairing of 21 bivalents at meiotic metaphase-I. Multiple disease resistant lines were also identified showing resistance to fungal diseases *viz*., rusts, Karnal bunt, head scab and spot blotch. Two *T. militinae* derivatives were found to be resistant to leaf rust, Karnal bunt, head scab, spot blotch; one showed resistance to yellow rust, Karnal bunt, head scab, spot blotch; eight were resistant to leaf rust, yellow rust, Karnal bunt. One *Secale cereal* derivative was resistant to leaf rust, yellow rust, KB; one to leaf rust, yellow rust, head scab; one to yellow rust, karnal bunt, spot blotch and one to karnal bunt and head scab.

Germplasm conservation: More than 6000 wheat, barley, oats, triticale lines, synthetics, CIMMYT advance lines, RILs carrying different leaf, stem, yellow, head scab, blight resistance genes, PHS sources and 1900 wild relatives are continuously maintained in both net house and field, evaluated and utilized at IARI, Regional Station, Wellington. The harvested seeds are conserved. Gene sources for *Lr19/Sr25, Lr19/Sr25, Sr36/Pm6, Lr24/Sr24, Lr24/Sr24/Sr26, Sr27, Lr28, Lr32, Lr37/Sr38/Yr17, Lr45, Lr47, Lr34, Lr46, Lr67 and Lr68, Yr10* and *Yr15* are continuously maintained

Development of cms (A) lines in the background of high yielding varieties: The six high yielding varieties namely HD2967, HD2733, HD3059, HD2932, HD3086 and HD3209 were converted into cytoplasmic sterile lines through backcross breeding.

Genetic stocks registered

HI 1619 (INGR20006): A bread wheat genotype showed significant superiority in grain yield (4.69 t/ha) of 0.2- 5.9% over checks in NIVT and AVT-I under restricted irrigation conditions of North Western Plains Zone trials. It was found to be resistant to leaf and stripe rusts, Karnal bunt and flag smut in multi-location testing. It also showed resistance to diseases like flag smut and Karnal bunt. It was registered with ICAR-NBPGR as source of resistance to leaf and stripe rusts, flag smut, Karnal bunt and high yield.

HI 8791 (INGR20005): HI 8791, durum wheat genotype is a high yielding genotype, with an average yield of 4.3 and 3.84 t/ha in NIVT and AVT-I respectively. It showed significant superiority of 16% to 2.6% in NIVT and AVT-I, respectively, in comparison to check variety HI 8627 in Central Zone. It was found to be resistant to stem, leaf and stripe rusts and flag smut in multi-location testing. It also showed immune response to flag smut over two years of testing at different locations. It was registered with ICAR-NBPGR as

source of resistance to stem, leaf and stripe rusts and flag smut along with high grain yield.

HS 628: HS 628, registered as genetic stock for rust resistance was developed from a cross HS240*2/FLW20(*Lr19*)//HS240*2/FLW13(*Yr15*) using Bulk-pedigree method of breeding. HS 628 has shown adult plant resistance under epiphytotic conditions to brown rust (AC1=0.1 to 0.6). HS 628 has been validated to carry *Lr19*/*Sr25* using STS markers PSY1-E1 and Gb.

IC290150 (INGR 19046): A wheat accession registered for stem, leaf and stripe rust resistance at ICAR-NBPGR, New Delhi.

Promising DH wheat lines resistant to rust identified: Eighteen doubled haploid lines were screened against eight races of yellow (*110S119*, *110S247*, *238S119*, *78S84*, *110S84*, *111S68*, *T* and *P*) and eighteen races of brown rust (*11*,*12-5*, *12-7*, *12A*, *77*, *77-1*, *77-2*, *77-5*, *77-7*, *77-8*, *77-10*, *77A-1*, *104-2*, *107-1*, *108-1*, *162-1*, *77-9* and *104-1*) at seedling stage and with mix race of yellow and brown rust in adult plant stage (at Dhaulakuan, Bajaura and Shimla). At the seedling stage, DH-1 showed resistance to all the yellow and brown rust pathotypes except for *77-5* race of brown rust. The adult plant response of this DH-1 line also showed resistance to both yellow and brown rust. The DH-1 was postulated to carry leaf rust resistant genes *Lr26+Lr23+1+* and yellow rust resistant gene *Yr9+* gene based on host pathogen interaction. Molecular characterization of the DH line with gene-specific primers showed that the developed DH-1 contains leaf rust resistance genes *Lr34* and *Lr32* genes. The DH line have been sent to NBPGR for further registration. At seedling stage, DH-4 also showed resistance to all yellow rust pathotypes tested, while DH-3 showed resistance to all eighteen races of brown rust pathotypes. Among other doubled haploid lines: DH-7, DH-8, DH-10,DH-11, DH-13, DH-14 also showed resistance at to all yellow rust pathotypes except for 28S119.

3.1.2 Barley

Barley germplasm resistant to yellow and brown rusts: Among 27 barley germplasm lines evaluated for seedling resistance to yellow rust pathotypes (24, 57, G and M) and brown rust pathotypes (H_1, H_2, H_3, H_4 and H_5), 17 lines *viz.*, BHS369, BHS371, BHS383, BHS462, BHS474, BHS475, BBM762, BBM820, BBM770, BHS474, BBM781, BBM782, BBM786, BBM787, BBM797, BBM800 and BBM814 were identified as resistant.

3.1.3 Rice

Pre-breeding - evaluation of wild rice accessions: A set of 80 different accessions of wild rice collections of *O. rufipogon*, *O. nivara* and *O. longistaminata* were evaluated and data has been recorded for different traits. These lines were also utilised in wide crossing for introgression of useful traits and also inoculated for screening by different isolates of *Xanthomonas oryzae pv. oryzae* (*Xoo*), causal organism of Bacterial blight (BB).

Evaluation of rice landraces for yield and other components: A set of 10,086 rice landraces collected from different parts of India and conserved in the National Gene Bank were evaluated for yield and components such as days to 50% flowering, plant height, number of tillers per plants and panicle length during *Kharif* 2020.

Field view of the evaluation of rice landraces during *Kharif* 2020

3.1.4 Maize

Development of genetic stocks from 'Sikkim Primitive': Sikkim Primitive is a maize landrace native to Sikkim. It possesses 5-9 ears per plant (depending upon environmental conditions). Thus, 'Sikkim Primitive' is an excellent source of 'prolificacy'. However, heterogeneous population can not be directly used in the breeding programme as target gene(s) may segregate. By continuous inbreeding, a homozygous breeding line, MGU-SP-101 has been developed. It

possessed up to five ears per plant in Delhi condition. This genetic stock has been used in studying the genetics and mapping QTL for prolificacy in 'Sikkim Primitive'. MGU-SP-101 is also being used as a donor for prolificacy in the baby corn breeding programme.

Presence of five ears in a single plant of MGU-SP-101

Development of high amylose maize: Maize grains possesses 25-30% amylose and high glycaemic index (GI: 80-90). However, *amylose extender1* (*ae1*) enhances amylose to the extent of 50-70% depending upon the genetic background, and reduces GI <50. Three inbreds lines (MGU-ae-145, MGU-ae-146 and MGU-ae-147 homozygous for *ae1* possessed >50% amylose were identified. These have been developed through inbreeding from segregating populations, and are first of its kind developed in the country. The selected lines are being used as donor for *ae1* gene towards development of high yielding maize hybrids with low GI.

3.1.5 Mustard

Maintenance and utilization of germplasm: Total 519 germplasm lines including *B. juncea* (288), *B. carinata* (170), *B. napus* (16), *B. rapa* (27), *B. nigra* (7), *R. caudatus* (4), *S. alba* (1), *Eruca sativa* (2), *Crambe* spp. (2) and *Lapidium* spp (2) were maintained by selfing and utilized in breeding programme.

Maintenance of Indian mustard germplasm and continuous screening against white rust: Thirty-one Indian mustard accessions with complete resistant reaction against all the "isolates" of *Albugo candida* present at Wellington are being maintained. Further, nine parental varieties were also maintained by controlled pollination for their further study and use.

3.1.6 Vegetables genetic resources

Tomato: Twenty five lines of cultivated tomato and 8 lines of cherry tomato were maintained under polyhouse conditions for evaluation and use in the development of variety/hybrid.

Brinjal: A total of 42 working germplasm lines were purified, evaluated and maintained, 65 segregating progenies were advanced. Wild accessions like *S. incanum*, *S. torvum*, *S. insanum*, *S. integrifolium*, *S. xanthocarpum*, *S. macrocarpum*, *S. atheopicum*, and *S. sysimbrfolium* were maintained and used in hybridization. A total of 15 new lines collected from various parts of the country were evaluated and maintained for characterization in 2021-22. A unique line from exotic collection of *S. macrocarpum* (EC790354) has been identified with white coloured fruit.

Chilli and Capsicum: At IARI Regional Station, Pune 19 capsicum and 22 chilli lines were screened and maintained. In chilli, EC777196, EC777201, EC777203, EC783760 and ATS-43 were found promising in different morphological and phenological traits. Genotypes, IC392212 and Selection-1 had negative response to CMV. Similarly, in capsicum KTP 141, ATS 89, KTC 153, SH-SP-4-1, SH-SP-603-1 and Sweet Banana were found promising for different horticultural traits. Genotypes, ATS 89, ATS 86 and KTC 153 possessed good amounts of Vitamin C in the fruits and had negative response to CMV.

Cauliflower: Fertile inbred lines (143) comprising early (73), mid-early (48) and mid-late (22) were evaluated. Of these, DC 205, DC 903, DC 28, DC 207 and DC 209 were promising in early group with curd yield >18 t/ha. In mid-early group DC 310, DC 313, DC 334 and DC 325 out-performed the check Pusa Sharad (24 t/ha). In the mid-late group, DC 453, DC 411, DC 407 and DC 124 were most promising for curd yield (>28 t/ha).

In total 61 new inbred lines (F_{4-5}) were also evaluated in early group (37), mid-early group (16) and mid-late

(8), of them DC 1503-03, DC 1503-01, DC 1508, DC 15-23-4 and DC 1515-6 were promising for curd yield (>25 t/ha), horticultural traits and October end to November maturity. DC-WD-15-350, DC-WM-17-12, DC-1530-3 and DC 16-45 are new inbreds for mid group (>30 t/ha). DC 1503-03 and DC 1503-1 produced self-blanched retentive white compact curds. A total of 50 advanced breeding lines and 10 inbred lines were maintained for black rot and downy mildew disease screening and other horticultural traits.

Besides, eight SI lines of early maturity group were maintained by sibbing. Horticultural traits were also observed from 24 CMS lines (BC_{5-14}) namely DC 8441-5, DC 8498-10, DC 999-23, DC 999-94, DC 999-41-5, DC 31-94, DC 31-415, DC 31-23, DC-MD-94, MD-PD-15, DC-MD-41-5, DC 394-41-5, DC 394-94, DC 175-8, DC-1817-7, DC-N-94, 4348-94 and 4348-41-5 of early group; four of mid-early group (DC-8409, DC9944-309, DC-8410, and DC-8410-22), and two of mid-late group (DC 8401, DC-MD-202) and maintained by their respective maintainers. Furthermore, conversion of 30 elite inbred lines using refined *Ogura* sterile cytoplasm and seven lines with *Eru(napus)* sterile cytoplasm have been advanced to BC_{6-9} stages.

Other Brassica vegetables: In broccoli, 14 $F_{2:3}$ progenies were raised for advancing to $F_{2:4}$. Of them, DC-Brocco-20-8, DC-Brocco-20-7, DC-Brocco-20-16 and DC-Brocco-20-2 showed desirable features. Two CMS lines DC-Brocco-64A and DC-Brocco-15A were also maintained with their maintainers to advance BC_6 generation. In tropical 'No Chill type' cabbage, three inbred lines (PA-1, PA-2, PA-3) and two CMS lines DC-PA-1A and DC-PA-2A were also raised and selected for head traits to maintain them. A black radish germplasm was also collected from open market and raised for purification and use.

Cucumber and wild species: Forty eight wild accessions of *Cucumis* (*C. hardwickii*, *C. hytivus* and *C. callosus*), 23 long fruited cucumber accessions were maintained through selfing. Besides, 15 tropical gynoecious lines were also maintained through induction of male flowers using silver thio-sulphate. Seven cucumber genotypes with high β-carotene were collected and maintained through selfing. Apart from IC-420422 and LOM-402 new carotene rich lines AZMC-1 and KP1291 collected from Mizoram through ICAR-NBPGR were found to be very promising with dark orange flesh colour on ripening and were crossed with our released varieties for studying genetics, creation of mapping population and transfer of the high β-carotene trait into desirable backgrounds of cucumber. A new line DGC-102 has been submitted for registration to ICAR-NBPGR, New Delhi.

Cucumber gynoecious line, DGC-102

Okra: Fifty nine 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 and in the cultivated background of Pusa A4, Pusa Bhindi-5 and DOV-92 were evaluated. Advance population of *A. moschatus* and *A. angulosus*, namely, Am66-2 and Am92-1 in the background of DOV-66 and DOV-92 had the desirable fruit set with improved fruits type. Resistant plants were selected for further generation advancement.

Screening of wild accessions of okra under natural epiphytotic conditions

Onion and garlic: Sixty five long day onion accessions imported from NRI, UK and NIAS, Japan were supplied to DIHAR, Leh for bulb and seed production.

Out of 65, 44 geminated and developed bulb and some of the accessions showed promising results. The promising accessions were sown again for seed production and evaluation. Fifteen onion germplasm lines were collected. The performance of 43 first generation inbreds was evaluated for *kharif* season bulb production. Five inbreds, namely, KP-109S1, KP-114S1, KP-117S1, KP-127S1 and KP-169S1 produced good quality bulbs through seedling during *kharif* season. One hundred thirty one *kharif* onion germplasm including promising selections, inbreds and synthetic crosses are being maintained.

A total of 50 single crosses between various accessions having desired traits were attempted. Under DUS programme, 44 onion and 12 garlic varieties were maintained by seed production. Experimental trials of hybrid onion (10 entries), germplasm (45 entries), S2M1 (25 lines) and bulb production of inbreds (96), hybrids and parents (340 lines) and exotic (45 lines) was achieved. Maintenance of germplasm (72), bolting free (110), S2M2 (38), elite lines and selfed material (300) were planted for seed production. Under AINRPOG, onion entries in *rabi* (40) and in garlic (14) were tested for yield and other traits. Six garlic accessions were imported from USDA, and their adaptation under Indian conditions is being evaluated at SKUAST Regional Station, Leh.

Pumpkin: Fifty five germplasm/ advanced breeding lines of pumpkin were characterized, evaluated and maintained. Pumpkin DPU-84 having lemon yellow flower colour, which can be used as a morphological marker was maintained. Fruits of DPU-84 are flattish round with average weight 5-6 kg and yellow-orange thick flesh.

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

Carrot: Forty inbred lines were characterized, evaluated and planted for maintenance, seed multiplication and use in hybrid breeding. Selected roots of ten genotypes were planted for purification and further multiplication. Five CMS lines were found to be uniform and are being maintained. Fifteen new germplasm were collected, purified and maintained.

Lettuce: Thirty one lettuce germplasm lines were evaluated and maintained for further assessment. 65 advanced breeding lines were phenotyped based on leaf colour and other traits were selfed and maintained

DL 134 **DL 128** **DL 110**

Lettuce lines

Other leafy vegetables: 3 *palak*, 2 spinach and 5 *chenopodium* advance breeding lines were maintained.

Temperate region vegetables: At IARI Regional Station, Katrain germplasm of several vegetables are maintained as given below:

Cabbage: 165 germplasm including 12 DH lines, 7 self-incompatible lines, 82 OP genotypes 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 2020. Besides these, five genotypes each of orange and purple coloured cauliflower were advanced to BC_3 generation at ICAR-IARI RS, Katrain.

Broccoli: Twenty germplasm and 8 CMS lines along with their maintainer lines were purified and maintained.

Capsicum: Three CMS lines of capsicum were maintained by crossing them with their respective maintainers. Besides, 50 other open-pollinated genotypes of capsicum and 10 advanced breeding

lines of chilli were also maintained under polyhouse conditions.

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

Onion (Long day): Forty advanced breeding lines of long day onion (red, yellow, white) were purified and maintained.

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

3.1.7 Fruit genetic resources

Mango: Ten exotic and indigenous mango germplasm have been procured. Indigenous (96), exotic (16), hybrids (150) and half-sibs (300) are being maintained at the field gene bank. New rootstock genotypes, namely, Indonesia, Peach, Green, *Mangifera odorata*, and *M. sylvatica* have been procured and maintained in nursery.

Grape: The wild indigenous grape species, namely, *V. himalayana,* and exotic *V. ficifolia* and *V. arizonica*have been established in the field. A total of 97 *Vitis* genotypes including commercial cultivars, hybrids, rootstocks and wild species are being maintained in the field gene bank.

Guava: Seeds of 35 new guava genotypes were introduced from the USDA, Hilo, USA through ICAR-NBPGR, New Delhi. From indigenous sources, jelly guava, cherry guava (*Psidium cattelianum*) and few superior seedling types were collected. About 150 genotypes, including varieties, hybrids, species *etc*. are being maintained in field.

Papaya: A total of 26 inbreds/ genotypes (*Carica papaya*) are being maintained besides six wild relatives of cultivated papaya, namely, *Vasconcellea parviflora, V. quercifolia, V. goudotiana, V. cauliflora*and *V. pubescens/ cundinamrcensis* have been raised and mainatained in Phytotron for intergeneric hybridization.

Temperate fruit crops: IARI Regional Station, Shimla maintains large number of germplasm in different fruit crops and has Status of germplasm of temperate fruit crops maintained in field gene bank as given below;

No. of germplasm of temperate fruit crops

Sl. No.	Temperate fruit(s)	No. of germplasm evaluated/ maintained
1	Apple	95
2	Pear	16
3	Peaches and nectarine	14
4	Prune and plum	08
5	Apricot	24
6	Strawberry	105
7	Kiwi	07
8	Walnut	18
9	Almond	08
10	Persimmon	05
11	Cherry	16

3.1.8 Flower genetic resources

Rose: Miniature rose varieties such as Baby blanket, Sweet Chariot, Rose Marine, Bharani, Golden Century, Royal Midrette, Chandrika, Flash Dance and Marigold Sweet Dream were collected from secondary sources to enrich the existing germplasm. Cut flower varieties such as Arka Swadesh, Arka Savi, Arka Ivory, Arka Pride and Arka Sukanya were procured from ICAR-IIHR, Bengaluru and planted for performance evaluation

Other ornamentals: At IARI Regional Station, Katrain, 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 at the station.

Collection of indigenous bulbous flowering plants: To enrich the gene pool of indigenous bulbous flowering plants, several species were collected, namely, *Curcuma leucorhiza, Canna indica, Hemerocallis flavus, Hedychium densiflorum, Hedychium ellipticum,*

Hedychium gardnerianum and *Lilium tigrinum*at IARI RS, Kalimpong, West Bengal.

3.2 BIOSYSTEMATICS AND IDENTIFICATION SERVICES

3.2.1 Insect biosystemetics

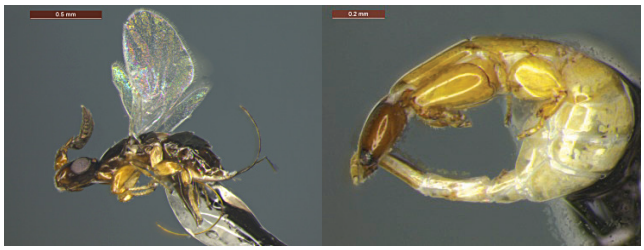
Entomological identification service: A total of 1902 specimens were registered/ identified for various correspondents from all over India. The details are: Coleoptera: 213; Hymenoptera: 857; Diptera:103; Hemiptera:119; Lepidoptera: 215; and Others: 395.

***Collection and suitable processing of the collected material for further studies*:** Collections were made from 10 states of India. Almost all the different groups of crops both their vegetative as well as their reproductive phases were covered during the surveys. Around 10,000 specimens could be collected and more than 700 field visuals on the various life stages and adults could be documented.

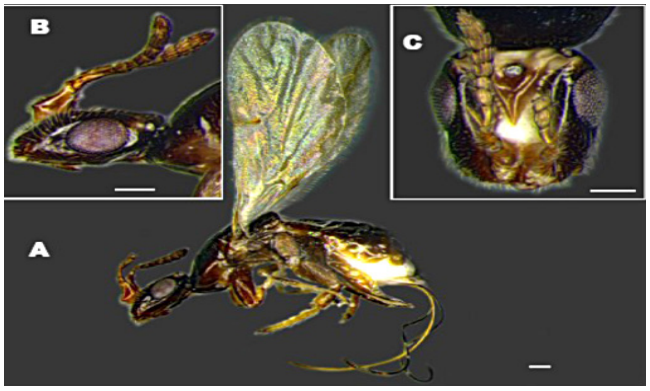
Locust survey in Rajasthan: Survey for noting locust breeding spots and swarms was conducted in various parts of Rajasthan. It was evident that extensive breeding and oviposition in agricultural fields of Nagour district. Field infestation and breeding and roosting behaviors in various surveyed locations were documented. The samples of adults and egg masses were collected and brought to the laboratory for further studies.

Biosystematic studies: Two new pollinating fig wasp species under genus *Dolichoris* Hill 1967 and *Eupristina* Saunders, 1883, namely *Dolichoris buxaensis* sp. nov.and *Eupristina (P.) rumphii* sp. nov.were reared from the fruits of *Ficus microcarpa* and *F. rumphii*, respectively described and illustrated. Diagnostic keys were also formulated to distinguish both sexes of four and eleven known *Dolichoris* and *Eupristina* species reported from India including the new species. Further the affinity of males and females of closely related genera of subfamily Agaoninae was also studied.

Leaf hopper genus *Vittaliana reticulata* gen. nov., sp. nov., was described from India, and placed in the tribe Opsiini based on characters like ocelli close to

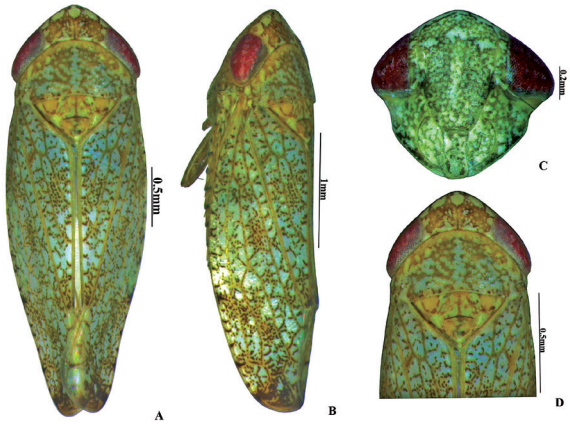


Female and male of *Eupristina (P.) rumphii* sp. nov.



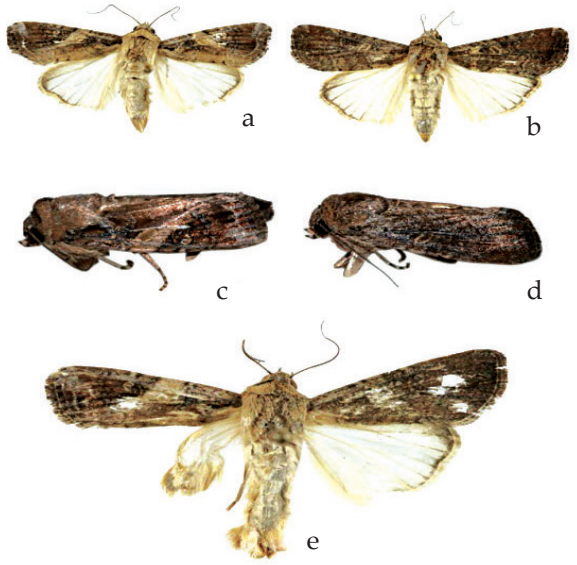
Female and male of *Dolichorisbuxaensis* sp. nov.

eyes, without carina on anterior margin of the face and bifurcate aedeagus with two gonopores. The placement of this new genus in tribe Opsiini was reconfirmed by phylogenetic analysis with maximum likelihood (ML) using IQtree v1.4.1 of combined data (Histone H3 and 28S rDNA).

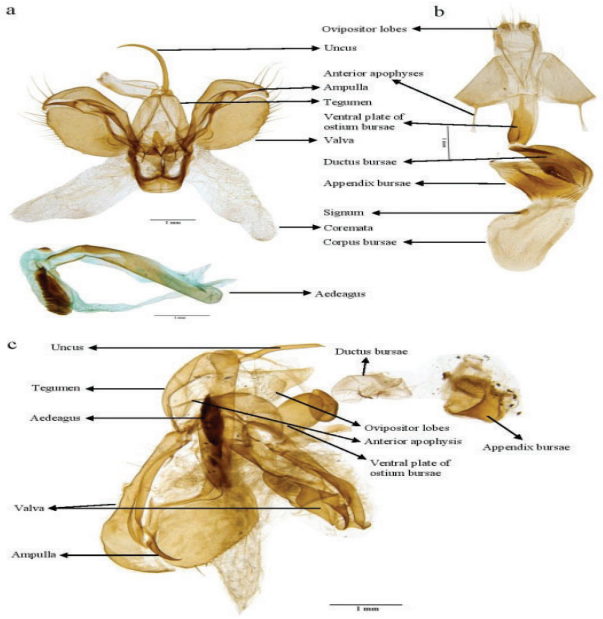


Adults of *Vittaliana reticulata* gen.nov.

The genus *Parasogata* Zhou, Yang & Chen, 2018 reported from India represented by a new species *Parasogata sexpartita* sp. nov. was collected during a recent exploration and survey of delphacids from Nagaland. A second and new species of *Eoeurysa* Muir, 1913 from India, *viz.*, *Eoeurysa sagittaria* sp. nov., was



Habitus of normal male (a & c), female (b & d) and gynandromorphic moth (e)



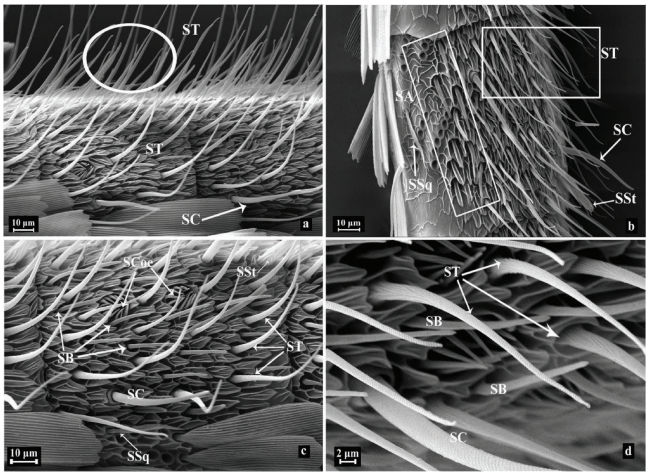
Genitalia morphology of *Spodoptera frugiperda a*. male b. female c. gynadromorph

The antennal morphology and sensilla tof both sexes of *Eariasvittella* (Fabricius)

found in Rampur, Una, Himachal Pradesh. Both new species are described with illustrations and molecular characterization with the mtCOI gene sequence. Genera and species of the subtribe *Hecalina* from the Indian subcontinent were reviewed. They included three genera, *Hecalus* (28 species), *Linna vuoriella* (1 species), *Thomsonia* (4 species) comprising of 33 valid species reported from the Indian subcontinent. Three new species, *Hecalus shanayai* sp. nov. (Maharashtra: Chikhaldhara), *Hecalus tumidus* sp. nov. (Himachal Pradesh: Kinnaurand *Thomsonia assymetrica* sp. nov. (Meghalaya: Barapani) from India are described and illustrated along with an annotated checklist and key to the genera of Hecalina from the Indian subcontinent. Similarly, four new species of leafhoppers, *Pseudosubhimalus asymmetricus* sp. nov. (Himachal Pradesh: Katrain), *P. dalangensis* sp. nov. (Himachal Pradesh: Dalang), *P. katraini* sp. nov. (Himachal Pradesh: Katrain), and *P. lachungensis* sp. nov. (Sikkim: Lachung), were described from the Indian subcontinent.

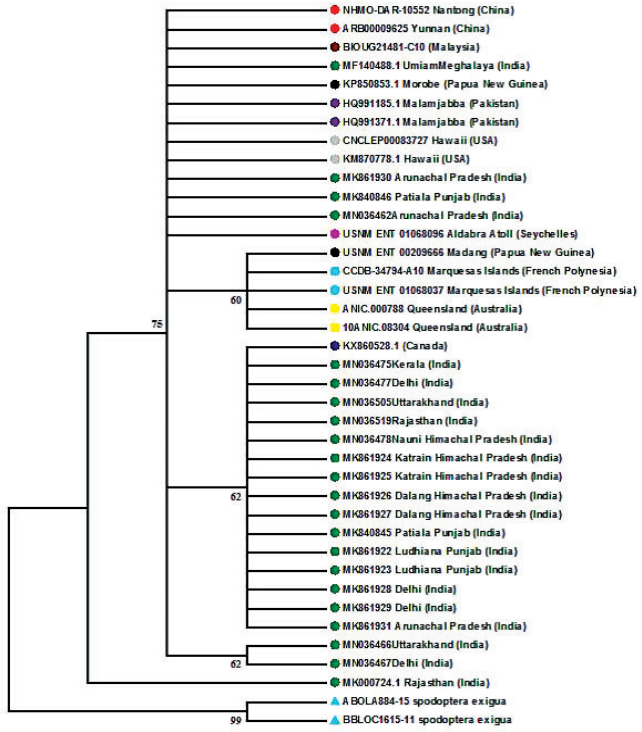
First report of gynandromorph in fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae): Gynandromorphism is a phenomenon in which an individual develops with sexual mosaic of male and female traits. It is a rare phenomenon that has been reported in certain group of organisms, *viz*., arthropods, birds, reptiles, amphibians, mammals. Gynandromorphs are expressed generally in two ways, bilateral and non-bilateral (sexual mosaics). In insects, bilateral gynandromorphs are most frequent, wherein left and right halves are of different sexes. During the routine rearing of *S. frugiperda* serendipitously an adult with an uncertainty in wing morphology was found suggesting it to be a gynandromorph. Detailed examination of morphological and anatomical structure of gynandromorphic moth revealed that wing pattern of left and right side resembled that of male and female, respectively and in thorax, patagium on left side was prominent like male while on right side it was inconspicuous like female depicting the bilateral type. Dissection of gynandromorphic moth genitalia revealed that genital structure was asymmetrical with male genitalic structures observed on one half and female genitalic structures on the other half, male structures are well developed representing, distinct uncus, valvae, aedeagus, tegumen, and ampulla as compared to the female structure.

(Lepidoptera: Nolidae) were examined using light and scanning electron microscopy. Nine distinct types of sensilla were identified on the antennae of both sexes: sensilla trichodea, sensilla basiconica, sensilla coeloconica, sensilla auricillica (multiporous), sensilla chaetica, uniporous peg sensilla (uniporous), sensilla styloconica, sensillasquamiformia and bohm bristles (aporous). Among all sensilla, the most widespread are multiporous sensilla trichodea with 42.90 ±1.77/ flagellomere in male and 37.38 ±1.38/flagellomere in female. Sensilla basiconica were the second most common sensillum type in male antennae with 15.67 ±1.92/flagellomere. Other multiporous sensilla such as auricillica (11.90 ±0.99) and coeloconica (4.57 ±0.25) were significantly more abundant in female than in male antennae. Results of the study provide morphological evidence that *E. vitella* antennae possess microscopic cuticular structures that can play a role in perception of pheromones, plant odours and other chemical stimulants. This will open up opportunities to assess the possibility of using pheromones and plant-derived compounds for the monitoring or management of *E. vittella* moths in the agricultural landscapes.



SEM images showing arrangement and distribution of different types of sensilla on male and female antennae of *E. vittella*. (a) Lateral view of a male flagellomeres, showing uniform arrangement of numerous sensillatrichodea (white circle) on ventral surface; (b) Latero- ventral view of a female flagellomere, showing random arrangement of sensillatrichodea (horizontal rectangular box) on ventral surface and lateral part showing many sensillaauricillica (SA) (vertical rectangular box) and sensillasquamiformia (SSq) (white arrow beside vertical rectangular box); (c) Ventral view of male flagellomere with leaf like surface, showing distribution of sensillatrichodea (ST), sensillabasiconica (SB), sensillachaetica (SC), sensillacoeloconica (SCoe), sensillastyloconica (SSt) and sensillasquamiformia (SSq); (d) Male flagellomere showing shape of sensillatrichodea with striated surface. ST, sensillatrichodea; SC, sensillachaetica; SA, sensillaauricillica; SSq, sensillasquamiformia; SSt, sensillastyloconica; SB, sensillabasiconica; SCoe, sensillacoeloconica.

Green garden looper, *Chrysodeixis eriosoma*, (Lepidoptera: Noctuidae: Plusiinae) has emerged as a major insect pest of agronomic and vegetable crops causing considerable crop losses. In the present study, samples from eleven different localities of India were used for the investigation of genetic diversity of *C. eriosoma* by employing a fragment in the mtDNA gene-encoding cytochrome oxidase I (COI). Based on the partial COI gene, less nucleotide diversity ($\pi = 0.00314$) among Indian and global *C. eriosoma* populations were observed, whereas nucleotide diversity within Indian populations was nonsignificant ($\pi = 0.00079$). Additionally, phylogenetic analysis of COI sequences grouped all the Indian and global populations into one cluster. This is the first attempt for diversity assessment of *C. eriosoma* populations from India.

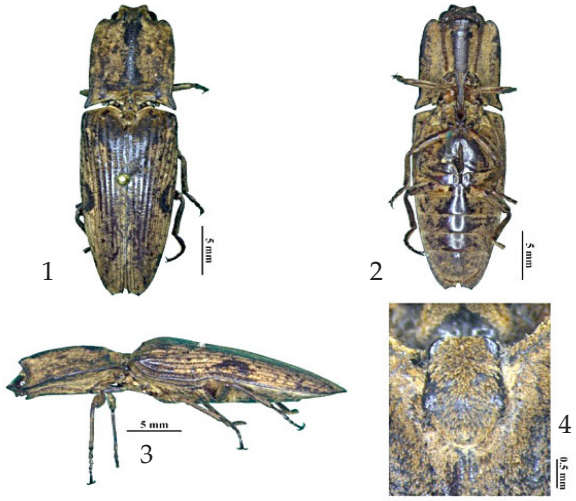


Maximum-likelihood (ML) phylogenetic consensus tree generated from the COI gene sequences of *C.eriosoma*. The consensus tree was inferred from 2000 bootstrap replicates.

A new species, *Lanelater andamanensis* sp. nov. was described from the Little Andaman Island located in the

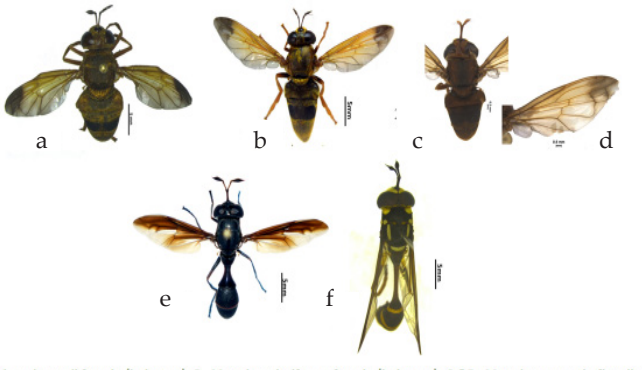
Andaman group of Islands, India. A modified checklist was prepared for the all the 20 species reported till now from Indian subcontinent. *Lanelater*Arnett is a new record for Andaman Islands.

Cryptalaus nodulosus (Waterhouse, 1877 (Coleoptera: Elateridae), was proposed as a new combination for *Alaus nodulosus* Waterhouse, 1877. This was recorded for the first time outside Andaman Islands, from the Nicobar Islands, India. *Cryptalaus nodulosus* was re-described along with illustrations of habitus, external morphology and male genitalia. Revision *Cryptalaus* species were initiated, 3 sps *viz.*, *C. speciosus*, *Cryptalaus sordidus* (Westwood, 1848) and *C. lacteus* (Fabricius, 1801) were redescribed. A modified checklist was prepared for all the 13 species reported till now from Indian subcontinent.



***Cryptalausnodulosus*. Habitus: 1) Dorsal, 2) Ventral, 3) Lateral. 4) Scutellar shield.**

Three new species of *Metadon*, *viz.*, *ghorpadi*, *nigrifemur*, *euxantho flagellumn* described from Karnataka, Tamil Nadu and Maharashtra were found close to *Metadona chetrbergi* Reemer but showed significant morphological differences in terms of antennal ratio, wing infuscation, color of femur, pile on pleura, tergite 5 and structure of sternite 3. Further, molecular analysis (based on Clustal omega software) of *Metadon xanthoflagellum* sp.nov. collected from Delhi showed 12% nucleotide divergence from the closest species *Metadon achterbergi* Reemer supporting the claim based on morphology of its new species status revisionary studies on genus *Monoceromyia* led to the establishment of two new species, *viz.*, *Monoceromyia nigra* and *M. flavoscutatus*.

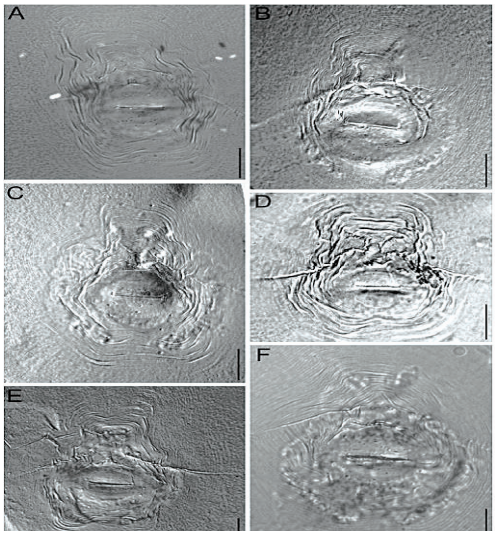


A. Metadon ghorpedi female (holotype), *B. Metadon* nigrifemur female (holotype), C&D. Metadon eusanthoflagellum (female holotype) habitus and wings, *E. Monocermya nigra* female (holotype), *F. Monoceromya* flavoscutatus female (holotype)

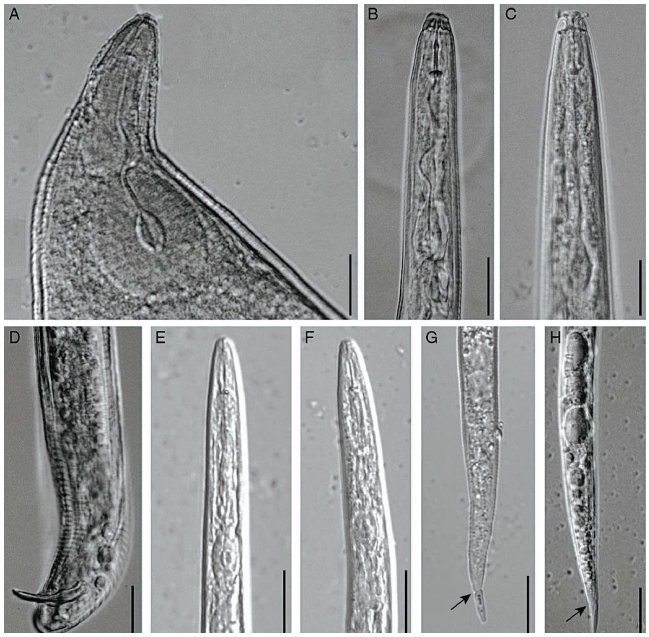
***Demonstration of efficient pollination service delivery by native pollinator Eristalistenax for small scale hybrid seed production of temperate vegetables*:** At IARI Regional Station, Katrain intensive surveys carried out in last three years revealed that *E. tenax* (Syrphidae, Diptera) is one of the most abundant native pollinators in Kullu Valley. This species can be mass reared and released for pollination. Pollination potential of this species was assessed for small scale seed production of CMS based cabbage and cauliflower hybrids, carrot and onion. In the present study pollination behavior as well as single visit pollen delivery was studied for both *E. tenax* and Indian honey bee *Apis cerenaindica* to understand the factors behind efficient pollination service delivery. Both species were found to be efficient pollinator but their pollination behavior showed remarkable differences. While *E. tenax* spent significantly more time/bout foraging on each floral unit, honeybees deposited more number of pollens in a single visit. With an average population density of 5 individuals/m^2*Apis cerenaindica* was found to be more efficient on cabbage, cauliflower and onion but for carrot *E. tenax* was equally successful. There was no significant difference in 1000-seed weight as well as germination percentage for all the four vegetables pollinated by either *E. tenax* or *Apis cerenaindica*.

3.2.2 Nematode biosystematics

First comprehensive phenotyping of Indian population of *Meloidogyne enterolobii:* A population of *Meloidogyne* sp. infecting guava in the Coimbatore region of Tamil Nadu, India was investigated for identification and confirmation of species. Detailed morphological and morphometric observations based on second-stage juveniles, males, females and perineal patterns showed resemblance of the isolated population with the original and subsequent descriptions of *M. enterolobii*. The identity of the nematode population was further validated by *M. enterolobii* specific SCAR marker and ITS rDNA. This is the most comprehensive morphology and morphometrics of an Indian population of *M. enterolobii* for its authentic identification.

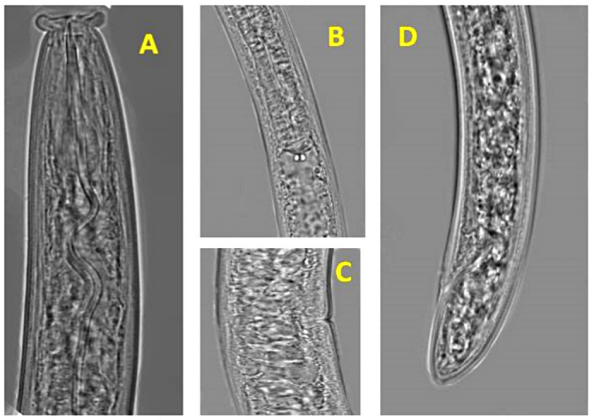


Photomicrographs of perineal patterns of *Meloidogyne enterolobii* Yang and Eisenback, 1983. (scale bar = 20 µm).



Photomicrographs of female, male, and second-stage juveniles (J2s). A: Anterior end of female; B, C: Anterior ends of male (lateral, dorsal); D: Posterior end of male; E, F: Anterior ends of J2; G, H: Posterior ends of J2 (arrow showing the constriction). (scale bar = 20 µm)

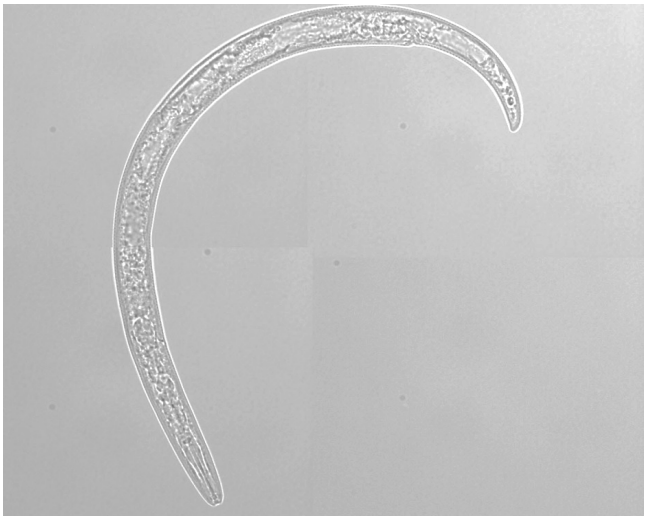
New species of a predatory nematode *Discolaimuspusai* sp. n.: A new species of a predatory nematode *Discolaimuspusai* sp. n. (Nematoda: Dorylaimida) is identified based on morphological and molecular characterization. This new species was encountered from rhizosphere of *jamun* (*Syzygium cumini*) trees, which are grown as avenue trees in ICAR-India.



***Discolaimuspusai* sp. n.: A – Anterior region; B – Pharyngeal region; C – Vulval opening; D –Tail**

Digitization of NNCI: Digitization of a part of type collection at National Nematode Collection of India was done. Fifty six specimens were digitized using programmable motorized Axioimager microscope. Digitization was done at 63x oil objective at 0.5 µm depths and at 40x and 1.0 µm depths for large nematodes. These high quality images occupied 310 GB of the storage space. Preparation of the image database of juveniles from root knot nematode and cyst was initiated for the purpose of usingit as a base for computer aided nematode identification through deep learning. About 1000 images of the nematodes

(whole nematode, anterior and posterior region) have been taken. More than 50,000 images each of cyst and root-knot nematodes would be required for training the computers for use in automated identification.



Digitized specimen of *Paratylenchusjasmineae* (Accession No. T-2607)

3.2.4 Microbial genetic resources

Conservation of microbial diversity associated with wheat and other graminaceous hosts: At IARI, Regional Station, Wellington 70 isolates of fungi cultures belong to different genera viz., *Bipolaris*, *Chaetomium* (Biocontrol agent), *Trichothecium*, *Alternaria*, *Sphaerellopsis* (Mycoparasite on leaf rust of wheat), *Epicocum*, *Fusarium*, *Acremonium* (Mycoparasite on stem rust of wheat), *Cladosporium* and *Pestalotia*, which were isolated, and identified based on morphological characters from wheat and other Graminaceous host in southern hills of India (Nilgiris, Tamil Nadu) are being maintained. For the first time, pure cultures of 260 isolates of *B. graminis*f.sp.*tritici* (*Bgt*) representing SHZ, NWPZ and NHZ are maintained at Wellington in specially designed controlled conditions facilities.

Conservation of microbial diversity associated with wheat and other graminaceous hosts: Seventy isolates of fungi cultures belong to different genera, viz., *Bipolaris*, *Chaetomium* (Biocontrol agent), *Trichothecium*, *Alternaria*, *Sphaerellopsis* (Mycoparasite on leaf rust of wheat), *Epicocum*, *Fusarium*, *Acremonium* (Mycoparasite on stem rust of wheat), *Cladosporium* and *Pestalotia*, which were isolated, and identified based on morphological characters from wheat and other Graminaceous host in southern hills of India (Nilgiris, Tamil Nadu) are being maintained. For the first time, pure cultures of 260 isolates of *B. graminis*f. sp. *tritici* (*Bgt*) representing SHZ, NWPZ and NHZ are maintained at Wellington in specially designed controlled conditions facilities.

Morphological and molecular characterization of fungi associated with wheat and other graminaceous hosts: The different genera of fungi, *viz. Trichotheciumroseum*, *Epiccocum nigram* and *Lasiodiplodia* sp., and *Cladosporium* have been characterized based on ITS region analysis. Stem rust samples of wheat and oats were collected from Nilgiris and the ITS region was amplified for 6 isolates of *Pgt* (*P. graminis*f.sp. *tritici*) and one isolate of *Pga* (*P. graminis*f. sp. *avenae*) and the sequences have been submitted in NCBI database.

4. CROP AND NATURAL RESOURCE MANAGEMENT FOR SUSTAINABLE ENVIRONMENT

The disciplines of the School of Natural Resource Management have made significant progress in developing efficient resource management technologies towards enhancing productivity, profitability, and sustainability of crops/cropping systems. Integrated farming system models for small and marginal farmers for year-round income and employment, conservation agriculture-based cropping systems, precision nutrient management options using gadgets/tools, and nano-fertilizers were developed for enhanced productivity, input/resource-use efficiency, and adaptation and mitigation to climate change. Significant improvement in nitrogen-use efficiency has been achieved through using nano clay polymer composites (NCPCs)-based fertilizer products, particularly the NCPC loaded with urea ammonium nitrate. Similarly, biodegradable clay-polymer (PVA/starch) blended coating film was synthesized for reduction in N and P losses from fertilizers. An integrated soil moisture and canopy temperature sensing device was developed for irrigation scheduling in wheat. A composite drought index (CDI) was developed using satellite data and validated in Marathwada, Maharashtra. Four Gram+ve bacterial strains were identified for reducing Ni, Cr and Pb from waste water. An artificial lighting module using smart LEDs system was designed and developed for suitable bud induction exclusively for off-season flower production of chrysanthemum. The second hybrid farm sunfridge/solar refrigerated evaporatively cooled (SREC) structure was built and a sensor based liquid fertilizer metering system was developed. A pedal-cum-solar operated paddy thresher was developed for small and marginal farmers in rural areas where there is lack of electricity or having erratic supply. Layer-by-layer coating of carboxymethylcellulose, chitosan and mixed plant extract of moringa + eucalyptus + marigold was found highly effective in reducing fruit decay and weight loss in Nectarine fruits. Research on microbiology could develop BGA-based composite liquid formulation (BGALF) for sustaining crop productivity and soil health. Two novel yeast strains, *viz*. *Meyerozyma* and *Lodderomyces* were found promising for production of biofuels/bio ethanol from rice straw. Pusa decomposer technology was perfected after large scale demonstration in farmers fields in Delhi and Punjab. Regional GHG emission from wheat fields was estimated using simulation model for N_2O and the simulated N_2O emissions were found higher in lower latitudes. An inventory of methane emission from different rice ecosystem in India was updated which revealed that Indian rice paddies emitted 3.47 Tg of methane annually. Sub-surface drip fertigation led to reduction in GWP by 84% in rice and 51% in wheat with considerable water saving (37-48%) in both crops.

4.1 AGRONOMY

4.1.1 Integrated farming system (IFS) for improving livelihood of small farmers in Northern India

An IFS model has been developed with the concept of integrating multiple enterprises (crops, livestock, beekeeping, fisheries, etc.) in a single farm unit with the objective of ensuring year round income and employment for a farm family with 1 ha irrigated land. Net annual income of this model was ₹ 3.87 lakh along with additional 628 man-days engaged throughout the year. The highest net income (₹ 1.68 lakh/year) was obtained from livestock (3 cross-bred cows) followed

IFS model, IARI, New Delhi

by growing crops (₹1.06 lakh), while duck (32 birds) and poultry (50 birds) generated ₹ 0.31 and 0.32 lakh annual income, respectively. Biogas plant (KVIC model) used for cooking also provides 0.30 to 0.58 m^3 gas depending on the season, the summer being more efficient than winter. Slurry of biogas plants are usually used for preparation of FYM and vermicompost.

4.1.2 IFS model for marginal farm holder

An IFS model (1 acre) has been established with the aim of maximizing income and nutritional security of marginal farmers. The enterprises included: polyhouse cultivation of vegetables (600 m^2 area for cultivation of tomato, capsicum and cucumbers), mushroom production (50 m^2 area), agri-horti system (1200 m^2 area), apiculture and open field cultivation of vegetables, flowers, cereals, oilseeds and pulses on 2200 m^2 area. During this period, net gain from the polyhouse was ₹ 66,250. Such profit from mushroom, agri-horti system, seasonal vegetables production and apiculture was of ₹ 51,400, 13,300, 19,196 and 3,100, respectively. The total annual net returns after sustaining the family was ₹ 153,246. Recycling of organic residue among different farm enterprises also had good effect on soil health.

4.1.3 Conservation Agriculture (CA)-based rice-mustard system for crop diversification in North-Western Indo-Gangetic plains

The CA-based direct-seeded rice (DSR)–mustard cropping system was undertaken for diversification of traditional transplanted puddled rice (TPR)–wheat system. The triple ZT rice-mustard-mungbean system, involving ZT DSR + summer mungbean (SMB) residue–ZT mustard (ZTM) with rice residue (RR)–ZT summer mungbean (SMB) with mustard residue (~MBR + ZTDSR–RR + ZTM–MR + SMB) gave 30.3% higher mustard seed yield (0.57 t/ha) than conventional till mustard (CTM). This CA-based system provided 44%

IFS model for marginal farmers

higher system productivity (~4.14 t/ha rice equivalent yield, REY) than TPR–CTM system, despite 10.9% lower rice grain yield (~0.55 t/ha) than TPR. This could be a better crop diversification option. It also gave 6.3% higher net returns in rice, and 37.8% in mustard. On the whole, this system including SMB provided 59.1% higher net returns than TPR–CTM.

Productivity and profitability of rice-mustard system under CA (5-years mean)

Treatment	System productivity (t/ha REY)	System profitability (×10³ ₹/ha)
ZTDSR-ZTM	8.17^{e}	84.9
ZTDSR+BM-ZTM	8.19^{e}	83.1
ZTDSR-ZTM (+R)	8.74^{d}	93.3
ZTDSR+BM-ZTM (+R)	9.12^{cd}	94.0
ZTDSR-ZTM-ZTSMB	12.32^{b} (3.06)†	129.4 (27.0)†
ZTDSR-ZTM-ZTSMB (+R)	13.56^{a} (3.38)†	142.7(31.6)†
TPR-ZTM	9.48^{c}	94.5
TPR-CTM	9.42^{c}	89.7

†REY and net returns of mungbean (×10³ ₹/ha) are given in parentheses

4.1.4 CA in maize–wheat–mungbean (M-W-Mb) system can reduce lodging in wheat and increase productivity

Under a long-term (>12 years) CA-based experiment, tillage, N and residue retention/ incorporation were evaluated for two consecutive cropping seasons in M-W-Mb system. Treatments were zero tillage (ZT) with residue retention (R) + 50% RDN (ZT+R+50% N), ZT+R+75% N, ZT+R+100% N and conventional tillage (CT) with residue incorporation (R) + 100% RDN (CT+R+100% N). The ZT+R+100% N resulted in 13.6% higher system productivity (maize equivalent yield) than CT+R+100% N. On the whole, ZT system gave 9.6% higher system productivity than CT. Moreover, residue retention was found to be better than incorporation. Wheat crop was more resistant to lodging under the CA system (~ZT+R+100%N) than CT.

System productivity and lodging index

Tillage residue and N management	System productivity (M-W-Mb) (t/ha)	Wheat lodging index
ZT+R+50%N	12.16^{c}	58.69
ZT+R+75%N	12.98^{b}	12.22
ZT+R+100%N	13.96^{a} (13.6%)	11.76
CT+R+100%N	12.29^{c}	87.50

CT+R+100% N plot (lodged)

ZT+R+100% N plot (non-lodged)

4.1.5 Conservation agriculture (CA) based maize–mustard–mungbean system for higher yield and income

CA systems utilize soils for crop production without excessive mixing and turning the soil and maintain crop residues on soil surface. In this study, the performance of mustard crop grown under Mz–Ms–Mb sequence in three long-term tillage and residue management (+R) options [*i.e.*, permanent raised bed (PB+R); zero till flat bed (ZT+R); conventional till flat bed (CT+R)] was assessed. It showed that the CA-based PB+R and ZT+R plots enhanced the mustard seed yield and economic profit by 17-21% and 24-29% than CT, respectively.

CA based maize–mustard–mungbean system

4.1.6 Sustainable intensification through conservation agriculture and pulse integration under rainfed systems

Application of residue as mulch recorded significantly higher system productivity in terms of chickpea equivalent yield (~3.09 t/ha). Application of residue @ 4 and 3 t/ha being at par found significantly better than 2 t/ha in respect of increasing chickpea equivalent yield. Growing of pearl millet-chickpea cropping system resulted in maximum system productivity, which was 5.8 and 12.35% higher than pearl millet-barley and pearl millet-lentil.

Pulse integration in CA

4.1.7 Improving nutrient use efficiency in wheat and mustard through nano-fertilizer

Results showed that there is a possibility of curtailing 25% N usage in wheat through application of nano-N fertilizer (2 sprays). Foliar sprays of nano-N and nano-Zn along with 50% of recommended N could produce wheat grain yield similar to what the recommended N had, indicating possibility of even 50% reduction in N fertilizer usage. In mustard also, nano-N fertilizer (2 sprays) could reduce N usage by up to 50%. Application of nano-N alone or in combination with nano-Zn (nano-N + nano-Zn) resulted in 10.2 and 13.9% higher mustard seed yield than the recommended N.

Wheat (left) and mustard (right) with application of nano-fertilizers

4.1.8 Performance of maize-wheat cropping system under different nutrient management and crop establishment methods

Different nutrient management strategies like soil test-based fertilizer recommendation (STCR), Nutrient Experts® (NE) and integrated use of STCR/NE along with GreenSeeker (GS) was evaluated for a CA-based maize-wheat system. Maize and wheat grown under the permanent raised bed with residue (PRB+R) resulted in 6.26 and 5.47 t/ha of grain yield, respectively. Similarly, NE+GS resulted in better crop growth, maximum root activity and higher grain yield of maize (5.82 t/ha) and wheat (5.05 t/ha) followed by NE alone and STCR.

4.1.9 Remunerative crop production systems for enhancing farm income and resilience in semi-arid tropics

The system productivity of different cropping systems varied significantly due to association of fruit

Effect different production systems on system productivity and farm income

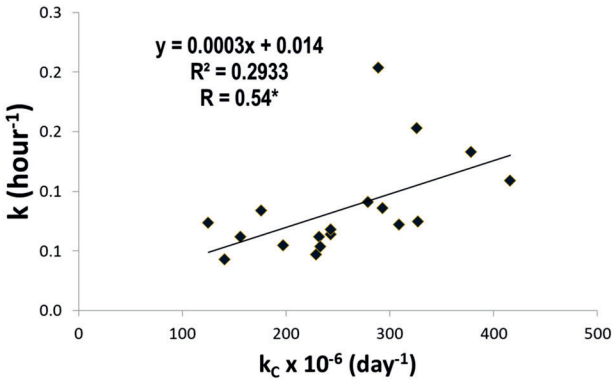
Treatment	System productivity (CEY; t/ha)	Net returns (₹/ha)	Net B: C ratio
Fruit crop			
Mango	3.58	104996	1.51
Kinnow	3.68	109962	1.58
No fruit crop	4.28	142206	2.14
CD (P=0.05)	0.39	-	-
Cropping system			
Maize (cob)-chickpea	3.93	124363	1.84
Babycorn-chickpea	4.65	154487	2.13
Maize (cob)-barley	3.47	102996	1.55
Babycorn-barley	4.08	127700	1.79
Cowpea-barley	3.98	128555	1.96
CD (P=0.05)	0.20	-	-

crops. However, owing to non-receipt of any output from fruit crops in initial years, sole cropping resulted in highest system productivity (~4.28 t/ha), which was 19.5 and 16.3% higher than crops grown with the association of mango and kinnow, respectively. Highest net returns and B: C were also obtained under crops grown without fruit crops. Among the cropping systems, the baby corn-chickpea system provided highest system productivity in terms of chickpea equivalent yield (CEY) followed by baby corn-barley system. This baby corn-chickpea system provided highest net returns and B: C as well.

4.2. SOIL MANAGEMENT

4.2.1 Determining humus desorption rate constant in humus desorption and decay rate constant in carbon mineralization under different cropping systems

Relationship between humus desorption rate constant (k) in humus desorption and decay rate constant (kc) in C mineralization were determined in soil samples collected from Ludhiana, Karnal and Meerut under two cropping systems at three different depths (0-15, 15-30 and 30-60 cm). The stability (1/k) was found to be higher in non-rice based cropping systems than rice-based systems, which decreased along the depth from surface to sub-surface layers. The value of kc was lower in non-rice based cropping systems compared to the rice based cropping. Humus desorption rate had positive relationship with the rate of C mineralization implying that C mineralization was inversely affected by soil C stability.



Relationship between humus desorption rate constant (k) in humus desorption with decay rate constant (kc) of C mineralization

4.2.2 Management practices affect build up and stabilization of SOC in CA

In an 8-years long CA-based maize-mustard system, the plot under triple ZT with residue had 14 and 11.6% higher soil TOC (total organic carbon) in the surface (0-5 cm) and subsurface (5-15 cm) soil, respectively than CT. However, double ZT without residue led to the highest NOC (non-labile organic carbon) pool at 0-5 cm layer. Proportion of NOC to TOC was higher in 5-15 cm layer than the top soil and this might be due to higher microbial activity in top soil, which quickly mineralize C and N added through residues resulting in higher proportion of LOC (labile organic carbon) in top soil than the subsurface soil. The highest carbon management index was observed in triple ZT with residue with 15 and 20% higher values than CT at 0-5 and 5-15 cm layers, respectively.

4.2.3 Assessing and arresting transfer of arsenic (As) from soil to rice plant

Relative As uptake ability of rice cultivars, its distribution in different plant parts, and consequent release of organic acids from rice roots as affected by As following applied silicate were assessed in pot and solution culture experiments. The relative As accumulation ability in rice grain was lower in Badshabhog than Khitish, IR-36 and Satabdi cultivars. Sodium metasilicate (Na_2SiO_3) applied at 250 and 500 mg kg^{-1} reduced As content in brown rice by 14.3 and 28.6%, respectively. Thus, integrated use of low As accumulating rice cultivars and silicate could be a promising strategy to arrest the transfer of As from soil to rice grain, grown in polluted soils.

4.2.4 Enhancing nitrogen-use efficiency (NUE) using nanoclaypolymer composites (NCPCs) based fertilizer products

Different N-fertilizers alone or in combination with NCPC were evaluated to assess NUE in three wheat varieties (namely GW 322, HD 2329 and Raj 3765). Results indicated that the NCPC loaded with urea ammonium nitrate (UAN) performed better compared to other fertilizers such as urea, UAN alone or NCPC

loaded with urea. This was more effective in increasing grain yield by 31.7% over that of urea. Moreover, agronomic use efficiency and apparent nitrogen recovery was 22.7, and 51.0%, respectively, whereas the physiological use efficiency was 45.3% under the treatment of NCPC loaded with UAN. It indicates that 25% N can be saved if N is applied through NCPC or NCBPC as a slow release carrier of N fertilizer.

4.2.5 Effect of applied silica on phosphorus availability in soil

In a lab study, results indicated that the application of soluble source of silica could decrease the adsorption of P and increase desorption of fixed P in acid soils. The value of maximum buffer capacity (MBC) decreased with increased Si application, indicating that P concentration at a given level of labile P could increase with Si application. Besides, the value of desorption index (DI) as a measure of hysteresis, decreased with increasing level of applied Si in all the soils. As value of DI decreased due to Si application, thus, making the P desorption more reversible.

4.2.6 Working out the minimum maintenance dose of K under intensive cropping

Depletion of K from non-exchangeable pool has been reported under intensive cropping, leading to deterioration of soil health. Hence, this study was carried out to workout minimum maintenance dose of K in relation to crop productivity and soil health using sorghum-sudan grass as test crop. Four successive crops were grown in two alluvial soils having widely different K fertility status with varying K doses [0, 10, 20, 30, 50, 100, and 200% of recommended dose of K (RDK)]. In both soils, beyond 50% RDK, there was no significant improvement in biomass yield. The 50% RDK corresponds to nearly 85% of K uptake in low K soil, and around 21% of K uptake in high K soil. The supplementation of K to meet up 85% of K removal in low K soil, and 21% of that in high K soil can produce similar biomass yield as that of 100% RDK. A minimum maintenance dose for low K soil is likely to be slightly greater than 85% of K removal by crop. But, in high K soil, there was a decline in almost all the soil parameters related to availability of K under 50% RDK. Interestingly, in this soil, higher doses of K application *i.e.* 100 and 200% RDK could not resist the decline in soil K parameters. Therefore, the decline in soil K parameters cannot be stopped completely rather the depletion of K from non-exchangeable and structural pools should be minimized to the possible extent.

4.2.7 Zinc deficiency tolerance index of rice landraces

A hydroponic experiment by using Hoagland solution was conducted to screen Zn deficiency tolerance response of 50 genetically diverse rice landraces under two-levels of Zn, *viz*. 0.01 mg L^{-1} Zn (deficient) and 0.05 mg L^{-1} Zn (sufficient) and their Zn deficiency tolerance index (ZDTI) was calculated. Principal component analysis (PCA) was carried out with the fourteen determined parameters. The five most sensitive parameters, *viz.* relative shoot Zn content, relative shoot weight to root weight ratio, relative shoot length, and relative root volume and Zn translocation efficiency, which had the highest weightage in the principal component analysis (PCA) of the maximum variability, were used to develop ZDTI. The rice genotypes with high ZDTI (>0.66), *viz.* GP-926, GP-759, GP-441, GR-12, GP-495 and GP-301 could be used for rice production in low Zn containing soils.

4.2.8 Synthesis of biodegradable clay-polymeric (PVA/starch) blended coating films for minimizing N and P losses from fertilizers

Biodegradable clay-polymer (PVA/starch) blended coating films (CPSBs) from wheat starch, polyvinyl alcohol and bentonite clay (0 to 20 wt%) were synthesized to reduce N and P release from CPSB coated fertilizers. Commercial DAP (18% N and 46% P_2O_5) was coated with CPSBs at 4 and 8 w/w%. The relative crystallinity index, density of CPSBs were increased, however, porosity, per cent absorbency and elongation, nutrient permeability of CPSBs were decreased with increasing clay content. Biodegradability test confirms that synthesized CPSBs

were biodegradable in soil, but the degradability could be further enhanced through the inoculation of *Aspergillus awamori* and *Trichoderma viride*. The CPSB coated fertilizers reduced N and P release compared uncoated-DAP. Bentonite is compatible to PVA-starch polymers and CPSBs which could be successfully used to control the N and P release from fertilizers.

4.2.9 Quantification of soil biological parameters for soil quality assessment under CA-based rice-mustard system

Under a seven-years-long CA-based rice-mustard system, the triple ZT, and rice and mungbean residues had significant positive impact on soil biological property. Productivity (rice equivalent yield) was used as management goal for developing soil quality index. In Gmean based method, the value of biological soil quality index varied between 0.59 to 0.96, and 0.52 to 0.86 at 0-5 cm and 5-15 cm soil depths, respectively. In PCA based method, the value of biological soil quality index varied between 0.52 to 0.94, and 0.50 to 0.90 at 0-5 cm and 5-15 cm soil depth, respectively. The CA-based triple ZT system with residue maintained better biological soil quality in both surface and subsurface soil in rice-mustard system under Inceptisol of the IGP.

4.2.10 Feasibility of using sewage-sludge as nutrient source in maize-wheat system

Impacts of long-term sewage sludge application on availability of trace element in relation to soil organic carbon (SOC) dynamics were studied. The SOC, cation exchange capacity, available N and P content, and biological properties like microbial biomass carbon, dehydrogenase activity, alkaline phosphatase and fluorescein diacetate activity were significantly improved due to application of sewage-sludge. Maize and wheat yields were also increased by sewage-sludge application. Maize and wheat grain was found to contain higher amount of Zn, Cu, Fe, Mn, Ni, Cd and Pb over control. The hazard quotient (HQ) that assesses the risk of trace element intake by human through consumption of maize and wheat grains (HQ <0.5 is safe limit), for Ni, Cd and Pb was safe in maize and wheat indicating productivity of maize and wheat as well as micronutrient density in grains (especially Zn & Fe) could be enhanced through combined application of recommended NPK dose and 2.5 t ha^{-1} sewage-sludge without any human health risk and adverse impact on soil health.

4.3 WATER MANAGEMENT

4.3.1 Irrigation scheduling and NPK fertigation in maize–wheat–greengram system

The performance of wheat (HD 3086), greengram (Pusa 1431) and maize (Pusa Jawahar 1) crops having irrigation at 60 and 80% of crop evapotranspiration (ETc) using surface drip and sub-surface drip and fertilized with 4 levels of NPK (0, 60, 80 and 100% of recommended doses) were compared with conventional practice (surface irrigation at recommended irrigation schedule and fertilized with 100% RDF of NPK). Both wheat and green gram yields were improved by 27-29% with 100% NPK compared to control. Use of 100% NPK and irrigation at 80% ETc was similar with the conventional practice on yield of these crops. Surface

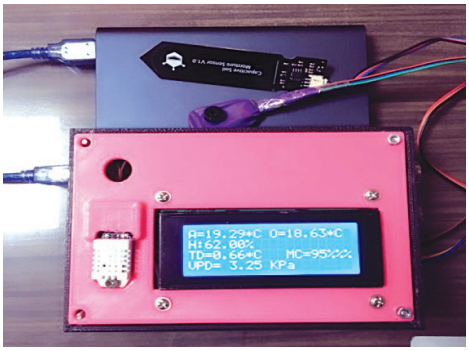
Effect of sewage-sludge application on maize yield (t/ha^{1})

Field view of wheat (a) and moong (b) cultivated with surface and drip fertigation

and sub-surface drip fertigation resulted in similar grain yields of wheat and greengram. However, irrigation at 80% ETc enhanced grain yields of wheat by 8% and green gram by 15% compared to the yields obtained at 60% ETc. Compared to the surface method of irrigation, surface or sub-surface drip could save 35-40% of irrigation water.

4.3.2 Integrated soil moisture and canopy temperature sensing device for irrigation scheduling

Integrated soil moisture and canopy temperature sensing device were developed by integrating the soil moisture, air humidity, air temperature and plant canopy temperature sensors along with the embedded software for their functionality. The soil moisture sensor of the developed system was used for scheduling of irrigation in wheat cultivar HD-2967 during *rabi* 2018-19 and 2019-20. The experiment under different irrigation regimes of 85, 70, 55 and 40% of field capacity (FC) resulted in water productivity of 13.2, 13.9, 14.8, 16.1 and 16.4 kg/ha cm, respectively and irrigation water used was 342 mm (FC) to 200 mm (40% FC). The soil moisture sensor of integrated sensing device was calibrated using the gravimetric method and indicated the trigger point for applying irrigation.



Integrated soil moisture and canopy temperature sensing device

4.3.3 Performance evaluation of revived village pond in Nuh, Haryana

One defunct village pond at Untka was revived using participatory and scientific approaches by digging 1.5 m and constructing two bath ghats, retaining walls with proper shoulder bunds. Due to an additional 22792 m^3 of storage volume created, the command area increased from 37 to 64 ha, which resulted in two folds increase in crop yield times and cropping intensity from 140 to 201%. Due to this renovation, water quality in the pond was improved as indicated by a significant reduction in salt content, SAR and residual sodium carbonate. Soil loss (8 t/ha/year) was found to be within the soil loss tolerance limit (11 t/ha/year). An optimal utilization plan was developed using LINGO software, showing an increase in income up to ₹ 99,331/ha/year.

4.3.4 Impacts of rainwater harvesting on groundwater recharge and water resource availability in Sundarbans delta

Hydrological impacts of rainwater harvesting pond and standing water in paddy field on ground water recharge and water resource availability in Kaikhali village of Kultali block in the South 24-Parganas district of West Bengal, which is part of Sundarbans delta were evaluated through field experiment and modeling (CROPWAT; HYDRUS-1D) for developing water utilization plan and enhancing irrigation intensity. Cumulative bottom flux from the paddy field was 13.6 cm. Percolation from the pond in 135 days was 25.1 cm but it did not contribute to groundwater recharge in adjacent areas. Water stored in the pond had no influence on groundwater recharge but enabled farmers to grow crops and fish. Irrigation

intensity with the water stored in pond in 0.2 ha area can be increased by 53% if farmers cultivate tomato on the entire area (64.48 m^2) and *rabi* paddy in half of the area (570 m^2) of the main land excluding the area under the pond.

4.3.5 Cultivation of summer groundnut using hydrogel

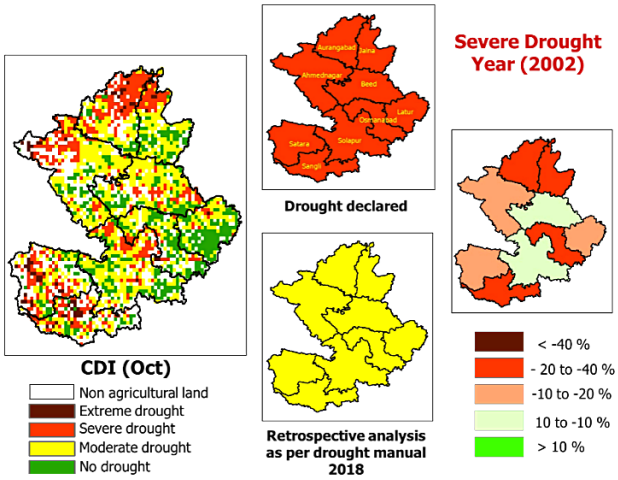
During summer, groundnut variety RG 559-3 performed better than TPG-41 under restricted irrigation showing resilience of this variety to high temperature (45 to 48°C) and soil moisture stress. The highest yield of 5.36 t/ha as against the national average of 1.7 t/ha, was obtained with the application of SPG 1118 gel at the rate of 2.5 kg/ha.

4.3.6 Site suitability analysis for rain water harvesting structures (RWHS)

To develope appropriate technology for groundwater recharge, site suitability analysis for the construction of different types of RWHS was attempted using remote sensing, geographical information system, analytical hierarchal programming, and boolean logicin *Gambhir* river watershed (26°36′0.8″ N to 26°57′35″ N and 77°0′2″ E to 77°16′54″ E). Nearly 32, 55 and 53% area was found to be highly suitable for construction of RWHS, farm ponds for irrigation purposes and percolation ponds for augmenting groundwater recharge, respectively.

4.3.7 Assessing drought monitoring capability of a composite drought index (CDI) in Marathwada, Maharashtra

A CDI was developed using satellite data derived monthly meteorological, biophysical and hydrologic indices, *viz.* SPI (Standardized Precipitation Index), NDVI Anomaly and ESI (Evaporative Stress Index) at 5 km resolution and validated for one of the most drought-prone regions of India, *i.e.* Marathwada Maharashtra using *kharif* season crop yield data for 16 years (2001-2016). The observed yield deviation map matched with the CDI products. Spatial comparison of CDI products with drought years declared by the state government and retrospective analysis using the drought manual 2018 indicates better spatio-temporal drought capturing capabilities of developed CDI products compared to the existing drought declaration protocol. The technique can be used for monitoring of drought onset, its progression and cessation along with severity, and helpful in timely assistance to the affected areas.



Spatial comparison of CDI product for a severe drought year 2002

4.3.8 Multi-metal sequestering bacterial isolates for bio-augmentation of waste water treatment

For assessing the metal sequestration potential of 4-short-listed macrophyte combinations in mixed culture, 12 mixed cultured mesocosm [*viz. Typha latifolia* + *Phragmites karka* (TA); *Phragmites karka* + *Arundo donax* (PA); *Arundo donax* + *Typha latifolia* (AT) and *Vetiver zizinoids* +*Typha latifolia* (VT)] were irrigated with (10 ppm) metal spiked IARI-waste waters and continuously monitored for their metal reduction potential. Simultaneously, 100 microbial strains were isolated from the afore-mentioned mixed cultured multi-metal spiked mesocosms. These were subjected to MIC analysis with respect to Ni (10-50 ppm), Cr (10-300 ppm) and Pb (10-300 ppm). Among these, four promising bacterial isolates (Gram +ve) were identified of which strain No. 47 (with equilibrium Ni, Cr and Pb reduction efficiency of 27, 43 and 53%, resp.) showed compatibility with strain No. 59 (with equilibrium Ni, Cr and Pb reduction efficiency of 48, 40 and 61%, resp.).

While the stain No. 71 (with equilibrium Ni, Cr and Pb reduction efficiency of 41%, 43% and 51%, resp.) showed compatibility with strain 92 (with equilibrium Ni, Cr and Pb reduction efficiency of 56%, 37% and 52%, resp.).

4.3.9 Organic and inorganic amendments influencing heavy metal dynamics and yield of potato irrigated with Ni spiked waste water

Organic (*viz*. paddy straw, sawdust) and inorganic (bentonite) amendments were evaluated for reductions in heavy metal accumulations in potato (var. Kufri Ganga) irrigated with wastewaters spiked with 5 and 10 times of the permissible limit (PL, 0.2 ppm) of Ni. Wastewater irrigated plots yielded 15% higher compared to groundwater irrigated plots, but the amendment applied plots were on par with it. Highest tuber yield (45 t/ha) was obtained from wastewater irrigated plots and amended with sawdust while lowest yield (34 t/ha) from plots irrigated with groundwater and amended with paddy straw. Available N in wastewater irrigated soil was 234 kg/ha N compared to 207 kg/ha in groundwater irrigated plots.

Potato irrigated with Ni spiked wastewater

4.3.10 Nutrients influence essential oil yield and quality of wastewater irrigated lemongrass

Nutrient [control, 50 and 100% of the recommended dose of NPK (N, P_2O_5 and K_2O were 150, 60 and 60 kg ha^{-1}) and irrigation with treated and untreated wastewater, conjunctive use and groundwater irrigation influenced essential oil yield and quality of lemongrass (*Cymbopogon flexuosus*; var. Krishna) and led to nutrient saving and changes in soil health. Lemon grass yield varied from 14.9 to 20.5 t/ha and was highest (19.6 t/ha) in plots irrigated with untreated wastewater followed by conjunctive use (19.1 t/ha), treated wastewater (17.7 t/ha), and the lowest in the case of groundwater irrigated plots (17.1 t/ha). Lemon grass herbage yield increased with an increase in N level. The treated wastewater reduced Ni and Pb accumulation in lemon grass herbage. Similarly, SOC and available N, P, Ni and Pb were higher in untreated wastewater irrigated soil compared to groundwater irrigated soil. The essential oil content in herbage ranged from 10.7 to 13.1 ml per kg of dry biomass of lemon grass. Quality of irrigation water had no impact on essential oil content.

4.4 CPCT

4.4.1 Crop water requirement and irrigation scheduling of Lettuce grown under greenhouse aeroponic system and drip fertigated open field

Crop water requirement and irrigation scheduling was determined for lettuce grown in indigenously designed aeroponic system and in open field with drip fertigation system. The area cultivated was 3.125 m^2 and 150 m^2 with 48 and 1200 plants, respectively, under aeroponic and open field systems. Total water consumed was found to be 24,000 ltr and 192 ltr in both the systems, respectively. Crop water requirement was found to be 20 ltr and 4 ltr per plant in open field and aeroponic system, respectively. Aeroponic system was found to be comparatively highly efficient water saving method for lettuce cultivation.

4.4.2 Pan evaporation based irrigation scheduling for greenhouse cucumber grown in soilless grow bag system

Greenhouse cucumber was grown in soil less grow bag system fitted with stake drippers inside 100 m^2 experimental area in climate-controlled greenhouse. Plants were transplanted on a spacing of one meter length grow bag filled with coco-peat. Pan evaporimeter was installed inside the greenhouse for evaporation measurement. Pan evaporation varied from 3-6 mm/

day during the experiment from July to September 2020 and crop water requirement varied from 300-600 ml per plant. Total crop water requirement varied from 75-150 ltr for 100 m^2 experimental area. Irrigation interval varied from 1-3 days.

Experimental setup of aeroponic cultivation

4.4.3 Nematode management in greenhouse tomato

Management of root-knot nematode and input-use efficiency of soil substrate was studied in greenhouse tomato cv NS-4622 using fortified organic amendments, *viz*. FYM and vermicompost in combination with bioagents, *viz*. *Purpureocillium lilacinum*, *Pseudomonas fluorescens*and (strains of *Trichoderma harzianum*). Nematicides, *viz*. fluopyram 1.2 ml/m^2 and fluensulfone 1.2 g/m^2 and solarization and non-solarization were also used. The combination of both composts, fortified with bio-agents, separately or mixed with soil and solarization for two weeks resulted in better control of root knot nematode, *Meloidogyne incognita* in tomato with lower root gall index and higher yield. The gall index due to this integrated approach was reduced to 0.4 compared to 4.4 to 5 in untreated plots. Both fluopyram and fluensulfone gave better results in combination with solorization Integrated use of three bio-agents applied after solarization for two weeks gave significant increase in fruit yields to the extent of 68% per picking over control.

4.4.4 Optimization of NPK in off-season cucumber varieties under plain area polyhouse

Four varieties, *viz*. Fadia, Defender, Mini-angel and Hilton of cucumber were transplanted in last week of August in paired rows with 50x30 cm spacing and drip irrigation system in forced-ventilated polyhouse. Four combinations of NPK @ 15:7:16 kg, 20:12:21 kg, 25:17:26 kg, and 30:22:31 kg/1000m^2 were applied with standard horticultural practices and fertigation. Parthenocarpic cucumber variety 'Fadia' provided highest total fruit yield of 12.30 kg/m^2 with a net return of ₹ 160.40 and B: C of 2.2 per crop with combination of the optimum NPK dose of 25:17:26 kg/1000m^2.

Off-season cucumber varieties under plain area polyhouse

4.4.5 Standardizing shading per cent and colours of shadenet cover for summer tomato production

Summer tomato varieties, *viz*. Pusa Rohini, Narenrda-2 and US-2853 were tested in March in protected structures covered with shade nets of green, black and white colour having 30 and 50% shading capacity. Pusa Rohini being on par with US-2853 provided highest fruits yield of 56.30 q/1000 m^2 with a net return of ₹ 85000/1000 m^2 and B: C of 2.6 in combination with 50% green coloured shade-net.

Shading per cent and colours of shadenet for summer tomato

This combination was more economical for growing tomato under 50% green coloured shade nethouse, and promoted earliness and quality yield. Also, green coloured shade nets with 50% shading intensity can decrease temperature by 1-2°C and evapo-transpiration, and increase relative humidity by 15-20% and retain more soil moisture during summer season.

4.4.6 Coloured capsicum varieties under multi-span fan-pad polyhouse during off- and early season

Coloured capsicum production is difficult in open condition, particularly during winter in India. Coloured capsicum, namely, yellow varieties (Swarna, Bachata, Ayesha, Orobelle, Arya) and red varieties (Pear peel, Inspiration, Bungi, Natasha, Indra) were transplanted in September at 30x50 cm spacing under multispan fan-pad polyhouse along with drip fertigation. Indra and Inspiration among red-coloured varieties were superior and provided comparable yield of quality fruits (10.20 kg/m^2). Swarna and Bachata among yellow-coloured varieties were most superior producing maximum quality fruits (11.30 kg/m^2). This technique can be profitable and feasible to the farmers in the plains too.

Coloured capsicum varieties under multi-span fan-pad polyhouse

4.4.7 Chilli varietal evaluation under fan-pad polyhouse during off-season

Chilli crop is susceptible to frost, viruses and wilt under open field conditions during off-season from October to May. Growing chilli under protected structures during this period may fetch higher price. Five varieties, namely, AHB-170, VNR-332, Indus-365, Nirala and Preeti were transplanted at 50x50 cm spacing along with drip irrigation and NPK @ 42:25:46 kg/1000 m^2. Among all the hybrid chilli varieties, VNR 332 was found semi-determinate in nature, having better quality and yield potential of 7.7 kg/m^2 with disease tolerance under protected structures during off-season in plain areas.

Chilli varietal evaluation

4.4.8 Direct seeding and transplanting of summer squash with and without plastic mulch under poly-tunnel with drip irrigation

Summer squash varieties, *viz*. Australian green, Pusa Alankar, Aditya, Sandhya, Sunnyhouse, Orilia and Pusa Pasand were planted during December adopting direct seeding and transplanting with and without plastic mulch in temporary plastic low tunnel condition. The long-fruited Pusa Alankar and round-

Seeding and transplanting of summer squash under poly-tunnel

Evaluation of different cladding material for vegetable production under low cost structures

fruited Pusa Pasand in combination with transplanting on plastic mulch exhibited highest yield (90.70 and 42.50 t/ha, respectively), and income (₹ 4.15 lakh/ha and 1.80 lakh/ha) during off-season under low-tunnel technology. Direct seeding had poor germination and delayed flowering and fruiting compared to transplanting.

4.4.9 Development of an artificial lighting module for Chrysanthemum

Chrysanthemum is a short day plant for flowering and requires a day length of ≤11 h for bud induction exclusively for off-season flower production. Using smart LEDs, a system has been designed and developed to evaluate the bud induction process under the influence of PAR @ 110 µ mol $sec^{-1}m^{-2}$. The illumination, however, varied from 90 to 160 µ mol $sec^{-1}m^{-2}$ on leaf canopy and can be controlled accordingly.

Smart LED module for bud induction in chrysanthemum

4.4.10 Cladding materials for growing cucumber, capsicum and tomato under naturally ventilated low cost structures

Among four cladding materials, the structure 1 (C1 - AF1 + UV3 + cooling) is highly UV resistant followed by structure 2 (C2- AF2 + UV2 + cooling) during summer. However, the strucures 3 and 4 have been found efficient during winter having maximum PAR infiltration resulting in higher vegetative growth of crops.

4.5. AGRICULTURAL ENGINEERING

4.5.1 Eco-friendly and profitable crop residue management centre at krishi vigyan kendra (KVK), village Tepla, Ambala

Eco-friendly and profitable crop residue management centre (EPCRMC) was established at KVK, Tepla, Ambala was inaugurated on November 09, 2020 with financial support from CNHI in its CSR programme. The technologies available are 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). Two sheds of size 8 m × 5 m × 3.5 m and 20 m × 5 m × 3.5 m were erected for housing these machines/equipment. Through these technologies and other commercially available technologies (baler, straw

rake and happy seeder), *in-situ* and *ex-situ* management of paddy straw has been demonstrated as solution to paddy straw burning. Demonstrations of animal feed mixer and animal feed block making machine were carried out for the benefits of farmers.

Eco-friendly and profitable crop residue management centre

4.5.2 Farm SunFridge at village Chamrara, Panipat, Haryana

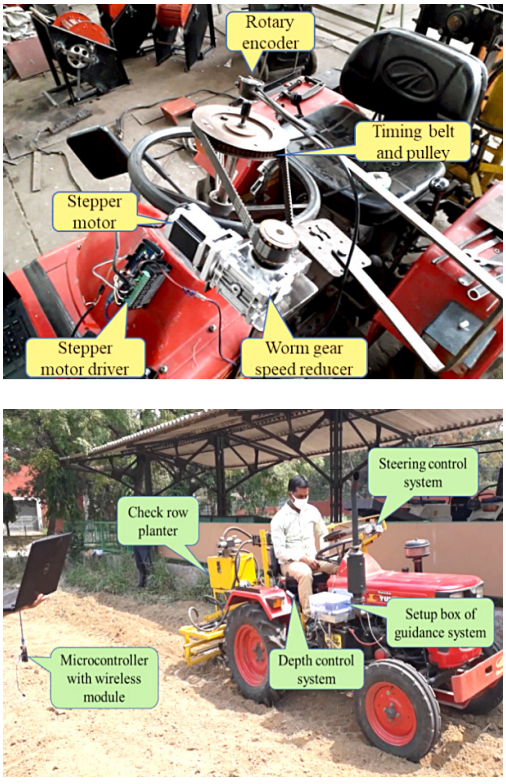
The second hybrid farm sun fridge (FSF)/ solar refrigerated evaporatively cooled (SREC) structure was built and inaugurated on November 9, 2020 at Chamrara, Panipat, Haryana. This sunfridge is a hybrid since the farm has intermittent connection/ supply of electricity, around 8 h out of 24 h with the 8 h slot provided at any time of the day or night. The structure has been prioritized to operate first on solar power and then on grid. Temperature, relative humidity and energy data are collected from the structure via remote monitoring system at 30 minute interval. These data are stored on the cloud *via* the HOBO™ remote monitoring station installed at the structure site at Chamrara and can be seen remotely at link below:

https://dashboard.hobolink.com/public/Farm%20SunFridge%20Chamrara%20Haryana

SREC Structure at village Chamrara, Panipat, Haryana

4.5.3 Tractor guidance system for precision planting

A steering control system was designed for Mahindra make and Yuvraj model tractor with maximum steering effort and torque of 98.90 N and 27.20 Nm, respectively. The developed tractor steering control system consisted of stepper motor, stepper motor driver, linear potentiometer, PID and microcontroller, timing belt pulley and gear box. Both the steering control and depth control systems were calibrated by optimizing the PID tuning parameters



Tractor guidance system for precision planting

of PID controller through Arduino programming of microcontrollers based on their operational parameters. This tractor guidance system was evaluated in field. The maximum lateral deviation and front wheel angle deviation of tractor from straight path by tractor guidance system was 10.1 cm and 1.3 degree for speed 2.8 km/h and 7.5 cm depth of planting, respectively, whereas for manual guidance, it was 32.01 cm and 4.1 degree, respectively for same speed and depth. The PID controller reduced the average lateral deviation up to 68.73, 72.79 and 72.83% for depth 2.5, 5.1 and 7.5 cm, respectively by increasing the speed from 0.97 to 2.80 km/h.

4.5.4 Sensor based liquid fertilizer metering system

A sensor based liquid fertilizer metering system based on design parameters has been developed. The physico-chemical properties such as pH, electrical conductivity (EC), specific gravity, dynamic viscosity, surface tension and percentage light absorbance of urea ammonium nitrate (UAN), aqueous urea, and aqueous neem coated urea (NCU) were determined at N concentration of 0.78, 0.9, 1.08, 1.33, 1.75, 2.54, 4.67 and 28% corresponding to the dilution ratios of 1:35, 1:30, 1:25, 1:20, 1:15, 1:10, 1:05, and 1:00. The developed EC sensor based metering system was evaluated in term of accuracy in output flow rate of three fertilizers (UAN, aqueous urea, aqueous neem coated urea) using the selected N concentrations. The accuracy in the output flow rate was higher at lower N concentration and decreased with increasing N concentration for all three liquid fertilizers. With 1.08 and 1.33% N concentrations of UAN, the accuracy was found to be 99.99 and 99.30%, respectively. Accuracy in output flow rate for aqueous urea and aqueous NCU was in the range of 97.67-99.79% for the N concentration at 1.33-2.54%.

4.5.5 Amelioration of subsoil compaction by roto tilling under farm conditions

The extent of subsoil compaction under roto-tilling and its impact on soil physical properties and crop growth were studied in an on-farm study under rice-wheat system. A survey was conducted in Shamli district of Uttar Pradesh using simple random sampling without replacement (SRSWOR) to elicit the farmers' perception about sub-soil compaction and its adverse impacts. It suggested that frequent use of rotavator (frequency>4 annually) over a period creates compacted soil layer just below the tilling depth, however, sub-soiling at 1.0 or 1.5 m once in every 2-3 years could be useful for managing soil compaction.

4.5.6 Pedal-cum-solar powered paddy thresher

A pedal-cum-solar operated paddy thresher was designed and developed for Small Farms. The diameter of threshing drum, length of threshing drum, number of strips, tip height and loop spacing in the threshing drum parameters were taken as 400, 500 , 12, 50 and 40 mm, respectively. Height of the developed thresher can be adjusted for male and female of different heights varying from 750 to 1267 mm, and accordingly pedal can also be adjusted to required step height. Field performance evaluation of this thresher demonstrated the threshing efficiency as 99.58-98.67% in solar mode compared to 98.54-97.01% for pedal. Threshing rate was 3.47 times greater in solar mode (231.67 kg/h) than that in pedal mode (66.63 kg/h). This thresher might be useful for small and marginal farmers in rural areas

Pedal-cum-Solar powered paddy thresher

lacking electricity or having erratic supply. It will also be very useful for farmers in hilly regions as its lighter weight facilitates easy transportation.

4.5.7 Battery-assisted mini electric agri prime mover (MEAPM)

A MEAPM, weighing 48 kg has been developed that consists of 24V 450W DC motor, gear box, chain and sprocket, C type chassis, two drive wheel, hitch and handle. Motor was powered with a battery pack of 24V 24Ah SMF lead acid batteries. The output with the mini prime mover for secondary tillage, planking and weeding with sweep and tyne are 470 m^2/h, 1120 m^2/h, 1000 m^2/h in 45 cm spaced row to row crop and 750 m^2/h in 22 cm spaced row to row crop at speed of about 2.5 km/h, respectively. MEPMA has potential to save 2-3 ltr diesel per h, and can reduce harmful emission load in environment.

Mini electric (battery-assisted) agri prime mover

4.5.8 Battery operated ginger washer

A continuous rotary drum type battery operated ginger washer was developed and investigated for its performance. The machine consists of the frame, feeding and discharge chutes, rotary drum with internal flights, pressure pump and nozzle assembly, battery and a drive unit. Feed rate (100, 150 and 200 kg/h) and residence time (15, 20 and 25 sec) were taken as study variables and performance of the washer was evaluated for washing efficiency, microbial washing efficiency, bruise index and colour of washed ginger. The best set of conditions under which this washer could be operated was 150 kg/h and 25 sec with 92.48% mechanical washing efficiency, 93.18% microbial washing efficiency, and 4.54% bruise index. Significant difference in the colour was found between washed and unwashed ginger; at selected operating conditions 'L', 'a' and 'b' values of washed ginger were 51.79, 7.57 and 19.97, respectively.

Unwashed ginger

Washed ginger

4.5.9 Infrared processing chamber

A lab scale batch type IR treatment chamber consisting two main components, an IR emitter, fitter with IR lamps and a vibratory sample tray was developed. Provision has been made to change IR emitters of different wavelength, wattage, distance between the sample and IR emitter and frequency of vibratory tray. Treatment chamber is made of MS sheet with insulation and internal chamber is made of reflecting stainless steel sheet.

IR treatment chamber

4.5.10 PUSA sanitizing tunnel and smart hand wash

Pusa sanitizing tunnel and smart hand wash system was designed and developed. The foot operated smart hand wash system enables washing of hands using liquid soap without touching the soap dispenser and the water tap. The sensor based sanitization tunnel uses quarternary ammonium compounds (QAC) at a concentration of 0.04% for full body fogging of the person passing through tunnel for a period of 10 second. The arrangement has been made first to have thermal scanning of the person followed by hand wash and tunnel sanitization. This facility protects a person from virus contamination through sanitizing the person and help fight against spread of COVID-19.

4.6 FOOD SCIENCE AND POST-HARVEST TECHNOLOGY

4.6.1 Layer-by-layer coating of hydrocolloids and mixed plant extract reduces fruit decay and weight loss during cold storage

Nectarine, being a climacteric fruit and succulent, exhibits high rates of respiration and ethylene, thereby making it highly perishable with a shelf-life of only 3-4 days at ambient temperature and ~15-18 days at cold storage. Different types of coating treatments, *viz*. MPE alone (mixed plant extract of moringa + eucalyptus + marigold), chitosan 1% (CH) alone, carboxy methylcellulose 1.5% (CMC) alone, layer-by-layer coating of CH-MPE, CMC-MPE, CMC-CH and CMC-CH-MPE, and control (water dip only) were used for reducing the fruit decay and improving shelf life of 'Snow Queen' Nectarine. It was observed that regardless of storage period, layer-by-layer coating of CMC-CH-MPE was highly effective in reducing fruit decay (3.26 ± 0.32%) over other coatings or control fruits (17.44 ± 0.42 %) with ~81% reduction in fruit decay and ~59% lower weight loss over control fruits.

4.6.2 Staggered application of hexanal extends postharvest storage life of apple under ambient conditions

Apple fruits cv. 'Royal Delicious' were subjected to hexanal dip treatment (0.01, 0.02, 0.03% for 2 and 3 min) at 1 and 2 month post cold storage followed by shelf-life studies under ambient conditions (20-25°C, 40-56% RH) up to 21 days. Post-storage hexanal application studies yielded that higher hexanal dose (@ 0.03%) in solution was more effective in preventing decay and retained postharvest quality of apple fruits when given for 3 min. Also, treatment given after one month of cold storage maintained better overall quality of the fruits kept on the shelf under ambient conditions (20-25°C, 40-56% RH) in comparison to hexanal exposure given after two month cold storage.

4.6.3 Quality retention of fresh-cut beans

Process for stabilization of pre-cut fresh beans was standardized. Application of ascorbic acid @ 1% could effectively inhibit the extent of browning in fresh-cut beans. It was also found that commercially available 51 micron packaging was best suited to maintain quality of fresh-cut beans till 9 days under low temperature storage conditions. Further, influence of edible coatings in conjunction with the browning inhibitor was studied to maintain the freshness of the cut beans. Sodium alginate yielded best quality cut beans that maintained the shelf life up to 11 days in low temperature storage.

Stabilized fresh-cut beans

4.6.4 Storage of osmo-vac dehydrated guava slices

To see the storage life of osmo-vac dehydrated guava slices, they were packed in 200 gauge HDPE, 200 gauge aluminum laminate (ALPE) and 250 gauge co-extruded pouches and stored at ambient

temperature and low temperature. After 4 months of storage the osmo-vac dehydrated guava slices packed in co-extruded film (250 gauge) pouches was found to retain the quality of osmo-vac dehydrated guava slices followed by storing at low temperature, when compared with ALPE and HDPE, as the samples retained high ascorbic acid, sugar content, rehydration ratio, sensory score and low moisture and non-enzymatic browning in the finished product.

4.6.5 Effect of pasteurization methods on processing of guava and grape

For the development of anthocynin rich guava nectar, the fruits of guava (Allahabad Safeda) and grape (Pusa Navrang) were processed using different pasteurization methods of microwave (300, 600 and 900 W), thermal (70, 80 and 90 °C) and irradiation (0.5, 1.0 and 1.5 kGy). Results revealed that TSS, titratable acidity, reducing and total sugars, total phenols increased and ascorbic acid decreased during pasteurization. Among the pasteurization treatments, microwave was superior for retaining better contents of ascorbic acid, total phenols and other nutrition attributes. However, the recovery of pulp and juice increased with decrease in pomace in guava and grape during pasteurization methods and maximum retention of pulp and juice and less pomace was found in microwave treatments compared to thermal and irradiation pasteurization.

4.6.6 Extraction of phenolics and bioactives from pomegranate peels

Synergistic use of two non-conventional extraction strategies, i.e. enzyme-assisted extraction (EAE) using a cellulolytic enzyme preparation (Viscozyme) followed by microwave-assisted extraction (MAE) for efficient recovery of phenolics from pomegranate peel (PP) was done. This optimized method was individually compared with EAE, MAE, and conventional solvent extraction (CSE) methods for recovering PP phenolics with maximum antioxidant activity (AOA). Response surface methodology (RSM) was used as an optimization tool to achieve maximum yield of phenolics and with highest AOA at power 443.5 W, time 131.0 min, and solvent-to-solid ratio 23.6:1. The predicted values for maximum phenolics and AOA obtained through RSM were 305 mg GAE/g, 1788 µmol TE/g (FRAP) and 2641 µmol TE/g (CUPRAC), respectively. Phenolic contents of only 94.6, 165.46, and 197.6 mg GAE/g were achieved through CSE, EAE and MAE, respectively. The extract can be commercially exploited for the development of functional foods, supplements, and natural preservatives.

4.6.7 Extraction protocol for beetroot betalains

Extraction protocol for beetroot betalains has been standardized through thermal extraction process. Blanching at 85°C for 2-3 minutes significantly improves the betalains yield in the extract. The overflow method of pasteurization was capable in extending the shelf-life of colourant for one year at room temperature without using any class-II preservatives. The extract can be used as natural colorant for acidic to neutral range food products more specifically having pH value of 3.0, 6.0 and 7.0.

Beetroot betalains

4.6.8 Ready-to-eat Pusa corn nut

Ready-to-eat Pusa corn nut was developed using thermal processing that involves raising the grain moisture content up to ~35% followed by heating and mixing alternately. Heating and mixing were

continued till the moisture content was brought below 3%. The corn nut is crunchy in texture with 10.06% protein, 0.844 mg/100g carotenoid, ascorbic content of 12.15 mg/100g, total phenol content of 61.45 mg/100g, antioxidant content of 5.91 µmoleTrolox/g. Shelf life of the product is 6 months in laminated flexible packaging at ambient condition with 10.06% protein, 0.844 mg/100g carotenoid, 12.15 mg/100g ascorbic content, 61.45 mg/100g total phenol, and 5.91 µmoleTrolox/g antioxidant content.

Pusa Corn Nut

4.6.9 Flaked corn grits

A process for flaking of corn grits was developed. Influence of hydration under varied conditions (at elevated temperature, at pressure, with plasticizers) on compression of corn grits was determined. Pressure cooking (1.05 kg/cm^2) of corn grits for 2 h resulted in lower solid loss (8.52±0.39%), higher degree of gelatinization (91.76±1.03%), and induced higher ductility properties to the grits. Inclusion of 8% sucrose in cooking medium for grits resulted in reduction of average flake thickness from 0.96±0.12 mm to 0.66±0.04 indicating higher plasticizing effect over as compared to brown sugar wherein flake thickness reduced from 0.91±0.16 mm to 0.83±0.10 mm. Double pass flaking of grits by passing through roller gap of 0.4-0.6 mm with intermediate heating by microwave (6 W/g for 30 s) was found suitable for obtaining lowered flakes thickness (0.625±0.305 mm) and improved spread value (67.55±5.53 mm^2).

Flaked corn grits

4.7 MICROBIOLOGY

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

BGA-based liquid formulation (BGA LF) with shelf-life of 18 months was found physically and biologically stable. Application of BGA LF gradually build up OC and available N, P and K in soil. Maximum available N was observed in treatment RDF + BGA LF followed by 75% N ($N_{90}P_{60}K_{60}$) + BGA LF and maximum increase was observed in $N_0P_0K_0$ + BGA LF. In farmers' fields at villages Dadhota, Amarpur and Katesra in Palwal district, Haryana, both the carrier-based and liquid formulation were used separately. Of the 37 demonstrations, farmers reported around 10% increase in yield by use of these biofertilizer inputs.

4.7.2 Conservation agriculture (CA) influences spore inoculum of AM fungi

Spore multiplication capacity of indigenous AM fungi (AMF) on farm under rice and wheat in various CA regime was investigated in order to rate the nutrient mobilizing potential of soil. In a rice-wheat system, rice recorded 16% increment of AM fungi (AMF) spore over wheat under various CA regimes, despite better proliferation of AMF in wheat. CA-based ZTDSR+WR-ZTW and ZTDSR+WR+BM-ZTW+RR resulted in 61 and 53, and 23 and 8% higher spore number in wheat and rice, respectively over farmer's practice. AMF spore density under different CA practices for both crops was as follows: ZTDSR + WR - ZTW > ZTDSR-

ZTW > ZTDSR + MBR - ZTW + RR - ZTMB + WR > ZTDSR + WR + BM - ZTW + RR. Native AMF isolates were categorized into 3 morphotypes based on spore diameter, and designated as A (>250 µm), B (106-250 µm) and C (53-106 µm), spore morphotype C population being highest followed by B and A.

4.7.3 Characterization of EPS for improving soil properties through *Anabaena* and *Nostoc* strains

Cyanobacteria produce exopolysaccharides (EPSs) that help formation of biofilm through association of microbial communities and act as reservoir of water and nutrients, and soil sealant. *Anabaena* sp. CCC 745 produced two types of polysaccharides, capsular polysaccharide (CPS) and released polysaccharide (RPS) which were purified using size exclusion chromatography (SEC). 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. Aqueous solution of both the negatively charged EPSs exhibited classically pseudoplastic fluid behaviour.

4.7.4 Microbe-mediated nutrient cycling under non-flooded (aerobic) and flooded (anaerobic) conditions for improved productivity in rice-wheat system

Microbial activities were examined under the application of N in combination with or without biofertilizers and soil application of Zn in two cultivars (Pusa Basmati 1509 and DRR Dhan 45). Fe reduction ranged from 90 to 160 µg Fe^{2+} g^{-1} soil d^{-1}; the rhizosphere of DRR Dhan 45 had higher concentration of reduced iron due to soil application of zinc, with or without biofertilizers such as B1-4, and biofilmed inoculant. Urease activity, which were between 10 and 23 µg NH_4-N g^{-1} soil h^{-1} were lower due to the application of microbial consortium with ammonium oxidizers along with the application of Zn. In both the cultivars, the application of recommended dose of fertilizers (NPK) led to lower activity of protease (760-790 µg g^{-1} soil $2h^{-1}$). N application led to highest gene copies of 2.9 × 10^8 g^{-1} soil. The application of Zn and bioinoculants led to characteristic changes in the gene copies of β-*proteobacteria* in rhizospheres of Pusa Basmati 1509 and 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.

4.7.5 Microbes mediated water stress alleviation in crops under maize-wheat system

Four different plant growth promoting (PGP) bacteria isolates/consortium namely C1: *Pseudomonas* sp Mix; C2: *Enterobacter asburie* (M23); C3: *Lactococcus lactis* (L37) and *Klebsiella* sp; and C4: *Pantoea* sp *Mix* (P49+P87) were applied in wheat and maize in combination with adequate (5 irrigations) and deficit (3 irrigations) supply of irrigation and nitrogen application (recommended dose 120 kg N/ha and limiting dose 60 kg N/ha). The system productivity (wheat equivalent yield) improved from 6.8 to 14.4% across limiting nutrient and irrigation conditions.

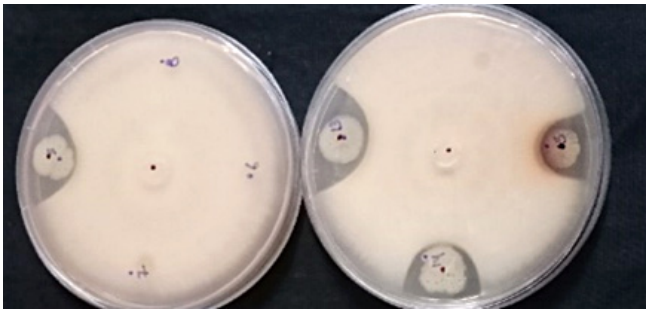
4.7.6 Microbiome profiling of seed endophytes of *Triticum* spp from different agro-climatic zones

Wheat seed genotypes of *Triticum aestivum* (22) from six agro-climatic zones, *T. durum* (4) and *T. dicoccum* (4) from two agro-climatic zones of India were collected and standardized the protocol of bacterial isolations and a new growth medium *WMM* (wheat matrix medium) for isolation of seed endophytes from endosperm of wheat seeds. A total of 220 isolates were isolated from these wheat species, *viz*. *T. aestivum* (171), *T. durum* (28) and *T. dicoccum* (21) by using seed crush and direct seed endosperm placement on three kinds of medium (NA, TSA & WMM) and preserved at -20^{0}C in 25% glycerol stock and in slants as working culture. These 220 isolates were morpho-metered based on colour, shape, pigmentation, gram/spore staining, growth at different levels of *p*H, salt, moisture and qualitative functional annotation for PGP attributes,

viz. nutrient solubilization (P, K, Zn), production of compounds and growth regulators (siderophore, IAA, AAC deaminase, HCN and nitrogen fixation), lytic enzyme productions, *viz.* (cellulase, amylase, xylanase, protease, pectinase, easterase, lipase, phytase) and biocontrol of three wheat major fungal pathogens. Total 62 isolates were selected on the basis of best multi PGP and lytic enzyme production.

4.7.7 Isolation of bacteria from probiotic agricultural product

Six bacterial isolates from probiotic product *Beejamrutha* and 12 from *Jeevamrutha* were isolated and characterized for PGP traits. Siderophore production was observed by three isolates whereas 15 out of 18 isolates showed ammonia production. Eight isolates could solubilize inorganic phosphate and 6 could produce IAA. Eight isolates could exhibit antagonism against phytopathogenic fungi. Majority of the isolates were identified as *Bacillus* sp based on 16SrRNA gene sequencing.



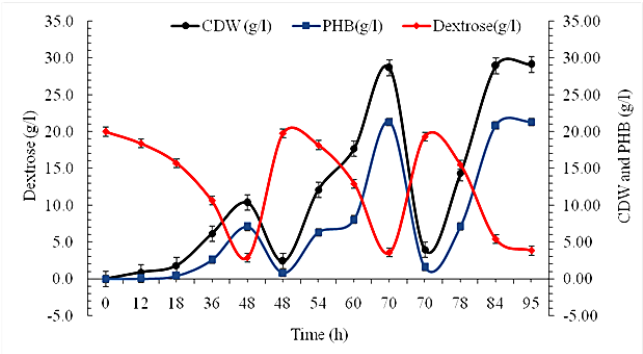
Antagonism exhibited by bacterial isolates against *F. solani*

4.7.8 Diversified uses of *Azolla* biomass in relation to nutritional quality for its efficient utilization as feed supplement and value added products

A feeding trial was conducted with prior approval from the institutional animal ethics committee (IAEC) for conducting animal experimentation. Ten *Murrah* buffaloes during their early stage of lactation (DIM, 30.40 ± 3.86) were selected and divided randomly into two groups of 5 buffaloes each. All the buffaloes were maintained on intensive feeding systems with individual feeding under the iso-managerial condition and housed in a well-ventilated concrete floor shed. Results indicated that replacement of 10% concentrate mixture with *Azolla* was helpful in the improvement of the digestibility of dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), and acid detergent fiber (ADF) in lactating buffaloes.

4.7.9 Utilization of agricultural residues for production of poly-β-hydroxyalkanoates, an industrially important biopolymer by microorganisms

The process parameters for the production of poly-β-hydroxybutyrate (PHB) by *Halomonas* sp LB7 were standardized for batch fermentation in a 7-L bioreactor using optimized growth media having sucrose as C source. When sugar concentration inside the bioreactor had depleted to a limiting concentration (below 10 mg mL^{-1}), the batch cultivation was converted to nutrient feed cycle mode wherein 80% (v/v) culture broth was removed from the reactor and refilled with fresh medium at 48, 70 and 95h. During first cycle of batch cultivation peaked at 48 h of growth, i.e. late exponential phase and yielded 10.36 g L^{-1} CDB and 7.08 g L^{-1} PHB with a volumetric productivity of 0.142 g Lh^{-1}. At the end of second cycle (at 70 h), a significantly high CDB and PHB concentration of 28.68 g L^{-1} and 21.32 g L^{-1} was obtained. The overall productivity of PHB with fed-batch in 95 h was 0.54 g L^{-1} h^{-1}, which was significantly higher than the batch fermentation (0.14 g L^{-1} h^{-1}). The harvested broth yielded 11.4 gL^{-1} CDM (cell dry mass) and 7.68 gL^{-1} PHB in first cycle. At the end of 5th cycle, 6 and 11% increase in cell dry biomass and PHB productivity, respectively were achieved.



Kinetics of continuous fed-batch fermentation LB7 in the 7L bioreactor

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

Two novel yeast strains, *Meyerozyma* and *Lodderomyces*, utilize and ferment 1% xylose efficiently to ethanol with 40% efficiency. In mixed sugar fermentation, both the strains ferment whole of glucose present to ethanol with >75% efficiency and use 33% of xylose also. Xylose is also completely utilised upon prolonged incubation but ethanol levels decrease. This is first report of these novel *Meyerozyma a*nd *Lodderomyces* strains producing ethanol from mixed sugars and present interesting platform for exploitation in bioethanol production from biomass.

4.7.11 Fungal inoculation and limited nitrogen fertilization accelerates *in-situ* degradation of the paddy straw

Consortium of two lignocellulolytic fungi, *viz. Coprinopsis cinerea* LA2 and *Cyathus stercoreus* ITCC 3745 were applied in the field for *in-situ* degradation of rice straw with five treatments: straw removed, straw retained @ 3 t ha^{-1}, straw retained + microbial inoculation @ 3kg ha^{-1} + urea @ 30 kg ha^{-1}, straw retained + urea @ 30 kg ha^{-1}, and straw retained + microbial inoculation @ 3 kg ha^{-1}. The (straw retained + microbial inoculation @ 3kg ha^{-1} + urea @ 30 kg ha^{-1}) led to stimulation of microbial population with 48-58% increase in fungal and bacterial population and 83% increase in cellulose degrading micro-organisms at 30 DAT. This treatment also led to significantly higher values of extracellular soil hydrolytic enzyme activities (~1.4-2.2 fold increase) in cellulase, xylanase and β-glucosidase. Soil microbial activity parameters (dehydrogenase, alkaline phosphatase, peroxidase) also registered 36-58% increase in this treatment. PLFA based microbial profiling of soil revealed that residue addition along with microbial and N priming significantly increased microbial abundance. Application of urea along with microbial consortium besides accelerating straw degradation also resulted in 20% increase in grain and straw yield of subsequent wheat crop along with improvement in soil organic carbon.

4.7.12 Pusa Decomposer

Large scale demonstration and validation of Pusa Decomposer Technology was carried out in farmers' fields in Delhi and Punjab. Pusa decomposer is a microbial consortium of 7 fungi. Four capsules of this product can be scaled up to 25 L liquid formulation which was applied *in- situ* to 1.0 ha of combine fitted with SMS harvested rice field having 5-6 tonnes of paddy straw. It accelerated the process of paddy straw decomposition and field was ready for wheat sowing in 20-25 days. The general practice to be followed for effective *in-situ* decomposition is spraying of Pusa Decomposer, followed by rotavator operation for proper mixing of residue in soil and then a light irrigation to ensure moisture in the field. Soil samples collected after 25 days of Pusa Decomposer application showed an improvement in organic C and available N. Pusa Decomposer capsules have been provided to the Delhi, Punjab, Uttar Pradesh and West Bengal Governments for use in 2000, 500, 12,500 and 1,250 acres, respectively. In addition, Pusa Decomposer kits have been provided to farmers and other agencies


Spray


Rotavator


Irrigation


***In-situ* decomposition**

in different states during 2019 (9388 acres) and 2020 (14,100 acres).

4.7.13 Microbial consortium with new fungi for degrading recalcitrant parts of rice stubble

As a part of microbial degradation of rice stubble, 19 fungal isolates were isolated after enrichment in lignin related substrates. Among them, isolate LN-1 with laccase and lignin peroxidase activities 1.345 µmol min^{-1} ml^{-1} and 2.967 µmol min^{-1} ml^{-1}, respectively , and isolate LN-14 showing 3.786 µmol min^{-1} ml^{-1} laccase activity and 1.865 µmol min^{-1} ml^{-1} lignin peroxidase were selected for forming lignolytic fungal consortium. These isolates have also shown significant xylanase and manganese peroxidase activity. The consortium is being tested for *in-situ* degradation of the rice stubble.

4.7.14 On-farm evaluation of microbial inoculants in different crops and agro-ecosystems of India

A total of 163 front line demonstrations (FLDs) were conducted at different locations, MGMG villages and IARI adopted model villages in NCR region. Besides, existing carrier based biofertilizers, *viz. Rhizobium, Azotobacter, Azospirillum*, Phosphate solubilizing bacteria (PSB) and VAM fungi, newly developed liquid formulations (*Azotobacter*, ZnSB and KSB) were evaluated in farmers' fields in wheat, chickpea, pea, maize, brinjal crops. Inoculation of liquid *Azotobacter*, ZnSB and KSB 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. Response of brinjal and banana crops to liquid ZnSB and KSB biofertilizer in farmers' field under KVK Durg and KVK Raisen (MP) was better, where liquid biofertilizers applied with drip irrigation system. *Azolla* was in huge demand by the farmers, mainly for cattle feeding. *Azolla* inoculum was given to large number of farmers directly and through KVKs and farmers were trained about its production technology. Application of biofertilizers in different crops enhanced crop productivity by 3.2-23.4% and reduced cost of cultivation and thus increased net returns. Farmers preferred liquid formulations over carrier based formulations due to their easy use and longer shelf life. Large number of farmers (>375) were trained about the benefits and use of biofertilizers in crop production.

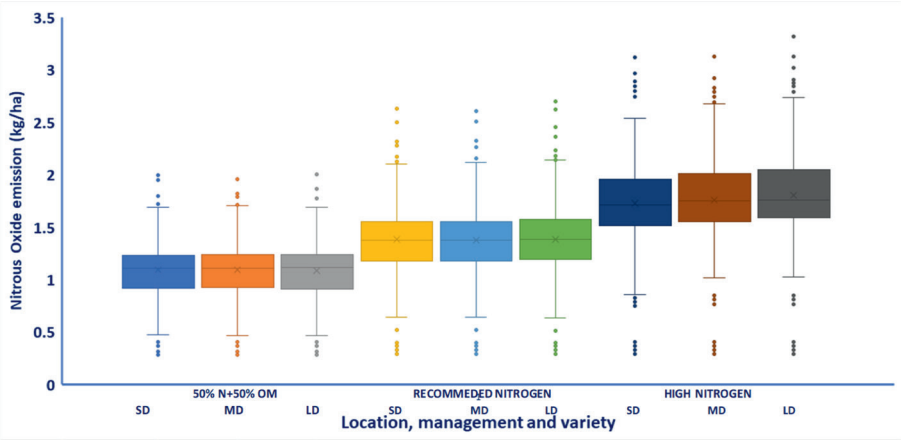
4.7.15 Bioresources and patent

The 16SrRNA gene sequences of 62 isolates from seed microbiota of *Triticum aestivum, T. dicoccum and T durum* collected from six agro-climatic zones of India have been submitted to NCBI GenBank (Accession Numbers; MT184815 – MT184873, MT672532-MT672534). The 16SrRNA gene sequences of 17 Sulfur Oxidizing Bacteria have been submitted with accession no. MT672287 to MT672303. Lactic acid producing bacterial 16S rRNA gene sequences of *Lactobacillus plantarum LP-9, Lactococcus petauri* LP-28, *Lactococcus garvieae LP-30, Lactococcus garvieae LP-31, Lactococcus petauri LP-32, Lactococcus garvieae LP-54, Lactococcus garvieae LP-60, Lactococcus lactis LP-68:* (Accession Numbers: MT000062 - MT000069) have also been submitted. 16S nucleotide partial sequence of plant-associated bacteria of *Datura metel* are: MW145156 (*Bacillus subtilis* strain NED-1), MW145157 (*Bacillus subtilis* strain NED-2), MW145158 (*Bacillus subtilis* strain NED-3), MW145159 (*Staphylococcus warneri* strain NED-4), MW145160 (*Staphylococcus sciuri* strain NED-5), MW145161 (*Bacillus subtilis* strain NED-6), MW145162 (*Bacillus safensis* strain NED-7), MW145163 (*Bacillus paramycoides* strain NED-8), and MW145164 (*Bacillus paramycoides* strain NED-9).

4.8. ENVIRONMENTAL SCIENCE AND CLIMATE RESILIENT AGRICULTURE

4.8.1 Regional GHG emission estimation from wheat fields using the simulation model

Analysis was done for N_2O emission and simulated data indicated that the InfoCrop model could capture variation in N_2O emission due to variation in management. Results indicates that if a short duration variety is given high dose of N (180 kg/ha), N_2O emission will be higher with a median value or 1.75 kg N_2O/ha compared to application of 120 kg N (median

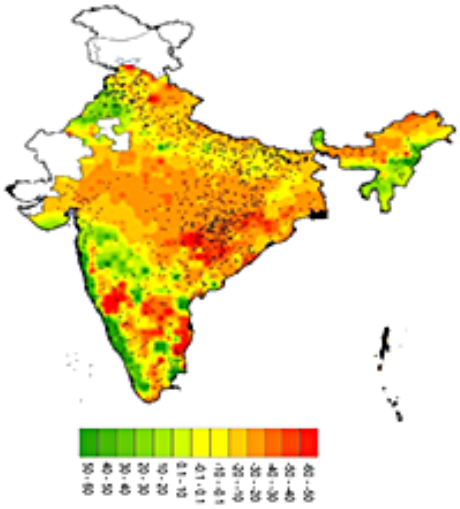


Simulated N_2O emission variation due to management and variety across major wheat growing areas in India. Each box plot represents spread of simulated data of 942 values from the wheat growing area in India.

value 1.34 kg/ha) and supply of just 60 kg/ha N along with FYM, which emitted a 1.1 kg N/ha (median value). However, a significant variation existed in simulation values across locations even under single set of variety, sowing and management condition, indicating significant spatial variation due to changes in temperature regimes, soil N supplying ability, soil moisture holding capacity, soil microbial load, pH etc., which greatly influenced the N_2O emission due to denitrification process in soil. The simulated N_2O emissions were higher in lower latitudes such as in central India than in the higher latitudes (North parts of India).

4.8.2 Climate change impacts and adaptation gains for irrigated and rainfed rice

Without adaptation, irrigated rice yield during *kharif* season is projected to be affected by about -3% in 2020, -2 to -3.5% in 2050 and -2 to -5% in 2080 climate scenarios in all RCPs. Productivity of rainfed rice is projected to reduce 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. Adaptation by growing short duration varieties with improved nutrient and water management can improve the irrigated rice productivity even up to 28% till 2050 climate scenario. Further, strategy of growing short duration varieties of less than 120 days than the current ones of about 120-130 days in North-west India may not prove beneficial even in near future. In rainfed conditions, 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. However, more heat and water stress tolerant varieties with high yield may need to be developed for sustaining the rainfed rice yield.



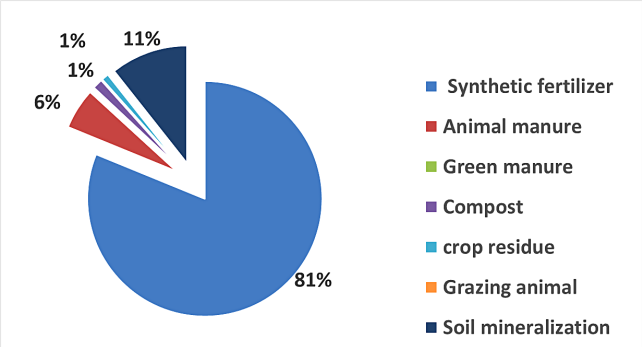
Relative yield deviation from mean yield of 2010-15

Impacts on rainfed *kharif* rice in 2020 (2010-2039) scenario

4.8.3 Estimates of methane and nitrous oxide emission from agricultural soils

An inventory of methane emission from different rice ecosystem in India was updated using the inter-governmental panel on climate change (IPCC) inventory preparation methodology for the base year 2015. Indian rice paddies emitted 3.47 Tg of methane

annually from different rice ecosystems. Continuous flooded rice ecosystem contributed about 32% of the annual methane emissions. Budget for direct and indirect nitrous oxide emission from agricultural soils of India was estimated to be 257.15 Gg. The direct emissions of nitrous oxide were found to be increasing due to an increase in the N fertilizer application wherein 81% was contributed by the synthetic nitrogenous fertilizer application.



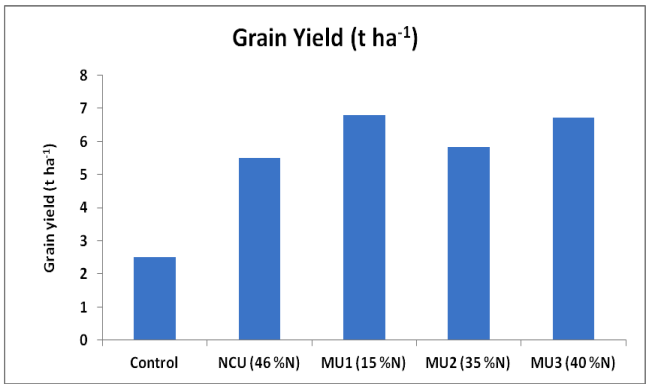
Contribution of different N sources to nitrous oxide emissions annually

4.8.4 Mitigating ammonium volatilization and denitrification losses using microbial interventions

The effect of *Azotobacter* and *Mycorrhiza* application was evaluated on ammonia emission from wheat field. The application of *Azotobacter* and *Mycorrhizae* along with recommended dose of N, P and K significantly reduced the ammonia flux and denitrification losses from wheat field compared to without *Azotobacter* and *Mycorrhizae*. Also, highest wheat yield (6.4 t/ha) was recorded under *Azotobacter* and *Mycorrhizae* along with recommended dose of N, P and K. Thus, *Azotobacter* in combination with *Mycorrhiza* led to reduction in N losses and increased crop yield.

4.8.5 Chitosan grafted modified urea for enhancing agronomic use efficiency and rice yield

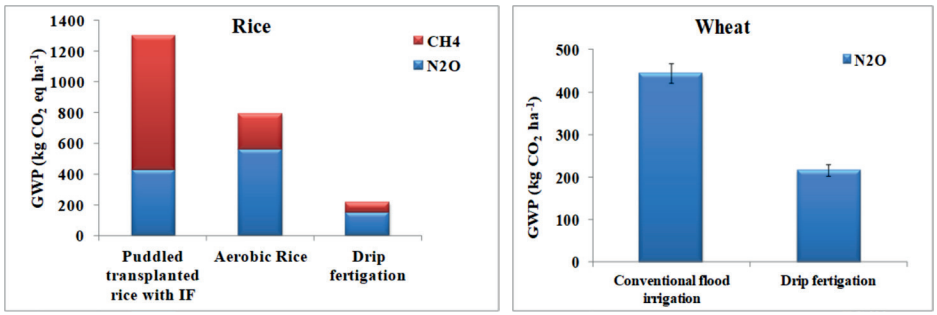
Chitosan grafted slow release modified urea (MU) fertilizers were synthesized and these products were evaluated under field condition. The N content in MU1, MU2 and MU3 were 15, 35 and 40 %, respectively. All three products were applied at 120 kg N/ha in two spilts (50% before last puddling and 50% three weeks after transplanting) and their performance were compared with neem coated urea (NCU) and control (no N). Rice yield in MU treatment increased by 6-23% in comparison to neem coated urea. Agronomic efficiency (AE) (kg grain yield increase kg^{-1} N applied) of NCU, MU1, MU2 and MU3 were 24.8, 35.6, 27.6 and 34.9 kg kg^{-1}, respectively. Thus, slow release MU could be a better N source for rice.



Rice grain yield as affected by different modified urea products

4.8.6 Water management for GHG mitigation in rice-wheat system

Rice (PB 1637) and wheat (HD 2967) were assessed for GHG mitigation potential under different water management practices. In aerobic rice, CH_4 emission was reduced by 70%, but due to aerobic and anaerobic cycle, the N_2O emission increased by 31.7%. However, with subsurface drip fertigation, emission of both CH_4 and N_2O was reduced by 70-72%. Aerobic rice reduced global warming potential (GWP) by 30% with 15% water saving and 3.8% yield loss compared to puddled transplanted rice with intermittent flooding (PTR-IF). Drip fertigation reduced GWP by 84% with 37% water saving and 6.5% yield loss. Irrigation water-use efficiency (0.5 kg grain/m^3 water) and field water-use efficiency (0.32 kg grain/m^3 water) was highest under aerobic method with SDI drip. In wheat crop, subsurface drip fertigation reduced GWP by ~51% and led to 48% saving of water.



GHG emission under different irrigation methods in rice and wheat crop

4.8.7 *Azolla* effects on growth and yield of rice under elevated tropospheric ozone

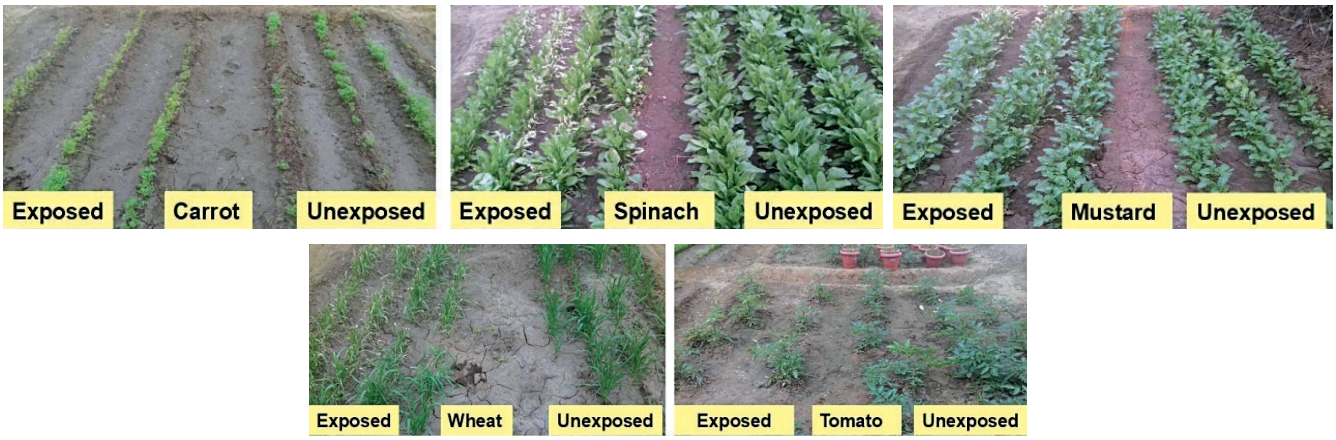
An experiment was carried out under free air ozone enrichment rings (FAOE) to assess the plant growth promoting *Azolla* based bio-fertilizer effects on rice under elevated tropospheric ozone (O_3). Rice variety PB 1509 was grown under ambient (seasonal average 31 ppb) and elevated O_3 (seasonal average 61ppb) with or without Azolla. Due to elevated O_3, rice yield decreased by 5.5 to 9.9% in different treatments. In the Azolla treatment with 100% N, rice yield under elevated O_3 was at par with control under ambient O_3. Thus, the presence of *Azolla* in flooded rice may be able to mitigate the effects of elevated O_3 under flooded rice condition.

4.8.8 Elevated ozone (EO_3) and carbon dioxide (ECO_2) affect soil microbial community

The effect of elevated ozone (EO_3 70±5 ppb) alone and in combination with elevated CO_2 (ECO_2 550 ppm ± 20 ppm) were assessed on enzyme activities and microbial communities at 0–15 cm depth of soil in free air ozone enrichment rings (FAOE) and free air CO_2 enrichment rings (FACE) with chick pea (Kabuli-3022) as test crop. The β-glucosidase, xylanase and β-D-cellobiosidase activities were suppressed under EO_3. Elevated ozone alone and in combination with CO_2 altered the abundance of major microbial sub-groups. Besides, the fungal/bacterial (f/b) PLFA biomass ratio decreased in EO_3 treatment. Highest f/b ratio was in ECO_2 followed by ECO_2+EO_3. This indicates that EO_3 alone or with elevated CO_2 may cause changes in microbial community composition and alter soil functions.

4.8.9 Air pollutant SO_2 as source of plant sulphur and mechanism of SO_2 tolerance in crops

A study was conducted in controlled fixed tunnels and especially designed field chambers to assess the effect of short term (7 days, 1h daily) and long term (30 days, 3h daily) enrichment of SO_2 (~25-50 µg m^{-3} over the ambient level) on growth and sulphur nutrition of crops, *viz*. bread and durum wheat, barley, chickpea, carrot, tomato, spinach and mustard. Durum wheat and tomato responded most positively to elevated SO_2 under the long and short term SO_2 enrichment, while chickpea and spinach were most susceptible to SO_2 stress. Activity of O-acetylserine (thiol) lyase (OAS-TL) and serine transacetylase (SAT) were significantly improved although the difference across species was obvious. In the long term SO_2 enrichment studies, the relative tolerance of crops to SO_2 was related to a lower level of superoxide, H_2O_2 radicals and lipid peroxidation and a higher level of antioxidants such as ascorbic acid and peroxidase activity with few exceptions. However, under short term SO_2 stress, superoxide radical activity was induced more under HSE than LSE. The level of antioxidants, i.e. ascorbic acid, peroxidase and superoxide dismutase activity, increased under SO_2 stress in vegetable, cereal and oilseed crops in a dose dependant manner (HSE> LSE). SO_2 stress tolerant species were found to utilize SO_2 towards S nutrition as evident from a higher activity of the sulphate assimilating enzymes and sulphur accumulation in plant shoot. Further, the foliar absorption of SO_2 and in-plant translocation of the assimilated SO_2-S was confirmed through radiotracer studies using ^{35}S in carrot. Short term $^{35}SO_2$ showed a



Crop response to SO_2 enriched air environment

higher accumulation of ^{35}S in roots than shoots of carrot cultivar. These results clearly reveal that the phytotoxic response of plants to SO_2 stress is species dependent and is determined by a regulated balance expression of the oxidative and antioxidative characteristics.

4.8.10 Heavy metals contamination of vegetables in Delhi region and their risk assessment

Heavy metals content (As, Cd, Cr, Hg, and Pb) in soil, water and vegetable samples of cultivated and marketed sites in Delhi region at some selected sites, i.e. Alipur, Shahdara, Mehrauli, Kanjhawala, Najafgarh, Okhla and Azadpur, and risk assessment was investigated. Accumulation of heavy metals in vegetables was within the permissible limits (as per WHO), except for Cd, which showed greater contamination in all vegetables at most of the sites, including cultivated and marketed sites. Mean concentrations of heavy metals in soil followed the sequence: Pb> Hg > Cr > Cd > As. Leafy vegetables (spinach, mustard) observed higher potential of heavy metal accumulation over root (potato, carrot) and fruit vegetables (okra, tomato). Among metals, As and Pb content observed higher in vegetables. Heavy metals uptakes in vegetables were observed below the permissible limit except Cd. The hazard quotient (HQ) for leafy and root vegetables was higher than the safe limits for As at most sites. The hazard index (HI) and metal pollution index (MPI) were found higher in spinach compared to other vegetables. Further, As and Pb appeared to be potentially harmful health hazards in target hazard quotient (THQ) at all sites.

4.8.11 Soil physico-chemical properties influencing greenhouse gas emission in organic rice

The emission of CH_4, N_2O, and CO_2, and their global warming potential (GWP), and correlation with soil physico-chemical properties under different organic

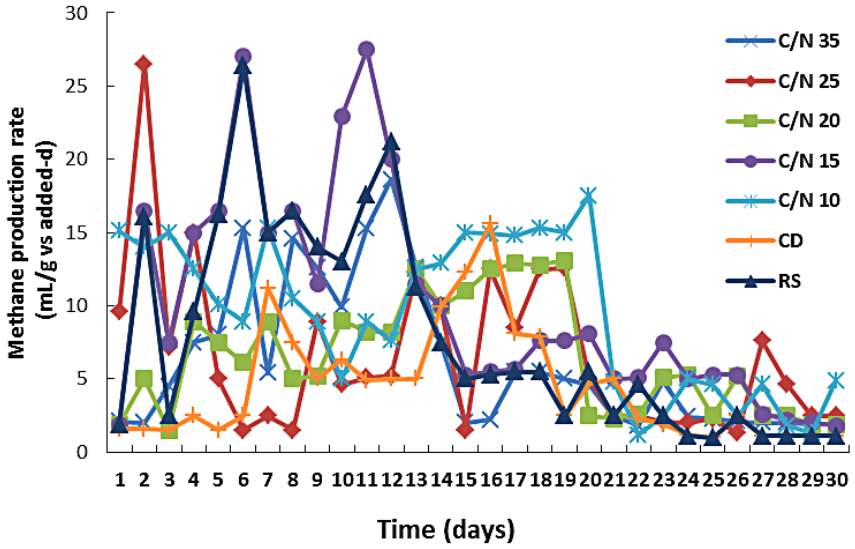
Hazard Index (HI) values of metals at all selected locations in the year 2017-18

Vegetable	Alipur		Shahdara		Mehrauli		Kanjhawala		Najafagrh	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Spinach	3.86	6.12	4.39	3.92	6.40	5.24	8.00	5.53	2.56	2.30
Okra	2.58	2.48	2.79	3.08	2.13	2.33	2.36	2.31	2.68	2.52
Potato	2.74	1.98	2.15	2.16	2.40	2.35	2.00	1.85	1.89	1.77
Carrot	2.18	2.08	2.07	1.53	1.24	1.50	1.34	1.10	1.34	1.25
Mustard	0.50	0.49	1.13	1.10	1.09	1.28	1.00	0.92	1.27	1.05
Tomato	0.70	0.72	1.13	1.62	0.88	1.06	1.13	0.96	0.75	0.87

and conventional treatments in rice-wheat-mungbean system were quantified. Among soil pH, EC, and bulk density, only bulk density was found to be correlated with CO_2 emission from rice, and the correlation was significantly negative. SOC also exhibited positive and significant correlation with CH_4 flux from rice and CO_2 flux from rice, wheat, and mungbean crops. SOC contains readily available carbon substrate for the microorganisms and contributes to CH_4 and CO_2 emissions. The positive and significant correlation was also observed between the N_2O flux and total N, NO_3^--N, and NH_4^+-N.

4.8.12 Biogas production from rice straw

The biodegradation of admixture of cattle dung and rice straw under biomass waste management was carried out to determine the methane yield at various C: N ratio. The cumulated methane yield from co-digestion of cattle dung and rice straw at C: N ratio of 35, 25, 20, 15 and 10 were recorded as 176.7, 221.3, 181.9, 333.9 and 295.2 ml/g VS added, respectively. The methane yields were observed to be 1.29, 1.62, 1.33, 2.44 and 2.16 times higher than digesting cattle dung alone, respectively. While the same were 1.37 and 1.22 times more than digesting rice straw alone at a significant C: N ratio of 15 and 10, respectively.



Biogas (Methane) production affected by different C: N ratio

5. CROP PROTECTION

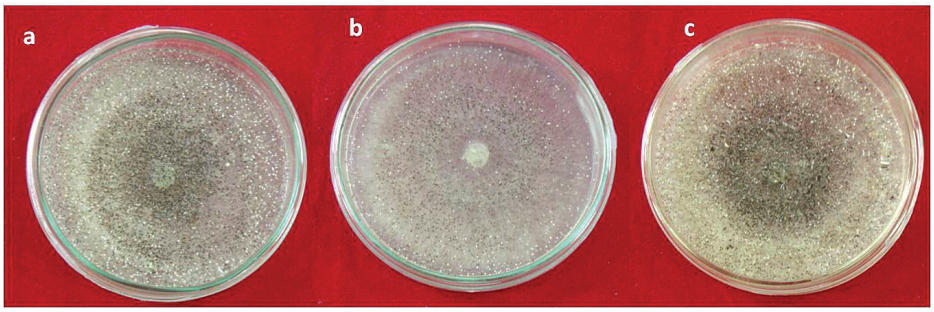
Crop protection school develops and implement innovative management strategies for counteracting the impact of diseases, insect-pest and weeds on field and horticultural crops. Changing climate is affecting pest and pathogen dynamics every year, therefore there is need to reorient crop protection research strategies that include all options of management for providing effective and sustainable solution. During the year under report, identification of new diseases, insect pest, vectors, development of diagnostic tools, diversity studies, host pathogen interaction, resistant sources, and development of new molecules and their efficacy against different pathogens and insects alongwith weed management aspects were undertaken and the results are summarized herein.

5.1 PLANT PATHOLOGY

5.1.1 Pathogen diagnostics, genomics, host pathogen interaction and variability

5.1.1.1 First report of *Sclerotium hydrophilum* Sace causing stem rot disease of rice in Pusa, Bihar

High incidence of stem rot caused by *Sclerotium hydrophilum* was observed in Eastern Gangetic plains of India including Eastern Uttar Pradesh and Bihar in the year 2016-17. Brownish to black water-soaked lesions without distinct margins were visually observed on rice leaf sheaths. Colonies of pure cultures on PDA medium were initially white and turned brown about 2 weeks. Large numbers of small globose sclerotia were observed on surface of the colonies at 5 days after sub culturing. The sclerotia were white at first and then turned black over time with maturity. The diameters of sclerotia ranged from 0.32 to 0.51 mm with an average of 0.41 mm (n = 50). DNA of a representative isolate named SH1 was extracted, and the ITS region was amplified by PCR with universal primer pair ITS1/ITS4. Sequence analysis showed 99.66% identity with *Sclerotium hydrophilum* isolate VC228 (accession no. KT362098) and accession no obtained (KX181457). Phylogenetic analysis based on Neighbour-joining method grouped the isolates alongwith other isolates from Asia. The pathogen was identified as *Sclerotium hydrophilum* on the basis of cultural, morphological, pathogenic and molecular characteristics. Further, culture was deposited in Indian Type Culture Collection, IARI, New Delhi. Koch's postulates were completed by inoculating rice plants with PDA disks of 5 mm in size bearing both mycelium and sclerotia of *S. hydrophilum* in 45 days old plants of rice genotype 'Samba Mahsuri' under glass house conditions. Pathogen was already reported with high disease incidence in Northern Karnataka. However, this is the first report of *S. hydrophilum* on leaf sheath of rice from North-Eastern plain zone of India.



***Sclerotium hydrophilum* isolates a: SH1; b: SH2; c: SH3 showing different colony characteristics in PDA**

5.1.1.2 Characterization of *Rhizoctonia solani* isolates collected from different hosts

A total of 36 isolates of *Rhizoctonia solani* collected from rice and other hosts were characterized morphologically and at molecular level through internal transcribed spacer (ITS) region amplification. Considerable amount of variability has been observed in these isolates in terms of colony color (white, light brown, dark brown, brown and cream), radial growth (0-8 cm), sclerotia pattern (peripheral, scattered, central, middle), total no of sclerotia (0-90) and weight of sclerotia (0-0.9 g). The phylogenetic tree of these isolates constructed based on maximum parsimony method, grouped the isolates of different hosts together. Based on pathogenicity, the isolate TP-3 followed by TP-26 was observed to be highly pathogenic on PB-1 cultivar. All the isolates were able to infect rice suggesting irrespective of the host.

5.1.1.3 Development of monosporidial lines of *Tilletia indica* and virulence analysis

Sixty monosporidial (haploid) lines of *Tilletia indica* was developed from isolates of *T. indica*. Seven markers showed high polymorphism (PIC> 0.58), 2 markers turned out to monomorphic and one was found to less significant (PIC= 0.18). The virulence analysis revealed that 27 monosporidial lines (ms) crosses produced the Karnal bunt disease of wheat after inoculation of *T. indica*. Few ms lines were found incompatible in nature. The coefficient of infection was varied from 0.75 to 36%. Monosporidial lines KB 7 MS 1 X KB 18 MS1 cross found highly virulent.

5.1.1.4 Pathogenic and genetic variability among *Fusarium graminearum* isolates causing head scab of wheat

Fusarium head blight samples collected from Lahaul Spiti and Wellington were examined for *Fusarium* spp. Twenty-nine *Fusarium* isolates were identified as *F. graminearum* based on morphological, cultural and ITS based approaches. A set of ten wheat varieties (UP 2338, PBW 343, Sonalika, HD 2967, HD 3086, HD 29, MACS 5049, HS 645, VL 1013 and Sumai 3) were used for studying the pathogenic variation among *F. graminearum* isolates. After 7 and 14 days of inoculation, isolates Fg-W10 and Fg-W24 were found highly pathogenic, while, Fg-W7 and Fg-W26 were found least pathogenic. Out of 23 SSR markers designed using whole genome sequence of *F. graminearum* PH-1 strain, 21 SSRs amplified *F. graminearum* isolates. Cluster analysis separated the isolates into two main groups. Group A consisting two isolates one from Wellington (Fg-W27) and another from Lahual Spiti (Fg-L2). Group B contained all other 27 isolates. This study has shown that there is considerable genotypic variability among *F. graminearum* isolates obtained from infected wheat ear heads from different geographic regions of India.

***Fusarium* head blight of wheat**

5.1.1.5 Development of qPCR-based marker for detection of *Tilletia caries*

A novel primer pair (TCF_{RASA40}/$TCF_{RASA606}$) specific to *T. caries* was designed using a PCR product of 567bp (Gene Bank accession No. MN971798) only in *T. caries*, with sensitivity of 100 pg. A single peak of the melting curve with high quantification efficiency (E=114.0 %) and optimal regression line (R^2=0.989) indicated the accuracy of qPCR. The qPCR was validated by verifying the optimized amplification reaction.

5.1.1.6 Virulence analysis of *Blumeria graminis* f.sp. *tritici* (*Bgt*) of wheat

To find out virulence pattern, 143 Bgt isolates were subjected to phenotypic reactions on newly constituted

differentials and the reactions pattern were elucidated by artificial inoculation at Wellington, the Nilgiris. Virulence and a virulence status of *Bgt* were identified. Designation of races/pathotypes was attempted with demarcation of three sets of differentials and tentatively named as BGT with single or multiple powdery mildew resistant gene(s). Virulence analysis pattern was found to be regional specific. *Bgt* isolates from Shimla were relatively more virulent than rest of the isolates from other zones. The seedling and adult plant testing protocols were refined for artificial inoculations and maintenance of powdery mildew pathogen of wheat at Wellington. By using these protocols, large number of genetic stocks and wheat lines can be evaluated to find out true level resistance patters against specific pathotype/isolate of *Bgt* anywhere from the country.

5.1.1.7 Molecular characterization and haplotyping of *Blumeria graminis* f.sp. *tritici* (*Bgt*) of wheat:

Protocols were refined to extract the genomic DNA of *Bgt* and 64 sequences are available in NCBI data base as maximum number of reference sequences from Wellington and collaborating centers as compared to Global submissions. In collaboration with other centers, haplotype analysis was performed for the first time in *Bgt* isolates and 53 haplotype groups were identified with haplotype diversity of 0.738 based on haplotype frequencies in the sample using the extent of differences among nucleotide sequences.

5.1.1.8 Characterization of *Bipolaris maydis* toxin

Characterized the toxin of *Bipolaris maydis*, the causal agent of MLB disease of maize and 11 compounds identified were Versiconol acetate, Bipolaramide, 2,5-Diketopiperazine, Bipolarilide, Averufanin Bipolarin, Xanthone derivative, Curvulin, Paecilin B, Spirosta phylotrichin U, Curvulinic acid and Terpestacin.

5.1.1.9 Identification of cryptic species of *Fusarium solani* species complex (FSSC)

The study was started to resolve the cryptic species of *Fusarium solani* Species Complex (FSSC) present in Indian soil. Based on translation elongation factor (tef) gene sequence data, *Fusarium falciforme, F. metavorans* and *F. striatum* were found predominantly among the eight identified cryptic species. Further species-specific molecular markers were developed for the identification of these three cryptic species. The conserved sequences from multiple alignments of tef-1 gene were used to design the primers for detection tef-1 gene sequence from 46 isolates of *F. falciforme*. Thirty three sequences from seven different cryptic species of *F. solani* were aligned and 210 base pairs amplicon size species specific oligonucleotide primers were designed. Similarly, *F. metavorans* and *F. striatum* oligonucleotide primers were also designed with amplicon size 365 base pairs and 208 base pairs, respectively. The specificity of primers was validated against seven different cryptic species of FSSC. Sensitivity for detection of primers was analyzed by observing PCR amplification band using highest dilution of primer. Furthermore, the primers were also validated against samples isolated from soils and infected plants.

5.1.1.10 Characterization of Indian *Trichoderma* spp.

Twenty different species *Trichoderma viz. T. aggressivum, T. asperellum, T. atroviride, T. brevicompactum, T. citrinoviride, T. crassum, T. erinaceum, T. ghanense, T. hamatum, T. harzianum, T. koningiopsis, T. longibrachiatum, T. longipile (Syn. Hypocrealongipilosa), T. minutisporum, T. pubscenes, T. reesei, T. saturnisporum, T. spirale, T. tomentosum* and *T. virens* were characterized based on ITS and ß-tub for their phylogenetic relationship. The ß-tub gene has clearly differentiated all 20 *Trichoderma* spp. whereas ITS region could not segregate all the species accurately. The morphological characters *viz.*, colony, conidiophores, phialides, conidia and chlamydospores of all the twenty species of *Trichoderma* were described along with photomicrographs. The ITS and β-tub gene sequences of all the 20 species studied have been deposited in the Genbank.

5.1.1.11 Easy PCR kits for the detection of begomovirus species

Sprecies specific detection of begomoviruses is difficult by PCR or ELISA due to high cross

reactivity. In order to overcome this problem, a PCR based method was developed to differentiate the closely related begomovirus species by a few unique nucleotides."The 3` polymorphic primers for species-specific detection of begomovirus" has been filed for granting of patent. Based on this finding, easy PCR kits have been developed for the major begomoviruses infecting tomato, chilli, okra and grain-legumes. The kit constituents have been simplified in a single tube containing *Taq* DNA *polymerase*, buffer, specific primers and dNTP. The kit has been designed with the ease of use, as only the test DNA to be added in the supplied tube to perform the PCR. Two of the easy PCR kits for the detection of tomato leaf curl New Delhi virus and chilli leaf curl virus were released by ICAR in 2020.

5.1.1.12 Rapid on-site assay using recombinase polymerase amplification for identification of *Thrips palmi*

Thrips palmi is an important pest of vegetables, ornamentals and legumes worldwide. Identification of *T. palmi* at an early stage is crucial in implementing appropriate pest management strategies. Morpho-taxonomic identification of *T. palmi* based on the adult stage is time-consuming and needs taxonomic expertise. Here, we report a rapid, on-site, field-based assay for identification of *T. palmi* based on recombinase polymerase amplification (RPA), its first application in insects. The RPA assay included three core enzymes *viz.* recombinase, single-stranded DNA binding protein, and strand-displacing polymerase. Three pairs of RPA primers were designed based on 3′ polymorphism at Internal Transcribed Spacer 2 region of *T. palmi*. Out of three pairs of primers tested, one pair (AG117F and AG118R) efficiently discriminated *T. palmi* without any cross-reactivity with other predominant thrips species. RPA was performed with crude extract of single *T. palmi* in sterile distilled water and could be completed within 20 min by holding the reaction tubes in the hand without any thermal cycling. The assay could detect as little as 0.2 atto-grams ($2x10^{-19}$g) of DNA. The assay was further simplified by using fluorescent as well as colorimetric dyes thus eliminating the gel-electrophoresis steps. The presence of *T. palmi* was visualized by a change in color from dark blue to sky blue. The assay was validated with known thrips specimens and found to be effective in diagnosing the presence of *T. palmi* in natural vegetation. This on-site, rapid assay for diagnosis of *T. palmi* can be used in the field of quarantine and pest management.

5.1.1.13 Detection of onion yellow dwarf virus by DAC-ELISA

Onion yellow dwarf virus (OYDV) is an important viral disease of onion and garlic crops which causes degeneration, dwarfing, yellow striping and crinkling in onion. Polyclonal antibody against OYDV was developed by recombinant technology which would be useful for routine indexing and screening of the onion and garlic germplasm. The total RNA was isolated from the symptomatic leaves of onion and gene encoding of the coat protein (CP) was cloned using the RT-PCR kit. The nucleotide sequencing analysis of the cloned cDNA contained ~776 bp which was cloned in pET-28a (+) expression vector for the expression of a ~30 kDa fusion protein with Histidine tag (His_6BP) at its N terminus in *E. coli*. The expression of fusion coat protein was clearly shown in SDS-PAGE which was confirmed by Western blot. The His_6BP-OYDV-CP was obtained in soluble state after purification and was used to immunize New Zealand white rabbit for the production of polyclonal antibody (PAb). The PAb to the purified fusion protein successfully detected OYDV from onion and garlic samples collected from field at 1:000 dilutions in indirect-enzyme linked immunosorbent assay (ELISA).

5.1.1.14 Designing duplex PCR assay for simultaneous detection of chickpea chlorotic dwarf virus and peanut witches' broom phytoplasma in chickpea

A duplex PCR assay was developed by optimizing PCR reaction components and cycles for the simultaneous detection of chickpea chlorotic dwarf virus (CpCDV) and a peanut witches' broom (PWB) phytoplasma associated with the chickpea stunt disease.

Two sets of CP specific primer pair (MCPF/MCPR) for CpCDV and *tuf* gene primer pair (TUF-II-F2/TUF-II-R1) for phytoplasma were used. Expected amplicons of 590 bp for CpCDV and 1090 bp for phytoplasma were consistently amplified from the symptomatic chickpea tissues in single and duplex PCR assays. This duplex PCR assay was found equally efficient and sensitive in detecting single or mixed infection of CpCDV and PWB phytoplasma in 148 symptomatic chickpea stunt samples in two states of India. The results indicated the robustness and reliability of the developed duplex assay for a sensitive and rapid detection of virus and phytoplasma indexing in chickpea samples associated with CpS disease. The designed duplex assay can also be useful for further resistance screening of chickpea genotypes.

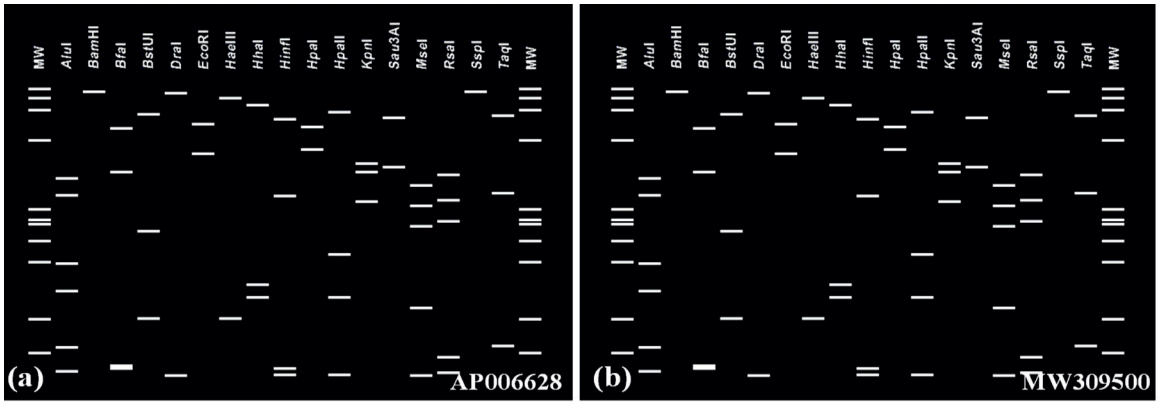
Gel electrophoresis image for duplex PCR assay results of phytoplasma and CpCDV showing expected amplicons from symptomatic chickpea isolates; Lane M: 1kb ladder, Lane PP: Phytoplasma positive control, Lane VP: CpCDV, Lane N: Negative control, Lane 1to 13: Samples positive for both CpCDV and phytoplasma

5.1.1.15 Occurrence of cucumber mosaic virus Subgroup I in Himachal Pradesh and its infection to new hosts like squash and a weed, Arrow leaf dock (*Rumex hastatus*), in India

In this study, 23 samples of bell pepper, squash, tomato, ornamental (calla lily, French hydrangea, spider lily) and weeds (Arrow leaf dock, Spanish needle) hosts originating from Himachal Pradesh were examined. Twenty samples were identified CMV positive based on electron microscopy, bio-assay, RT-PCR and sequence analyses of coat protein (CP) gene. The CMV-CP gene sequences from eight isolates cloned and sequenced in this study shared 96–100% amino acid sequence identities with CMV Subgroup I isolates. This study forms the first report of the natural occurrence of CMV on squash and a weed host, Arrowleaf dock (*Rumex hastatus*), in India as well as the occurrence of CMV Subgroup I in the cooler hilly regions of India. These findings suggest the expansion of the host range as well as ecological niche of CMV.

5.1.1.16 Confirmation of association of aster yellows phytoplasma with flat stem and witches' broom disease of *Hibiscus cannabinus* Linn. (Malvaceae) in North East region of India

Hibiscus cannabinus is a hot-season annual bast fibre crop growing in tropical as well as temperate areas of India. During October 2020, symptoms of flat



(a) 16SrI-B reference strain **(b) Kenaf isolate 2**

Comparison of virtual RFLP pattern derived from in silico digestion of ~1.25kb 16SrRNA sequences of reference phytoplasma subgroup with 17 different restriction endonucleases using *i*phyclassifierprogramme (a) 16SrI-B reference strain (Acc. No. AP006628), (b) Kenaf isolate 2 (Acc. No. MW309500)

stem and witches' broom symptoms were observed on 12.5% of plants grown in Agriculture College campus of Lembucherra, Tripura. Amplification of ~1.25kb product was obtained only from symptom-bearing HC plants and the positive control, but not from the asymptomatic plants. The R16F2n/R16R2 gene sequences of the HC phytoplasmas strains (GenBank Accession Nos. MW309499 -MW309500) showed 99.2-100% sequence identity with those of the reference phytoplasmas of the former aster yellows (16SrI) group, '*Candidatus* P. asteris'. The phylogeny analysis and virtual RFLP profiles of HC phytoplasma isolates were found it very close to '*Ca.* P. asteris' related strain of the 16SrI-B subgroup with a similarity coefficient of 1.00. This is the first report of '*Ca. P. asteris*' affecting HC worldwide.

5.1.1.17 Serological and molecular diagnostics of important viruses affecting brinjal and carrot

Brinjal virome analysis was done from total RNA isolated and pooled from infected brinjal samples collected from the experimental field of IARI, New Delhi. Small RNA library was prepared using TrueSeq small library preparation kit which included adapter ligation, reverse transcription and amplification of cDNA. Further the SE Illumina library was loaded onto NextSeq 500 for cluster generation and sequencing. NGS data showed the presence of sequences of tobacco etch virus (Potyviridae), barley yellow mottle virus (Potyviridae), soybean chlorotic mottle virus (Caulimoviridae) and Tospovirus resistance protein B.

5.1.1.18 Cotton leaf curl Multan virus-Rajasthan (CLCuMuV-Raj) strain is the cause of cotton leaf curl disease in North West India

Cotton leaf curl disease (CLCuD), transmitted by *Bemisia tabaci*, is a major constraint in cultivation of cotton (*Gossypium hirsutum*) in North West (NW) India. Based on cloning and sequencing of complete genome (~2.7 kb) and phylogenetic analysis, all the present CLCuD begomoviruses of NW India analyzed in 2019, are cotton leaf curl Multan virus-Rajasthan (CLCuMuV-Raj) strains but they are recombinant, and different from the CLCuMuV-Raj strains prevailed earlier during 2012 to 2014 in MW India. Based on βC1 and Rep genes, only single betasatellite species, cotton leaf curl Multan betasatellite (CLCuMB) and two alphasatellite species cotton leaf curl Multan satellite (CLCuMA) and *Gossypium darwinii* symptomless alphasatellite (GDarSLA) are prevalent and associated with the present CLCuMuV-Raj strains.

5.1.1.19 Genetic diversity of whitefly in North East India

Bemicia tabaci is considered to be a complex of morphologically look-alike cryptic species. Based on sequence polymorphism of mitochondrial cytochrome oxidase subunit I (mtCOI) gene, 43 genetic variants of *B. tabaci* have been known globally. We have collected *B. tabaci* specimens from different crops and weeds in North East India. A total of 81 *B. tabaci* isolates were sequenced. Intra- and inter-specific genetic distance was calculated using MEGA X with the K2P model to determine the threshold value in discriminating the species complex. Bayesian inference was carried out using Mr Bayes with Markov Chain Monte Carlo algorithm and gamma distribution. A total of 2052 *B. tabaci*mt COI sequences retrieved from NCBI along with 81 sequences generated in the present study were considered to determine the genetic divergence of *B. tabaci*. Based on intra- and inter-species distance, the global threshold value of *B. tabaci* genotypes was determined as 4%. For phylogenetic analysis, similar sequences were excluded and 481 *B. tabaci* mt COI sequences including 81 sequences from North East India were considered. Based on Bayesian phylogeny at 4% cut off, four genotypes were recorded in North East India where *B. tabaci* Asia II 5 and Asis II 1 were predominated. Analyses of available sequences in NCBI indicated the presence of nine genotypes of *B. tabaci* in India *viz*. Asia I, Asia II 1, Asia II 5, Asia II 7, Asia II 8, Asia II 11, China 3, Asia IV, and MEAM 1. *B. tabaci* Asia II 1 and Asia Iis prevalent in northern India. In southern India, *B. tabaci* Asia I and Asia II 8is wide spread.

5.1.1.20 Severe outbreak of viral diseases in tomato in Maharashtra

In Maharashtra, a massive (60-80%) loss of tomato crop in an area of approximately 5000 acres in Nashik,

Ahmednagar, Satara and Pune districts was reported during April-May 2020. This loss was attributed to a complex of viruses causing uneven and early ripening, yellowing and distortion. Samples received from Maharashtra State Agriculture Department (Taluka Agriculture Officer, Haveli, Pune) showing uneven ripening, greenish-yellow, deformed and spongy symptoms on fruits were analyzed. The samples were tested using ELISA and PCR/ RT-PCR for major viruses affecting tomato crops which are transmitted by insect vectors – aphids, whitefly and thrips. Tests results revealed the samples were positive for cucumber mosaic virus (CMV), groundnut bud necrosis virus (GBNV), tomato mosaic virus (ToMV), pepper mottle virus (PMoV) and potato virus *Y* (PVY) alone or in combination. CMV was found to be the proponent virus alone or incubation with other viruses.

5.1.1.21 Papaya ringspot virus (PRSV) interaction with papaya at molecular level

Transcriptome analysis in tolerant papaya line (PS3) and susceptible (PM) cultivars against PRSV infection was studied. The results revealed an average of 172, 827, 456 reads were generated with approximately 89% reads mapped in pairs, 7% were mapped in broken pairs and 3.95% remained unmapped at 21 days after PRSV infection. The numbers of differentially expressed genes (DEGs) were higher in tolerant papaya line than in susceptible cultivar and higher numbers (393) of DEGs were up-regulated and down-regulated DEGs (47) were 8 times lower. Most DEGs were involved in plant hormone signal transduction, plant-pathogen interaction, phenylalanine metabolism, defense response, carbohydrate and lipid metabolism. The GO enriched analysis exhibited different network of biological, molecular and cellular changes in response to PRSV infection.

5.1.1.22 Identification and molecular characterization of viruses and phytoplasma associated with carrot

Carrot is an important vegetable crop in India and the world. Recently two viruses namely potyvirus, begomovirus and one phytoplasma have been isolated from samples collected from IARI, New Delhi. Molecular characterization of all the associated pathogens is under progress.

5.1.1.23 Association of chickpea chlorotic dwarf virus and peanut witches' broom phytoplasma with chickpea stunt disease and identification of new host crops and leaf hopper vectors

An investigation was carried out to identify and characterize the phytoplasma and viruses associated with the chickpea varieties showing severe stunting, leaf reddening, yellowing and phyllody symptoms during the summer season of 2018-19 and 2019-20 in eight states of India. The average disease incidence was recorded from 3 to 32% in different states. Presence of chickpea chlorotic dwarf virus (CpCDV) was confirmed in thirty-seven chickpea samples by amplification of CpCDV coat protein gene and sequence comparison analysis. *Brassica nigra*, *B. juncea*, *Lens culinaris*, two weeds (*Heteropogan contartus*, *Aeschynomene virginica*) and one leaf hopper (*Amaras cabiguttula*) were identified as new putative hosts for CpCDV. Association of peanut witches' broom phytoplasma was confirmed in chickpea samples, *Sesamum indicum*, five weeds hosts and two leafhopper species (*Exitianus indicus, Empoasca motti*) using nested PCR assays with primer pairs P1/P7 and R16F2n/ R16Rn. The results of phytoplasma association in plants and leafhopper samples were further validated by using five multilocus genes (*sec*A, *rp,imp,tuf* and *sec*Y) specific primers. Sequence comparison, phylogenetic and virtual RFLP analysis of 16S rRNA gene and five multilocus genes confirmed the identity of association of 16SrII-C and 16SrII-D subgroups of phytoplasma strain with chickpea samples collected from Andhra Pradesh (AP), Telangana, Karnataka, Madhya Pradesh, Uttar Pradesh and New Delhi. Mixed infection of phytoplasma (16SrII-D) and CpCDV was also detected in symptomatic chickpea samples from AP and Telangana. The report of association of 16SrII-C sub-group phytoplasma with chickpea stunt disease and the report of 16SrII-D subgroup phytoplasma association in *C. sparsiflora* and *C. roseus* are the new host records in world and from India, respectively.

5.1.1.24 Aster yellows phytoplasmas association with a little leaf disease of papaya in Kerala

Symptoms of papaya little leaf were observed in papaya plants in Vellayani, Thiruvananthapuram, Kerala, India with a disease incidence of 4%. Phytoplasmas were detected in the symptomatic papaya leaf samples by nested polymerase chain reaction with primer pairs amplifying 16S rRNA and *sec*A genes. Pair wise sequence comparison and phylogenetic analysis of these gene sequences indicated the presence of phytoplasmas related with strains in the aster yellows ribosomal group. *In silico* RFLP analysis using the *i*PhyClassifier of the 16S rDNA sequence allowed the detected phytoplasma classification into the 16SrI-D subgroup. This is the first report of 16SrI-D subgroup association with a papaya little leaf disease.

Littler leaf and witches broom symptoms in papaya

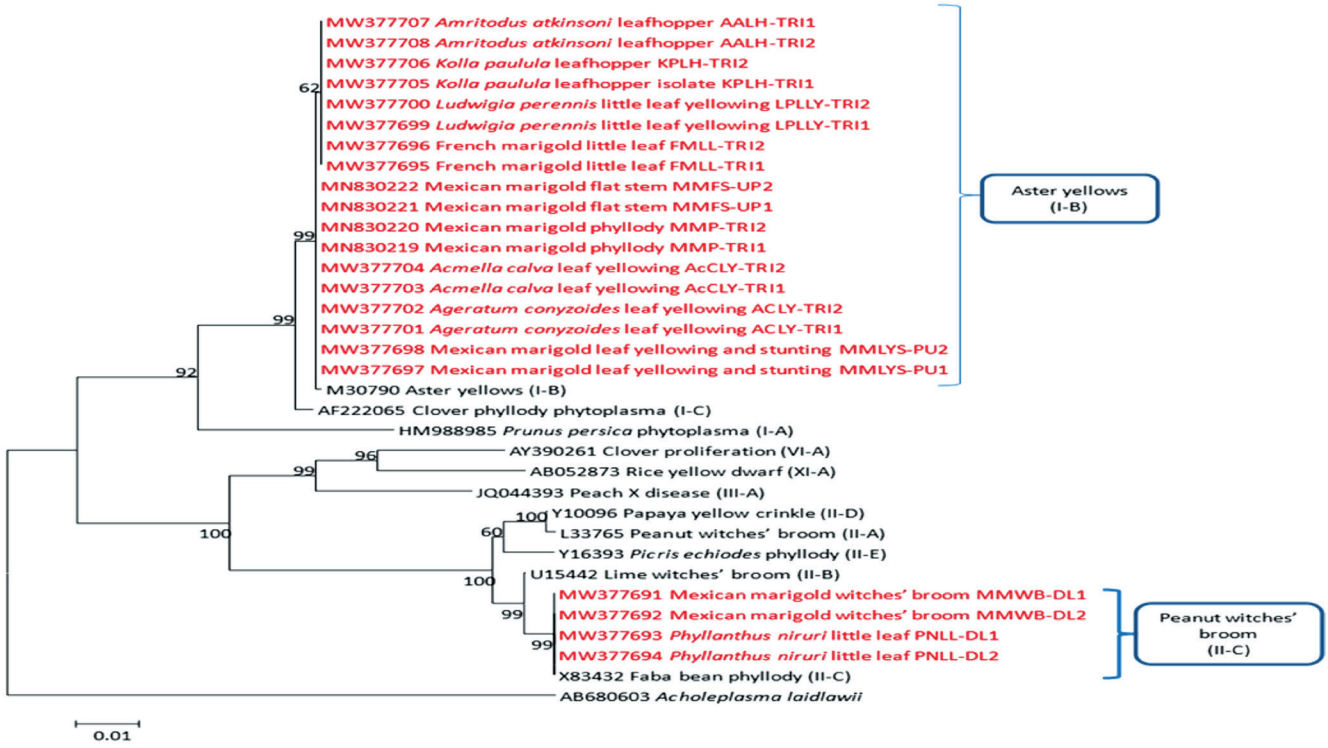
5.1.1.25 New phytoplasma disease associated with *Phaseolus vulgaris* in India

Candidatus Phytoplasma australasia' –related strain of 16SrII-D subgroup was detected first time in *Phaseolus vulgaris* exhibiting symptoms such as proliferation of branches with shortened internodes, reduced leaf size, twisting of shoots, virescence and phyllody in fields near Pune. The phytoplasma association was confirmed by amplification of ~1.8 kb and 1.2 kb DNA products of 16S rRNA using phytoplasma specific primers P1/P7 and R16F2n/R2. The sequence analysis of amplicons and virtual RFLP analysis confirmed the classification and placed the phytoplasma into 16SrII-D subgroup.

5.1.1.26 Multilocus genes-based identification and management of phytoplasmas strains associated with Mexican and French marigold species in India

Symptoms of witches' broom, phyllody, flat stem, little leaf and leaf yellowing and stunting were recorded in Mexican and French marigold fields at Delhi, Tripura, Uttar Pradesh and Maharashtra states of India during survey from 2018 to 2020. The disease incidence was recorded in range from 3 to 30%. Amplicons of ~1.2 kb were consistently amplified in symptomatic marigold samples from all the states using universal phytoplasma specific nested primer pairs P1/P7 and R16F2n/R2. Pair wise sequence comparison, phylogeny and virtual RFLP analysis of *16S rRNA* gene sequences confirmed the identification and taxonomic assignment of Mexican and French marigold phytoplasma strains into '*Candidatus* Phytoplasma' strain subgroup C (16SrII-C) from Delhi and '*Ca.P. asteris*' strain subgroup B (16SrI-B) from Tripura, Uttar Pradesh and Maharashtra. Similar results were further established and validated by amplifying phytoplasma specific multilocus candidate genes in all the symptomatic Mexican and French marigold isolates by utilizing primers of *secA*, *rp*, *secY* and *tuf* genes. Besides four weed species, growing in symptomatic marigold fields, *Phyllanthus niruri* (16SrII-C) at Delhi and three weeds species *viz.*, *Ludwigia perennis*, *Ageratum conyzoides* and *Acmella calva* (16SrI-B) at Tripura were also identified to be associated with similar phytoplasma strains by utilizing *16S rRNA* and multilocus gene specific primer

Flat stem symtpoms in French marigold (a) Witches' broom symptoms in Mexican marigold



Phylogenetic tree of 16S rRNA gene sequences constructed by neighbor-joining method of the partial 16S rRNA gene sequences from 16SrI and 16SrII group of phytoplasma strains showing the relationships among Mexican and French marigold phytoplasma isolates, weed isolates, alternate host and leafhopper with reference phytoplasma strains. The tree was rooted with *Acholeplasma laidlawii* (AB680603). Number on branches are bootstrap values obtained for 1000 bootstrap replicates. The bar represents a phylogenetic distance of 0.01.

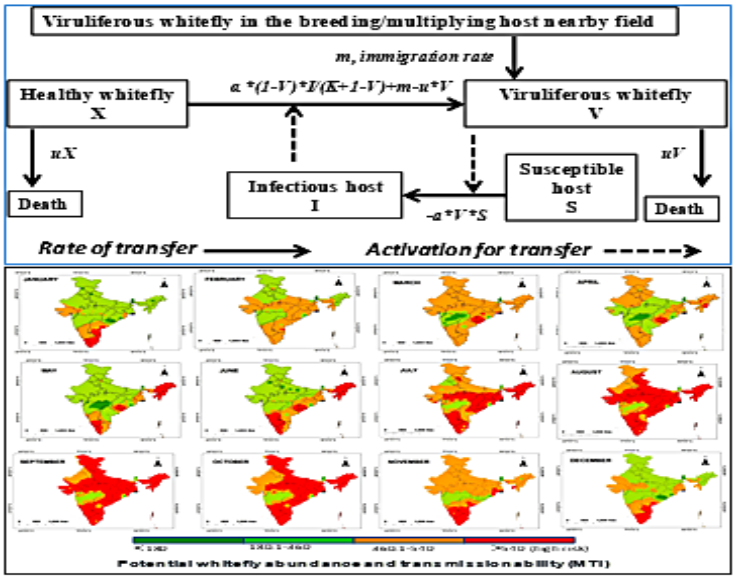
pairs. Two leafhopper (*Kolla paulula* and *Amritodus atkinsoni*) species were also tested positive for 16SrI-B subgroups of phytoplasma collected from nearby French marigold fields at Tripura by utilizing similar set of primers and confirmed as putative vectors for 16SrI-B subgroup phytoplasma strain. In a separate field experiment, spraying of imidacloprid 70% WG (6 gm/1000 ml) and oxytetracycline (100 ppm) combination was recorded effective for management approach against marigold phytoplasma diseases.

5.1.1.27 Citrus tristeza and citrus greening: the major biological factors for decline of citrus industry in Northeast India

Tristeza caused by citrus tristeza virus (CTV) and citrus greening (Huanglongbing/HLB), caused by citrus tristeza virus (CTV) and caused by *Candidatus* Liberibacter asiaticus (*Ca*. Las), are the most destructive diseases to cause citrus decline in Northeast (NE) India. Several citrus samples were collected from many cultivars of four citrus species, *Citrus reticulata* (cvs Khasi, Kinnow and Nagpur mandarin), *C. sinensis* (cvs Sweet and Valencia orange), *C. limon* (cv. Assam lemon) and *C. jambhiri* (cv. Rough lemon) from different farms of Assam. Using DAC-ELISA and PCR, it was found that most of the citrus samples were infected by both of the CTV and *Ca*. Las in all the cultivars. Nucleotide sequence analysis showed that most of the CTV isolates are the decline inducing severe CTV-Kpg3/VT group members and HLB isolates are the members *Ca*. Las species. It revealed that CTV and *Ca*. Las are prevalent and considered to be cause of citrus decline in Assam and NE India.

5.1.1.28 Occurrence of *huanglongbing* (HLB) disease affecting citrus in the Eastern India

Declining citrus orchards in the Kamrup district of Assam were surveyed for the association of HLB in citrus decline. Citrus orchards at seven locations, *viz*., Haldhipara, Kampaduly, Kanhibama, Chakrasila,



Leaf curl disease risk simulated based on tripartite interaction and temperature influence on whitefly population abundance

Amrengkona, Bakhrapara and Kanhikuchi were visited. Citrus orchards at Barapani in Khasi hills and Wahzier in Jaintia hills of Meghalaya were also surveyed. Altogether 69 No. of composite samples from apparently healthy and decline-affected trees were drawn. Symptoms of decline appeared when the plants reached bearing stage. Most of the declining plants were more than 15 years old. Samples were collected from orange (*Citrus reticulata*), *golnemu* (*Citrus jambhiri*), *sokolatenga*/key lime (*Citrus aurantifolia*), pummelo (*Citrus grandis*), Assam lemon & *Jaintia* lemon {*Citrus limon* (L.) Osbeck} and *joratenga* (*Citrus medica* L), trifoliate orange (*Poncirus trifoliata*), *Khasi* papeda/ *soh kymphor* (*Citrus latipes*), Rangpur lime (*Citrus limonia*) and mosambi (*Citrus sinensis*). Symptoms of citrus decline were evident in 21 to 65% of the trees in the orchards. HLB was found to be present in all the orchards visited and all the citrus species tested. Upon indexing by RT-PCR, presence of HLB bacterium was detected in 52 of the 69 plant samples collected.

5.1.2 Epidemiology

5.1.2.1 Simulation of leaf curl disease in chilli

In a population dynamic modeling framework, leaf curl epidemic in chilli has been simulated incorporating tripartite interaction between host (S)-vector and the virus. Dynamic feature in disease incidence (I) has indicated epidemic is a whitefly-mediated process. Immigration of viruliferous whitefly (V), transmission (a) and acquisition rates are the major parameters operating in the epidemic process. Equilibrium population of host and vector is observed to be sensitive to immigration parameter (m) as small change or increase in the parameter has caused increase in infectious population of both the host (I) and vector (V). Based on underlying principles of temperature influence, spatio-temporal pattern of disease risk indicated southern parts is favorable almost throughout the year. Prevention of initial viruliferous vector population in the chilli field is the critical to control the disease. Using plant cover immediately after transplantation is noted to be effective against leaf curl incidence. Initial protection of the field is the basis for evolving efficient management strategy.

5.1.2.2 Temperature influence on leafhopper population and its potential distribution in predicting spread of chickpea stunt disease in India

A study was planned to predict potential distribution of chickpea stunt disease based on the environmental influence on leaf hopper population

abundance. Temperature index estimated as a measure of leaf hopper population based on the beta model potential leaf hopper population distribution has been predicted. Spatio-temporal pattern of vector population has indicated entire country is favorable for leafhopper growth round the year except the northern parts of India during the months of December to February. Since leaf hoppers are the natural vectors of virus and phytoplasma pathogens associated with chickpea stunt disease, beta model-based prediction of environmental suitability indicates leaf hopper is the reason for natural spread of the disease in larger geographical area. Spatio-temoral distribution pattern would be useful in predicting the disease spread in different chickpea growing areas for evolving efficient management strategies.

5.1.2.3 Standardization of weather variables for predicting stripe rust on wheat

Correlation and regression analysis using weather-based and host variables as independent variable was used to develop predictive model for disease appearance and development. No. of hrs with temperature between 5-20°C, RH >87% and no of hrs with leaf wetness (period) were positively correlated with strong r-value ($R^2$0.9821) in case of stripe rust.

5.1.3 Host resistance

Wheat: Among the IARI-PDSN entries (541**)** evaluated for rusts and leaf blight resistance at different hot spot locations, 30 lines were found to be highly resistant against three rusts and leaf blight at adult plant stage across the test locations. IARI-CVT genotypes (166) were evaluated against major pathotypes of three rusts at seedling stage (SRT). Seventeen lines *viz.* DW1647, DL3258, PS 1222, DW1656, SBP-17-9, SBP-17-12, CSW168, ID 1715, ID 1704, SBP-17-17, SBP-17-18, SBP-17-20, ID 1711, DL3139, WBM 3704, DL3302 and DL3304 were resistant to all the rusts at seedling stage across the test locations. Evaluation of race-specific adult plant resistance in AVT wheat genotypes against most predominant and virulent pathotypes 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 pathotypes. Evaluation of IPPSN (1250 lines), PPSN (418 lines), EPPSN (58 lines) and MDSN (38 lines) wheat genotypes revealed that 578, 189, 36 and 28 lines, respectively were found to be resistant to moderately resistant against both stripe and leaf rust.

In multiple disease screening nursery (MDSN), out of 34 genotypes evaluated against Karnal bunt disease, seven wheat genotypes *viz*., GW 1346 (D), MACS 4059 (D), NIAW 3170, DDW 237, DDK 1054, GW 491 and WH 1218 were found resistant to Karnal bunt. In advance lines and released varieties, genotypes *viz*., HI 1636, MP 1361, MACS 6747, HI 8627, UAS 466, UAS 472, DBW 110, MP 3288, DDW 47, MACS 3949, HI 8818, DDW 49, HI 1646, HD 3090, RAJ 4083, UAS 3008, HW 1098, DBW 332, DBW 303, DBW 329, HD 3378, WH 1270 showed resistance to KB. Out of 164 genotypes evaluated against head scab disease of wheat only ten wheat genotypes *viz.*, HS 507, HS 668, HI 1612, HI 1636, HI 1634, UAS 3008, DBW 187, DBW 329, WH 1270 and GW 322 (Durum) were found moderately susceptible (disease grade upto 3). On the basis of % spikelet infection recorded after 7 days of inoculation, 11 genotypes *viz.*, UP 3016, HI 1624, HS 668, DBW 290, HD 3331, K 1317, HD 3377, MACS 6747, HD 2864, NIDW 1149 (durum) and MACS 4087 (durum) were free from disease. On the basis of disease grade based on spikelet data recorded after 21 days of inoculation, only two genotypes *viz.*, HI 1636 and HD 3377 were having disease score up to 2 (moderately resistant). AUDPC values were also calculated by recording three observations at an equal interval of 7 days on spikelet infection in all varieties. On the basis of categorization of varieties based on AUDPC values, only three wheat genotypes were grouped between 101-200 group (HD 3377, NIDW 1149 (durum) and HI 1612). In rest of genotypes, AUDPC values were more than 200 while maximum AUDPC value of 900 was obtained in highly susceptible variety, Sonalika. Only four genotypes *viz*., HI 1612, MACS 6747, UP 3016 and MACS 4059 (durum) were having rAUDPC values less than 25% of susceptible variety, Sonalika. Since most of popular

cultivars grown in India are susceptible to head scab, so there is a need to screen more indigenous and exotic wheat lines for incorporating head scab resistance in popular wheat cultivars.

Stem rust isolates of wheat have been collected and pathotyping was carried out using Indian standard differential sets and Ug 99 differential sets. The pathotype 40-A was found to be predominant at Wellington. Disease screening nursery trials under AICWIP programme were laid out during *Rabi 2019-20* at Wellington. Nearly 2687 lines received under different nursery trials *viz.,* IPPSN (1322), EPPSN (58), PDSN (585), MDSN (34), NIVT (260) and AVT (137), LBSN (121) and PMSN (170) were screened for stem rust resistance. Stem rust incidence was maximum during this season when compared to previous years. Nearly 474 lines in IPPSN were susceptible for stem rust.

A total of 198 bread wheat genotypes showing leaf tip necrosis ('ltn') phenotype were screened with molecular markers at IARI, Indore. The four resistance genes were identified in 127 bread wheat genotypes. Many of these genotypes were carrying multiple rust resistance genes. A total of 71 genotypes were not found to be associated with leaf rust resistance genes indicating that they may be carrying unidentified APR genes. It was observed that susceptible genotypes usually lacked the seedling resistance. Several genotypes had high leaf rust resistance than the ones with known APR genes indicating the presence of unidentified APR genes.

A total of 1826 entries included in PPSN (418), IPPSN (1312), MDSN (38), and Elite PPSN (58) were evaluated for field resistance to stem and leaf rusts under artificial inoculations using mixtures of important pathotypes. Of these, 755 entries (~41% of the total) showed resistance (coefficient of infection value up to 15.0) to both stem and leaf rusts at Indore. While 56.9% of PPSN entries showed resistance to both the rusts and 34.9% of IPPSN entries were resistant. In addition, the AVT entries (59) were evaluated in isolation for adult-plant resistance to stem rust pathotypes 40A and 117-6 (race-specific APR Nursery). Around 61% entries were resistant to both stem pathotypes. Entries *viz.,* HI 8812, HI 1633, HI 1634, HI 8807, HI 8805 and HI 8802 possess high degree of resistance to both stem rust pathotypes. HI 8627 and HI 8805 were resistant to 46S119 and 110S119 pathotypes of stripe rust and HI 1612 was resistant to 77-5 and 77-9 leaf rust pathotypes in APR nurseries at multi locations.

A total of 541 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, 236 entries (~77% of the total) showed resistance (Coefficient of infection value up to 10.0) to both stem and leaf rusts at Indore. Out of 100 bread wheat entries from Indore, 67 genotypes were found to be resistant to stem and leaf rusts. Indore entry, HAS 2709 genotype was found to be resistant to all three rusts in multi locations. The IARI common varietal trials (CVT) entries (total 166) were evaluated for seedling response to stem rust pathotype 40A and leaf rust pathotype 77-5. Out of these entries, 27 entries were segregating for either of the test pathotypes. Out of remaining 139 entries, 53 entries were observed to be resistant (38.1%) to both stem and leaf rust pathotypes.

Rice: Among 31 basmati rice entries evaluated against leaf blast disease under artificial epiphytotic conditions, 20 entries were found resistant. Three hundred twenty-three rice entries included in NSN 1 were evaluated under Uniform Blast Nursery (UBN) pattern. Among 323 rice genotypes, 43 entries were showed resistant reaction (score 1). Likewise, In (field monitoring of virulences of *Pyricularia oryzae*), 26 entries were evaluated. Entries like Raminad STR-3, *O. minuta,* Zenith, Tetep and Rasi found resistant. Out of 570 entries (NHSN, DSN, NSN-1) evaluated against sheath blight disease genotypes HR-12, JGL36181, IBT-WGL-31, KNM10207, RP-Patho-5, C101LAC and Tetep were identified moderately resistant.

Maize: A total of 396 maize genotypes were evaluated in 13 different trials for identifying resistance sources to maydis leaf blight (MLB, *Bipolaris maydis*) and banded leaf and sheath blight (BLSB, *Rhizoctonia solani*) diseases. Out of the total genotypes, 139 were found

resistant to MLB and 43 were resistant to moderately resistant for BLSB. Among them, 14 genotypes were resistant against both the diseases. In case of 20 sweet corn genotypes, only one genotypes showed resistance to BLSB disease while in case of 21 baby corn genotypes, 6 were resistant to MLB and only one was resistant to BLSB. In case of QPM (QPM I II III) genotypes 7 were resistant to MLB and only one was resistant to BLSB.Ten maize genotypes were evaluated under trap nursery to know natural occurrence of diseases under Delhi condition. Only two diseases namely MLB (score 2.0-6.0) and PFSR (post flowering stalk rot, score 1.5-6.0) were recorded in 8 and 6 genotypes, respectively.

Pearl Millet: In 2020, under Pearl Millet Blast Variability Nursery (PMBVN) trial, out of 65 entries, three entries (PMBVN-20-10, PMBVN-20-18, PMBVN-20-17) were identified as resistant and Under Disease Screening of Advance Pearl Millet Hybrids and Varieties (PMPT II) trial, One resistant entry (PAT207) and six moderately resistant entries (PAT203, 204, 206, 208, 222, 223) were identified against blast.

Soybean: A total of 45, 19 and 20 entries of soybean were evaluated under IVT, AVTI and AVTII and promising entries with MYMV resistance trait were identified. Soybean variety Pusa 6 (DS3106) with mungbean yellow mosaic virus resistance has been identified.

Chickpea: Two hundred forty one chickpea accessions were evaluated against dry root rot under artificial inoculation condition in the net house. Twenty seven entries were found resistant and eight entries were found moderately resistant.

Brinjal: Forty four brinjal accessions comprising of parental lines were screened against brinjal mosaic mottle disease by visual observations followed by electron microscopy. Of the accessions screened, only 15 showed field resistance against the disease.

Papaya: Eleven papaya lines, Pune Selections- 1,2,3,5, Red Lady, Local Selection, Phulevijaya, Vinayak, Pakeeza, Honey Dew and Nanha-Munna. Were evaluated for papaya ring spot virus. Among all Red Lady recorded maximum severity to Papaya ring spot *virus* while all the Pune Selection lines were found tolerant. The performance of Pune Selections lines was found promising in all respects than other varieties.

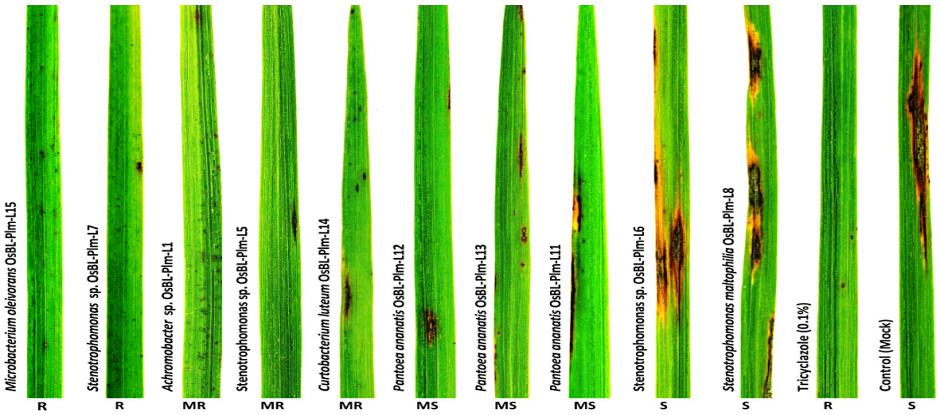
5.1.4 Management

5.1.4.1 Biocontrol of Fusarium wilt of tomato

Seed treatment and soil application of the carrier-based formulation of the biocontrol consortia comprising of varying combinations of *Pseudomonas* sp. (TEPF), *Bacillus* sp. (S2BC-1), *Trichoderma* sp. (S17TH) and *Chaetomium* sp (CG-A) challenge inoculated with *Fusarium oxysporum* f.sp. *lycopersici* resulted in a significantly lower incidence (>45% reduction) of *Fusarium* wilt relative to the pathogen control without biocontrol agents in a polyhouse (18–20 °C). This lower incidence was associated with an increase in the plant vigor index of >50%, relative to the pathogen control.

5.1.4.2 Exploration of phyllosphere microhabitats for novel microbiomes with potential for rice disease management

Microbiome of foliar microhabitats such as adaxial phyllosphere, abaxial phyllosphere, blast-lesion, and spermosphere was profiled using mNGS and microbiological tools. The analysis revealed unique as well as core microbial species associated with rice niches. Several promising antifungal antagonists against *Magnaporthe oryzae* were identified. Polyphasic taxonomic characterization revealed the identity of promising rice-phyllosphere-microbiome belong to *Brevundimonas vesicularis; Microbacterium oleivorans; Microbacterium testaceum; Pantoea ananatis; Pantoea deleyi; Pantoe adispersa; Pantoea vagans; Pseudomonas fulva; Pseudomonas parafulva;* and *Stenotrophomonas maltophilia*. Blast disease suppression and growth promotion in rice were also shown by microbial treatment. Phyllosphere lesion associated bacterial species *Microbacterium oleivorans* and *Stenotrophomonas maltophilia* were found to activate rice MAMP triggered Immunity (MTI) genes, OsCERK1, and OsCEBiP. Other defense genes, OsPAD4, and OsEDS1 were also found up-regulated upon bacterization suggesting microbial biostimulant activity in rice seedlings.



Suppressive effect of lesion associated bacterial foliar spray on rice blast; *Microbacterium oleivorans* OsBL-Plm-L15; *Stenotrophomonas maltophilia* OsBL-Plm-L7 and *Achromobacter piechaudii* OsBL-Plm-L1 triggered hypersensitivity type of reaction instead of large lesions observed in mock; HR type of reaction indicates over expression of defense genes. The number of lesion and size of lesions was found reduced in bacterized plantlets; plant responses are scored as per Mackill and Bonnman (1992) [R- Resistant; MR- Moderately Resistant; MS- Moderately Susceptible; S- Susceptible]

5.1.4.3 Total and culturable microbiome profiling of maize and their evaluation against maize disease mNGS guided total microbiome analysis

Total microbiome profiling of maize: Microbial profiling by polyphasic taxonomic tools including mNGS (metagenomic next generation sequencing technology) of maize holobiont revealed unique microbiome in maize plants cultivated by adopting conservation and reduced/ zero-tillage practices. Maize plants appear to harbor *Acinetobacter; Bacillus; Burkholderia-Caballeronia-Paraburkholderia; Klebsiella; Pantoea; Pseudomonas; Serratia; Sphingomonas; Sphingobacterium* as its core-microbiome. Linear Discriminant Analysis (LDA) indicated the association of *Klebsiella; Burkholderia-Caballeronia-Paraburkholderia; Aureimonas; Candidatus-Alysiosphaera; Hymenobacter*in zero tillage maize only whereas *Haliangium* and *Methylobacterium* were uniquely found in conventional tillage maize. No unique microbial communities were found associated with reduced-tillage maize. The analysis further deciphered geographical location (Bihar and Delhi), plant niche (cob, leaf, and root), and cultivation practice (Maize-Mungbean-Mustard; Maize-Wheat-Mustard) specific bacterial communities in maize.

5.1.4.4 Comparative microbiome analysis of maize grown in contrasting cultivation practices

Maize-wheat-mustard cropping system showed an association of *Aureimonas, Gemmata, Udaeobacter, Actinobacterium, Pontibacter, Paenarthrobacter,* and *Cohnella* with maize. Maize-mungbean-mustard uniquely displayed *Burkholderia-Caballeronia-Paraburkholderia, Klebsiella, Methylobacterium, Pedobacter, Hymenobacter, Alysiosphaera, Haliangium, Quadrisphaera, Microbacterium, Aquicella, Solibacter, Roseomonas, Myxococcus, Pseudacidovorax, Berkiella, Cellulosimicrobium, Azospirillum,* and *Pseudonocardia*.

5.1.4.5 Microbiological tools guided culturable microbiome analysis

Culture dependent microbiome analysis revealed association of *Acinetobacter pittii; A. soli; Bacillus aerius; B. megaterium; Enterobacter cloacea; E. hormaechei; E. soli; Gamma proteobacterium; Klebsiella aerogenes; K. michiganensis; Pantoea agglomerans; P. ananatis; P. dispersa; P. stewartii; Pseudomonas fluorescens; P. monteilii; P. prosekii; P.psychrotolerans; P. putida; Serratia marcescens* and *Stenotrophomonas pavanii* with maize crop in Bihar. Maize plants sampled from Delhi showed *Acinetobacter pittii; Bacillus cereus; Burkholderia cepacia; Enterobacter cloacae; E. hormaechei; Klebsiella aerogenes; K. pneumoniae; K. variicola; Pantoeadispersa; Pseudomonas fulva; P. oryzihabitans*and *P. putida***.** Maize associated *Burkholderiacepacia, Klebsiella aerogenes,K.michiganensis K. varicola, Enterobacter cloacae, Pantoeaananatis, P. dispersa, Pseudomonas monteilii,* and *Serratia marcescens* were found promising for pathogen suppression.

5.1.4.6 Effect of potassium phosphite (200 mM and 400 mM) on transgenic rice (Nipponbare introgressed with *ptx*D gene) microbiome

Leaf epiphytic and endophytic microbiome: Epiphytic microbiome of transgenic rice phyllosphere recorded *Acinetobacter, Achromobacter, Aeromonas, Allorhizobium-Neorhizobium-Pararhizobium-Rhizobium, Brevundimonas, Burkholderia-Caballeronia-Paraburkholderia, Chryseobacterium, Lysinibacillus, Ochrobactrum Pseudomonas Serratia Sphingobacterium* and *Stenotrophomonas.* The microbiome profiles of the phyllosphere were not significantly affected by potassium phosphite (200mM or 400mM) spray-on rice foliage. The distribution of the pattern of major culturable bacterial genera of the leaf appears to be nearly identical for mock and phosphite treated rice. A similar trend was also observed for the endophytic microbiome of rice that showed an abundance of *Achromobacter, Brevundimonas, Burkholderia-Caballeronia-Paraburkholderia, Chryseobacterium, Lysinibacillus, Myroides, Ochrobactrum, Pseudomonas Serratia, Sphingobacterium* and *Stenotrophomonas*.

Root epiphytic and endophytic microbiome: Epiphytic bacterial species belong to *Acinetobacter, Aeromonas, Allorhizobium-Neorhizobium-Pararhizobium-Rhizobium, Arcobacter, Azospira, Bacillus, Blastocatella, Burkholderia-Caballeronia-Paraburkholderia, Chryseobacterium, Delftia, Exiguobacterium, Flavobacterium, Hydrogenophaga, Luteolibacter, Lysinibacillus, Microbacterium, Myroides, Ochrobactrum, Pseudomonas, Sphingobacterium* and *Stenotrophomonas* were found in the transgenic rice rhizosphere. The microbiome profiles of the rhizosphere were found unaffected by potassium phosphite spray-on rice foliage. The distribution of the pattern of major culturable bacterial genera except *Lysinibacter* appears to be nearly identical for mock and phosphite treated rice, *Lysinibacter* count appeared to be affected by potassium phosphite application. Bacterial genera such as *Acinetobacter, Aeromonas, Allorhizobium-Neorhizobium-Pararhizobium-Rhizobium, Bacillus, Burkholderia-Caballeronia-Paraburkholderia, Chryseobacterium, Lysinibacillus, Microbacterium, Myroides, Ochrobactrum, Pseudomonas, Sphingobacterium,* and *Stenotrophomonas* found in the endophytic niches were also found unaffected by potassium phosphite spray.

Soil microbiome. Bacterial genera such as *Acidovorax, Acinetobacter, Aeromonas, Allorhizobium-Neorhizobium-Pararhizobium-Rhizobium, Arenimonas, Azospira, Brevundimonas, Candidatus-Solibacter, Chryseobacterium, Delftia, Devosia, Flavisolibacter, Gemmobacter, Haliangium, Hydrogenophaga, Lysobacter, Myroides, Nitrospira, Ochrobactrum, Ohtaekwangia, Paracoccus, Pseudomonas, Pseudoxanthomonas, Ramlibacter, Rhodobacter, Serratia, Sphingobacterium, Sphingomonas,* and *Treponema* were found in rice bulk soil samples. The microbiome profiles of soil were found unaffected by potassium phosphite spray-on rice foliage. The distribution of the pattern of major culturable bacterial genera appears to be nearly identical for mock and phosphite treated rice.

5.1.4.7 Management of bakanae disease of rice using rice seedling treatment

Out of 12 fungicides evaluated against bakanae disease of rice as seedling dip treatment (12 hrs) fungicides carbendazim 50% WP @ 1g/ L of water and tebuconazole 50% + Trifloxystrobin 25% w/w (75 WG) @ 1.0 g/L of water were found effective with the disease inhibition of 80% and 74% respectively.

5.1.4.8 Evaluation of rhizosphere bacterial antagonists for their potential against wheat against leaf rust (*Puccinia triticina*)

Talc-based bioformulation of 3 different rhizosphere bacterial antagonists, *viz. Pseudomonas, fluorescens* strain DTPF-3, *Bacillus amyloliquefaciens* strain DTBA-11 and *B. subtilis* strain DTBS-5 and their combination at 3 different conc. @ 5.0, 7.5 & 10.0 gm/kg seeds were obtained and tested for their ability to induce resistance in wheat against leaf rust under glasshouse conditions. Significant reduction in disease severity (93.24%) were observed with *B. subtilis* DTBS-5 @ 10.0 gm/kg seed in comparison to other antagonists. Biocontrol efficacy was higher in *B. subtilis* DTBS-5 treated plants, followed by

B. amyloliquefaciens DTBA-11 and *P. fluorescens* DTPF-3. The effective dose (10 gm/kg seeds) of antagonists and their combinations were also assessed for PGPR ability in wheat under glasshouse conditions. Increased plant growth ability was observed with *B. subtilis* DTBS-5 in comparison to other antagonists. Defence enzymes, *viz.* peroxidase, polyphenol oxidase, catalase and chitinase, and biochemical (phenol content and soluble protein) activity analysis in antagonists inoculated wheat plant after infection with leaf rust were studied. Increased defence enzymes activity and biochemical activity changes were observed in plant inoculated with *B. subtilis* DTBS-5 @ 10.0 gm/l followed by *B. amyloliquefaciens* DTBA-11 and *P. fluorescens* DTPF-3.

5.1.4.9 Biocontrol strategies (bioprospection, bioformulation) for major diseases of wheat

Through *in vitro* interaction studies, three potential isolates of *Chaetomium globosum* which have been isolated from Nilgiris, Tamil Nadu was found to have antagonistic action against *Bipolaris sorokiniana* which causes spot blotch in wheat. These three potential isolates of *C. globosum* are being maintained for further studies. A Mycoparasitic fungus *Acremonium* sp. colonizing on uredosori of black rust pathogen *Puccinia graminis*. f. sp. *tritici* of wheat at wellington was purified. The inhibitory effect/ biocontrol potential of *Acremonium* sp., on uredospore germination and germ tube elongation of black (*P. graminis*. f. sp. *tritici*) and brown (*P. triticina)* rust of wheat, crown rust (*P. coronata*) and stem rust (*P. graminis* f. sp. *avenae*) of oats was confirmed through in *vitro* and *in vivo* experiments.

5.1.4.10 IDM module for managing maize diseases

For MLB disease management, three modules *viz.*, organic, chemical and IDM were evaluated for the second season. Of these, the chemical module comprising seed treatment with Thiram (@ 3 gm/kg of seed), foliar spray of Mancozeb 75 WP (2.5g/L of water) at 45 DAS, foliar spray of Azoxystrobin 18.2% + Difenconazole 11.4% w/w SC (Amistar Top 325 SC) @ 1 ml/L of water at 55 DAS was provided 44% disease control and 49 sq/ha grain yield. It was followed by the IDM module comprising seed treatment with *Trichoderma harzianum* (10 gm/kg of seed), foliar spray of *Pseudomonas fluorescens* (10 gm/L of water) at 45 DAS, foliar spray Azoxystrobin 18.2% + Difenconazole 11.4% w/w SC (Amistar Top 325 SC) @ 1 ml/L of water at 50 DAS and foliar spray of cow urine (20%) at 60 DAS.

For the management of BLSB, four approaches namely one chemical module, two organic modules and one IDM modules were evaluated. The IDM module comprising soil amendment with *Trichoderma* formulation [@ 6 t/acre FYM] + seed treatment with Salicylic acid [100 ppm]+ foliar spray with Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC @ 0.1% using 500 l water/ha [at 3 DAI] and Neem leaf extract [@ 1%, at 15 DAI] was the best with 50% disease control and 47 q/ha grain yield. It was followed by the chemical module comprising seed treatment with salicylic acid [100 ppm] + foliar spray with Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC (@ 0.1% using 500 l water/ha, twice at 3 and 15 DAI) that provided 45% disease control and 44 q/ha grain yield.

5.1.4.11 Prevention of tospovirus infection by exogenous application of dsRNA of NSs gene

Groundnut bud necrosis virus (GBNV) is the most significant tospovirus affecting several crops in India. There is hardly any effective management option available against GBNV. The efficacy of direct foliar applications of dsRNA of NSs gene (ds-NSs) of GBNV in cowpea and *N. benthamiana* was evaluated following challenge inoculation of the tospovirus. The GBNV inoculated plants leaf exhibited many local lesions at 6 dpi, whereas ds-NSs treated plant showed either no local lesion or a few lesions in some leaves. Majority of the nontreated plants shows systemic necrosis and died by 10 dpt, whereas, the plants which were treated with ds-NSs survived for a long time. The viral RNA analysis by qRT-PCR also showed significantly reduction of virus load in the treated plants. Our results suggest that the external application of dsRNA of NSs gene is potential for prevention of GBNV infection.

5.2 ENTOMOLOGY

5.2.1 Integrated pest management

5.2.1.1 Cereals

Rice: Forewarning model of BPH: A forewarning model developed earlier for BPH, based on weather and the pest data during 2000-2013 including two outbreak years (2008 & 2013) was validated during 2019. The BPH incidence pattern over long period of time had indicated that a greater number of rainy days (>30) during June to September months perhaps played an important in the flareup of BPH population. During *kharif* 2019, there was no BPH outbreak and number of rainy days were 19 during June to September. Scanty rains during 2019 thus did not result in BPH outbreak, thereby validating the observation in regard to association of more frequent rains with BPH outbreak.

Investigation on migratory behavior of rice BPH: Higher proportion of macropterous form of BPH observed towards start (July-August) and end of the crop season (November), indicating towards migratory behavior of the pest. Brachypterous population of the pest dominated during September-October. Besides, protein, carbohydrate and glycogen contents were higher in the pest population in November compared to that of August population, pointing to the fact that the nutrients might have been consumed for immigration flight during July-August, while these were stored for emigration flight during November.

Wheat: Experiment on zero budget natural farming (ZBNF): An experiment was conducted to test the impact of four farming systems *viz*., integrated (recommended), ZBNF, organic and inorganic (conventional) on the dynamics of wheat aphid, *Rhopalosiphumpadi* on wheat (var HD 3118). It was observed that inorganic farming systems attracted a greater number of wheat aphids per spike followed by organic, ZBNF and integrated systems.

5.2.1.2 Vegetables and fruits

Weather based prediction model for the incidence of the mite, *Tetranychus urticae Koch*, whitefly, *Bemisia Tabaci Gennadius* and *its predator, Nesidiocoris Tenuis (Reuter)* in tomato: Studies on the tomato pest dynamics *vis-a-vis* weather factors indicated the presence of only whiteflies from 31 to 39 SMW *i.e.* end of July to September and mites from 14 to 21 SMW i.e. April and May above economic threshold level (ETL). Further thepopulation of the natural enemy of whitefly, *Nesidiocoris tenuis* (Reuter) (Hemiptera: Heteroptera: Miridae) increased with increase in the whitefly population and declined with the reduction of whiteflies. Weather based forewarning model depicted that maximum temperature, minimum temperature, evening relative humidity and wind speed influenced the whitefly dynamics [(8.37 -0.055 (Tmax)+1(Tmin)+0.02 (ERH)-1.79 (WS)] while maximum temperature, morning relative humidity and wind speed [64.17+0.95 (Tmax) -0.88 (MRH)-1.14(WS)] influenced the mite population.

Ecological engineering in Cole crops: An experiment was conducted to assess the role of crop diversification on insect pest and their natural enemies in cole crops. Among the different crops tested for diversification, soya crop attracted a greater number of cabbage aphids per plant on cabbage; whereas, coriander, tomato and berseem were found at par with control. It was also noticed that radish as a border crop could attract a greater number of cabbage aphid and coccinelid beetles compared to other crops like soya, fenugreek, sunflower, marigold, tomato, coriander, rijka, and berseem.

Evaluation of summer cauliflower breeding lines against cabbage head borer, Hellulaundalis: Thirty-eight cauliflower lines were evaluated against head borer, *Hellulaundalis* during *kharif* of 2020 under field conditions. Among thirty-eight lines many of the lines witnessed head borer damage and could not bear curd either. However, lines *viz*., B-46 and B-1 44 fared better than other lines with respect to lower head borer damage.

Evaluation of cabbage breeding lines against major insect pests: Ten relatively susceptible and ten relatively tolerant cabbage lines were evaluated for both DBM (*kharif* season) and aphid (*rabi* season) tolerance along with standard check Golden Acre at IARI, Katrain. In addition to pest incidence tolerance lines were also evaluated for natural enemy preferences. Final

evaluation re-confirmed higher level of tolerance in two lines *viz*. Green Emperor and 9A which also attracted significantly higher number of natural enemies of both DBM and aphid as compared to very susceptible line Pusa Mukta. It was further observed that in tolerant lines two initial insecticide sprays can be avoided since occurrence of ETL is delayed by 20 days as compared to susceptible check.

Evaluation of cauliflower breeding lines against major insect pests: Ten relatively susceptible and ten relatively tolerant cabbage lines were evaluated for both DBM (*kharif* season) and aphid (*rabi* season) tolerance along with standard check Pusa Snowball K-1 at IARI, Katrain. Higher level of tolerance for DBM was established only in Italian Giant and for aphid in three lines *viz*. Italian Giant, KTK 15 and Supreme × late as compared to the standard check.

Screening of different accessions of various Brassica species including wild ones: Thirty-two *Brassica* accessions collected from Kolasib, Mizoram and 10 wild Brassicaceae species *viz*. *Alliaria petiolata*, *Brassica tournefortii*, *Brassica critica*, *Cardamine hirsute*, *Capsella bursa-pastoris*, *Nasturtium officinale*, *Rorippa islandica*, *Sisymbrium officinale*, *S. irio* and *S. orientale* collected from Kullu Valley were maintained at Katrain station and evaluated for aphid resistance traits. One *Brassica* line *i.e*. 'Fern Sahia' collected from Mizoram demonstrated very strong resistance against cabbage aphid *Brevicoryne brassicae* but the same line was found to be very susceptible to flea beetle damage during early growth stage.

Chemical management of pre mature leaf fall in apple: Premature leaf fall is important disease in applecaused by *Marsonina coronaria.* Various fungicides tested against the disease at IARI, Amartara. It was found that Tebuconazole 50%+ Trifloxystrobin 25% w/w WG was the most effective fungicide for the management of PLF followed by Fluxapyroxad 250g/l +Pyraclostrobin 250g/l and Fluopyram 17.7%+ Tebuconazole 17.7% w/w SC.

Apple woolly aphid trap: Woolly apple aphid is becoming important pest in Himachal Pradesh that weakens the apple plant by feeding both at root and shoot. Movement of woolly aphid from above ground plant parts to roots can be restricted through tying insecticide + oil treated jute bag on the apple stem after fruit harvesting. After tying jute bag treated with insecticide + oil, insecticide recommended for the management of woolly aphid was sprayed at at IARI, Amartara. Apply insecticide (chloropyrifos @ 2.5 ml/ litre) + oil on the jute bag before onset of spring season. It was observed that for best results adoption of this technique should be on community level. At least all the adjoining orchardist should follow this practice for good results.

5.2.1.3 Soybean

Incidence and seasonal dynamics of insect pests of soybean: The major insects found in soybean variety JS 335 were whiteflies and stem fly. The stem fly infestation based on stem tunnelling was 14.78% while the maximum whitefly infestation during 38th SWM was 17.7 adult whiteflies per plant.

5.2.1.4 Pulses

Occurrence and outbreak of *Tetranychus btruncatus* Ehara (Tetranychidae: Acari) in north India on *Vigna*spp: Unusual occurrence and outbreak of *Tetranychus truncates* Ehara in north India was noticed during November third week during 2019-20. Usually, mites are known to occur during summer with their population declining after the onset of winter, but during the crop season of 2019-20, apart from this unusual occurrence, outbreak was also noticed. Field populations biology was studied both under laboratory conditions. Mites completed their life cycle in 14.89 ±1.5 and 6.42±1.07 under laboratory conditions. Outbreak was positively influenced by maximum temperature (r =0.67), minimum temperature (r =0.85) and sunshine hours (r =0.58) but negatively influenced by morning relative humidity (r= -0.65) and evening relative humidity (r =-0.82), respectively.

5.2.1.5 Oilseeds

Yield loss assessment in recently released two Indian mustard genotypes due to aphid, *Lipaphis erysimi* damage: Yield loss assessment due to *L. erysimi* was carried out on two recently released Indian mustard

varieties *viz*., PDZM 31 and RH 725. There was significant reduction in numbers of aphids/plant after first and second insecticide applications in both varieties. After first insecticide application, there was 76.3% and 92.5% reduction in aphid population in PDZM 31 and RH 725, respectively while after the second insecticide application, thereduction in aphid population was 67.3 and 60.0%, respectively. Yield loss assessment in the two varieties revealed significantly higher seed yield and lower aphid population under protected as compared to unprotected conditions. The seed yields under protected condition were 2197.8 and 2093.7 kg/ha, while under unprotected conditions it was 1807.3 and 1880.1 kg/ha in PDZM 31 and RH 725, respectively. Need based insecticide application resulted in 21.6 and 11.4% increase in seed yields of PDZM 31 and RH 725, respectively.

Evaluation of newer insecticides for their efficacy against mustard aphid: Five insecticides, Imidacloprid 17.8 SL, Thiamethoxam 25 WG, Acetamaprid 20 SP, Dimethoate 30 EC and Clothianidine 50 WDG along with control were evaluated for management of mustard aphid in variety PM 30. Two sprays of insecticidal sprays were given for each treatment. The percent aphid reduction was non-significant across treatments after the first insecticidal application. However, there were significant differences before and after the second insecticidal application, and the aphid population varied from 16.4 to 39.8 and 4.8 to 26.3 aphids/plant. There were significant differences in seed yield among different treatments, and the treatment with Imidacloprid 17.8 SL@ 0.25 ml/ lrecorded significantly higher yield as compared to other treatments. The incremental benefit cost ratio was also higher as compared to other treatments.

5.2.2 Storage Entomology

Fumigation toxicity of monoterpenoids: Fumigation toxicity of different monoterpenoids against pulse beetle, *Callosobruchus maculates* revealed carvacrol as the most effective fumigant with LC_{50}=1.8 and LC_{90}=4.24µl/L air) followed by trans-anethole (2.4 µl/L air), fenchone (2.88µl/L air) and linalool (3.2µl/L air). The biochemical analysis of these monoterpenoids revealed considerable difference in SOD, catalase, EST and CYT enzyme activity of *C. maculatus.* Out of 130 cowpea germplasm lines were screened against pulse beetle, *Callosobruchus spp*., 43 lines were found comparatively resistant with minimum number of eggs and less adult emergence.

5.2.3 Biological Control

5.2.3.1 Biology of 6-spotted ladybird beetle, *Cheilomenes sexmaculata* on Cotton aphid, *Aphis gossypii*

Cheilomenes sexmaculata (Fabricius) is one of the important native aphidophagous species widely distributed all over the country and is known to prey on different soft bodied insects preferably aphids. Its predatory potential was studied on cotton aphid, *Aphis gossypii* Glover. Investigations were carried out to know the prey-host specific biology of *C. sexmaculata* on *A. gossypii* on cotton. *Aphis gossypii* was found to be the most suitable host for *C. sexmaculata* as evidenced by faster development (6.21±0.03 days), greater longevity of females (67±4.7 days) and higher fecundity (756.5 eggs/ female). These positive biological attributes of *C. sexmaculata* on *A. gossypii* could contribute to its mass production for augmentative biological control.

5.2.3.2 Orientation behavior of coccinellids

Extraction of Mustard plants volatiles was done using volatile collection unit. The abbreviations used are as follows: WOAI: Extract without aphid infestation (extract from un-infested plant), WAI: with aphid infestation (extract from aphid infested plant), WAI&WOB (A): with aphid infestation and ladybird beetles were removed and volatiles were collected, WAI&WOB (B): with aphid infestation and ladybird beetles were remained on plant at the time of volatile collection. At 50 per cent concentration, it was found that female ladybird beetles' attraction was highest in WAI volatiles (83.3%). The least attraction was also shown by female ladybird beetles in WAI and WOB (B) volatiles (16.6%). At this concentration, the highest attraction by male ladybird beetles was shown in WAI and WOB (B) volatiles (66.6%), while the least attraction was shown in WAI & WOB (A) volatiles (16.6%). At 100 per cent concentration, it was found that female ladybird beetles' attraction was highest in WAI volatiles (100%) and in remaining volatiles it

was 66.6%. While at this concentration, the highest attraction by male lady bird beetles shown in WAI, WAI and WOB (A) and WAI and WOB (B) volatiles (66.6%) while the least attraction was shown in WOAI volatiles (33.3%). GC-MS analysis of collected volatiles results revealed variation in chemical composition and relative abundance of different compounds in different extracts. GC-MS analysis revealed the presence of some compounds present in all the treatment like in un-infested plant volatiles, infested with aphids, in absence of *C. sexmaculata* and in presence of *C. sexmaculata.* These, twenty-five compounds were: Toluene;1-Octene; Acetic acid-butyl ester;4-Hydroxy-4-methyl-2-pentanone; Ethylbenzene; o-Xylene; Nonane; Heptanal; 4-Methoxy-4-methyl-2-pentanone; (1-Methylethyl)- benzene; 1-Ethyl-3-methyl- benzene; 1,2,3-Trimethyl- benzene; Octanal; 1,3-Dichloro-benzene;3-Carene; 1,3-Dichloro- benzene;4-methyl-decane; Undecane; Nonanal; d-Menthol; Azulene; Dodecane; Decanal; Dodecane and Tetradecane.

5.2.3.3 Biology and feeding potential of the *Sycanus croceovittatus* (Hemiptera: Reduviidae):

Total developmental duration of generalist predator *Sycanus croceovittatus* was observed to vary between 38 to 45 days when reared on *Spodoptera litura* F. Incubation period was 12-18 days, nymphal period was 2-3, 4-5, 4-5, 4-7 and 6-8 days for 1st to 5th instars respectively with a total nymphal period of 20-28 days. Pre-oviposition period lasted for 1-1.82 days and longevity of adults was 5-12 days. Further studies on the feeding potential of the 1st, 2nd, 3rd, 4th and 5th instars bugsindicated a consumption of 6-8, 5-20, 10-16, 15-25, and 25-30 third instar larvae while an adult female consumed 22-35 fourth instar *S. litura* larvae.

5.2.4 Insect Physiology

Characterization of gut bacterial isolates have led to identification of novel bacterial phylotypes unique to Eri silkworm, *Samiaricini* (Lepidoptera) and whitegrub, *Anomola dimidiata* (Coleoptera) viz., ES-ANE-EFG-4 (96% similarity) and ES-ANE-EMG-5A (93% similarity) from *S. ricini*; and isolates WG37 (96% similarity), WG40 (89% similarity) and anaerobic bacterium isolate WG-ANE-MG5 (93% similarity) from *A. dimidiata*. Detailed investigation on Cellulolytic gut bacterial isolates in *A. dimidiata* have unravelled the cellulolytic potential of gut bacterial isolates from *A. dimidiata*

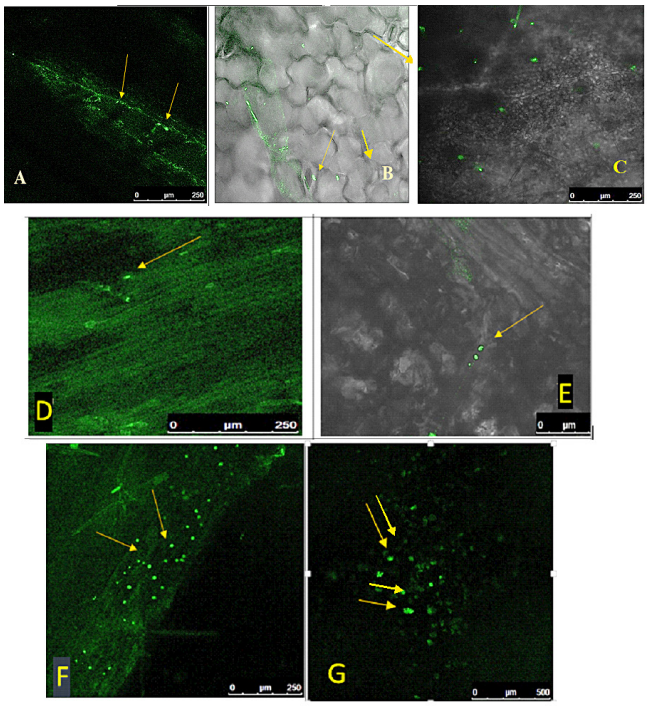
Temporal and spatial dynamics of endosymbionts of *B.tabaci* Asia II-1 revealed significant variation in the profile of key facultative endosymbionts of *B.tabaci* over seasons, across locations and host plants. While, *Porteira*and *Arsenophonus*are stable while, drastic changes in *Wolbachia* and *Ricketsia*varied with infection frequencies. Dynamics of endosymbionts in *B.tabaci* have physiological implications on management of this pest.

5.2.4.1 Sexual bias in culturable gut bacterial diversity of Pink bollworm, *Pectinophora gossypiella* larvae from different cotton growing regions of India

Culturable gut bacterial communities of field collected Bt cotton resistant *Pectinophora gossypiella* population from different locations were evaluated. 16S rRNA based survey was done to assess all the culturable bacteria of *P. gossypiella*. The study indicated a higher bacterial diversity associated with populations from Adilabad and Khandwa. A total of 37 bacteria (21 from male and 16 from female) were obtained and gut bacterial diversity was higher in males compared to females. *Enterococcus casseliflavus*, *Enterobacter hormaechei* subsp. *xiangfangensis* and *Bacillus cereus* were shared between both the sexes. This study highlights the variation in the gut bacterial composition in different sexes of *P. gossypiella* though insects were collected under same conditions. These bacteria may play an important role in the development of pink bollworm.

5.2.4.2 Colonization of native *Bacillus thuringiensis* strain VKK-BB2 as endophytes in brinjal plant

Plant-bacteria mutualistic symbiosis as endophytes can benefit plants by increasing its fitness by inducing resistance to insect pests. Studies were conducted on endophytic ability of native *Bacillus thuringiensis* strainVKK-BB2(BtVKK-BB2) tagged with a Green Fluorescent Protein (GFP) gene. and was inoculated into seeds and seedlings through seed treatment, soil drenching and foliar spray. After inoculation GFP



Confocal microscopic images of *Bacillus thuringiensis* strain VKK-BB2 inside the Brinjal plant. A-C seed treatment method: A, B: Colonies in stem and leaf tissues of 15 days old seedling in Seed treatment; C: Colonies in leaf on 30th day after seed treatment. D&E Soil application method: D- Colonies in stem and E- leaf tissues in Soil at 10th day after application. F&G Foliar spray method; F: Colonies in leaf at 7 day after foliar treatment; G: Colonies in leaf at 15 days after foliar treatment

marked Bacteria could be re-isolated from all parts of the plant. Confocal Laser Scanning Microscopy (CLSM) of brinjal revealed that *B. thuringiensis* strain VKK-BB2 was able to colonize the brinjal leaf through seed treatment, soil application and foliar spray. Further, the green fluorescent cells could be detected in the leaf tissue till 30, 15 and 10 days in case of seed treatment, foliar spray and soil application respectively. Thus, for sustainable colonization of bacteria as endophytes repeated application of foliar spray is required at fortnight intervals.

5.2.4.3 Stage specific effect of hot events on biological attributes and reproductive fitness in *Spodoptera litura* (Lepidoptera: Noctuidae):

Temperature is one of the most important environmental variables affecting growth, reproduction and distribution of insects. Ambient temperature often fluctuates with shorter periods of extreme high temperature, termed as hot events and these hot events are predicted to become more intense and frequent in near future due to global warming. To study the stage specific effects of heat shock on biological attributes of *S. litura*, 4 developmental stages *viz*., eggs, 3rd instar larvae, pupae and adults were exposed to two higher temperatures for different durations *viz*., 42°C for 2, 4, 8, 12, 16, 20 hours and 46°C for 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 hours using temperature-controlled incubator. Insect culture maintained at 30±1°C was considered as control. The effect of thermal stress on survivability of *S. litura* larvae varied among the temperature treatments, survivability decreased with increasing duration both at 42°C and 46°C. Zero percent maturation success was observed at more than 8 hours and 1.5 hours of exposure for egg stage at 42°C and 46°C respectively while in case of the larval stage, maturation success was nil at 46°C for 3 hours. Effect of temperature on fecundity varied statistically among the different temperature regimes. It was observed that increasing thermal exposure duration had negative effect on the fecundity of the *S. litura*at both higher temperatures. Adults emerging from stressed larvae evinced maximum fecundity compared to adults emerged/ surviving from other stressed developmental stages. Mating success showed almost decreasing trend, while mating frequency showed increasing trend with increasing exposure durations at 42 and 46°C as compared to control.

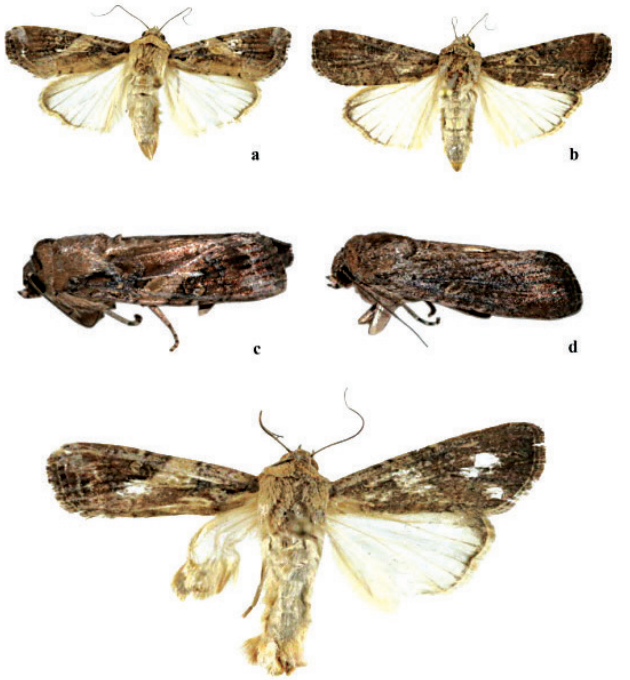
5.2.4.4 Antioxidant defense system in chickpea in response to gram pod borer, *Helicoverpa armigera* (Hubner) stress

Studies were conducted to elucidate the biochemical defensive response of chickpea genotypes against *H. armigera* feeding to understand plant defense system in selected chickpea genotypes *viz*., NBeG – 786, GL -13001, ICC - 3137 (susceptible check), ICCL - 86111 (resistant check), GL-13042 and RSG-959. Investigations were carried out on enzymatic [superoxide dismutase (SOD), peroxidise (POX), catalase (CAT) and polyphenol oxidase (PPO)], non-enzymatic [hydrogen peroxide (H_2O_2), malondialdehyde content (MDA)], nutritional compounds (reducing sugar and protein content), and anti-nutritional compounds (total phenols and tannins content) at four intervals *viz*., 24, 48, 72 and 96 h after infestation by *H. armigera* in the seedlings of different

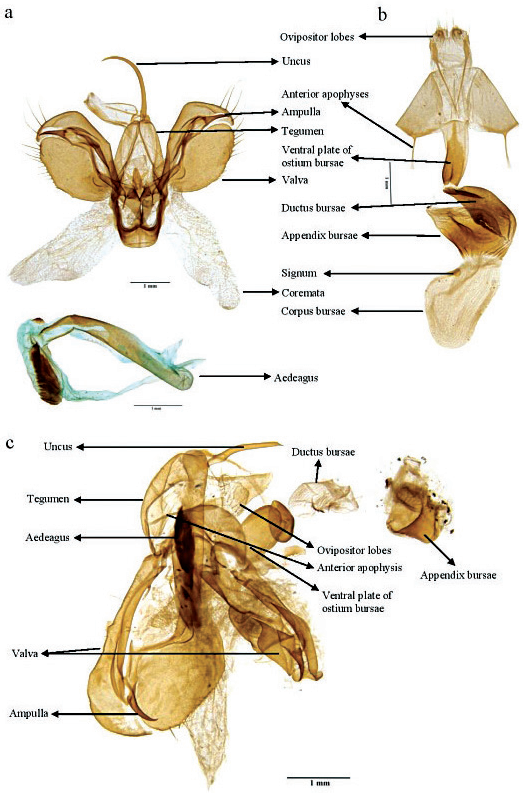
chickpea genotypes. The activities of superoxide dismutase, peroxidase, polyphenol oxidase and the contents of hydrogen peroxide, malondialdehyde, reducing sugar, protein, total phenols and tannins increased while catalase activity decreased in the *H. armigera* infested plants compared to the uninfected plants. Clustering and heat map analysis for all the biochemical constituents under study of six chickpea genotypes at 48 hrs after infestation revealed that biochemical constituents *viz*., superoxide dismutase, catalase, polyphenol oxidase, total phenols and tannins are affected similarly across the genotypes and they are said to be more predominant components in chickpea under insect pest stress and can be used in developing the pod borer tolerant varieties of chickpea.

5.2.4.5 First report of gynandromorph in fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

Gynandromorphism is a phenomenon in which an individual develops with sexual mosaic of male and female traits. It is a rare phenomenon that has been reported in certain group of organisms *viz*., arthropods, birds, reptiles, amphibians, mammals. Gynandromorphs are expressed generally in two ways, bilateral and non-bilateral (sexual mosaics). In insects, bilateral gynandromorphs are most frequent, wherein left and right halves are of different sexes. During the routine rearing of *S. frugiperda* serendipitously an adult with an uncertainty in wing morphology was found suggesting it to be a gynandromorph. Detailed examination of morphological and anatomical structure of gynandromorphic moth revealed that wing pattern of left and right side resembled that of male and female, respectively and in thorax, patagium on left side was prominent like male while on right side it was inconspicuous like female depicting the bilateral type. Dissection of gynandromorphic moth genitalia revealed that genital structure was asymmetrical with male genitalic structures observed on one half and female genitalic structures on the other half, male structures are well developed representing, distinct uncus, valvae, aedeagus, tegumen, and ampulla as compared to the female structure.



Habitus of normal male (a & c), female (b & d) and gynandromorphic moth (e)



Genitalia morphology of Spodoptera frugiperdaa. male b. female c. gynadromorph

5.2.4.6 Genomic variability in diapausing and nondiapausing *C. partellus* strains

The BLASTX hits revealed that the number of predicted genes with significant BLASTX match were comparatively lower in aestivation (9491 genes) as compared to hibernation (11507 genes) and non-diapause (11443 genes) strains of *C. partellus*. Gene ontology revealed that the biological process, molecular function, and cellular component gene items drastically reduced in aestivation (803, 852 and 280) than hibernation (773, 840 and 284) and non-diapause (721, 796 and 260) strains of *C. partellus*.

5.2.4.7 Reaction of diapausing and nondiapausing *C. partellus* populations to diverse maize and sorghum genotypes

Diapause is the survival strategy in insects to overcome the harsh environmental conditions. *Chilopartellus* undergoes hibernation under North Indian conditions and aestivation under South Indian conditions, wherein these strains might be responsible for temporal and spatial variation in expression of resistance to this pest. Therefore, we studied differences in damage potential of F_1 generation of diapausing and non-diapausing strains of *Chilopartellus* in resistant and susceptible maize and sorghum genotypes. The leaf damage and deadhearts were significantly higher by hibernation as compared to aestivation and nondiapause strainsof *C. partellus* in both resistant and susceptible maize and sorghum genotypes.

5.2.5 Insect Toxicology

Compounds influencing oviposition of Fall Armyworm (FAW), *Spodoptera frugiperda* were identified from methanol extracts of its larval frass. The methyl esters of fatty acids *viz*., pentadecanoic acid and linoleic acid caused significant oviposition deterrence. These methyl esters were also found to influence orientation behavior of larvae and adults of fall armyworm. Flonicamid, a new group of insecticide was tested for resistance development to *Bemisia tabaci*. The population collected from Bathinda region of Punjab during August 2019 had a resistance ratio of 8:12 compared to the lab susceptible population through adult bioassay confirming a low level of resistance development to flonicamid.

Toxicological studies were conducted with commercially available neem formulations on desert locust, *Schistocerca gregaria* reared on maize plants under laboratory conditions at a temperature of 33±2^{0}C, low relative humidity 20-25%, proper aeration and sunlight. Feeding technique was used in the laboratory to study the effect of different concentrations of neem oil on first instar nymphs. No mortality was observed at 0.1% after 24 hrs even though feeding was observed. 100% mortality was observed at a concentration of 0.5% after 48 hrs. Significant difference was there in leaf area eaten at1% (9.27±1.79) and 0.1% (111.93±1.05) concentration of neem oil, estimated in mm^2/one locust nymph and both were significantly different from control (295.4±1.39). It is been confirmed that neem oil can be used as an antifeedant for first instar nymphs of locusts.

5.2.6 Webinar on "Desert locust management: Current status & future strategies"

A Zoom Webinar on "Desert Locust Management: Current Status & Future Strategies" was organized with initiation and motivation of Dr Trilochan Mahapatra, Secretary-DARE & DG-ICAR on May 30, 2020 by ICAR-IARI, New Delhi. The goal of the webinar was to review the current status of desert locust (*Schistocerca gregaria*) outbreak, affected States/ regions in India, currently available strategies for the

Webinar on desert locust management

management of this dreaded pest. Besides a lecture on "Desert locust: an overview in Indian context"the webinar also included a brain storming for finding solutions for the locust menace, by better strategizing for future by integration of biological and physical sciences through active collaboration with different National organizations and other stakeholders.

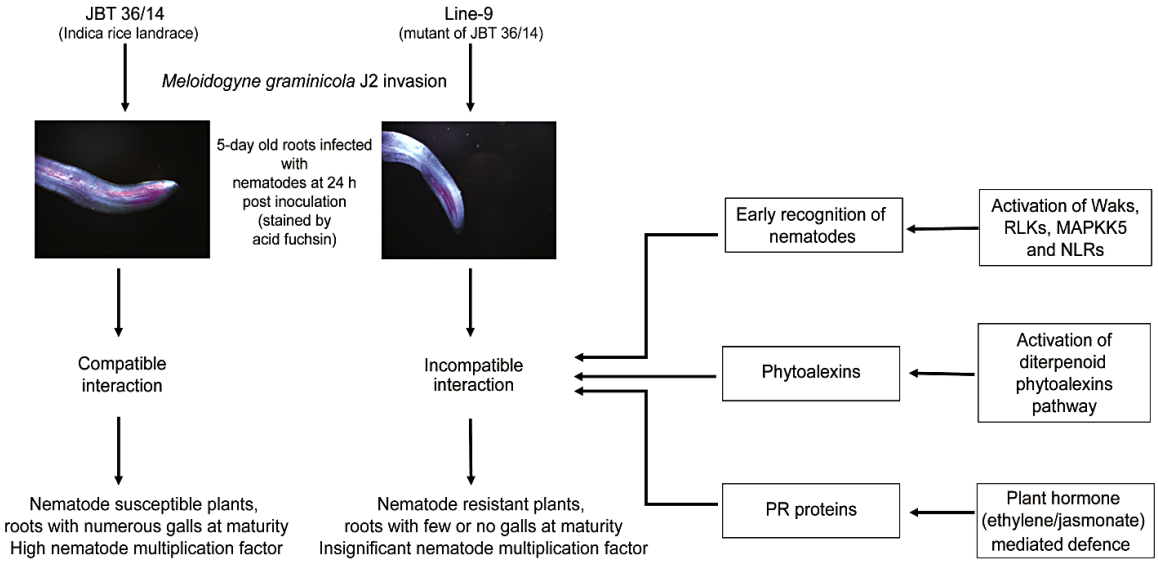
5.3. NEMATOLOGY

5.3.1 Nematode genomics and transcriptomics

5.3.1.1 A high-quality genome sequence of *M. graminicola*

*Meloidogyne graminicola*is the most destructive plant-parasitic nematode disease of rice (*Oryza sativa* L.) in India, causing losses amounting to ₹ 23,272.32 million per annum. The draft genome assembly of *M. graminicola* has been finalised, and it contained 514 scaffolds, and was of 36.86 million base pairs (Mbp) in size. The N50 value for the draft genome assembly was 105 kb, and the G+C% was 24.24%. The genome completeness assessment by BUSCO was done using the 303 conserved Eukaryota genes showed 88.8% complete genome. This will facilitate functional genomics in *M. graminicola*. In addition, 369 diverse land races and cultivars of rice were screened to identify nine nematode-resistant cultivars.

Using transcriptomics to understand rice plant resistance to *Meloidogynegraminicola*: Further, to investigate the molecular mechanisms conferring *M. graminicola* resistance to rice, the transcriptome of an activation tagged mutant line-9 was compared to susceptible parent JBT 36/14 at 24 h post-infection.A total of 674 transcripts were differentially expressed in line-9. Early regulation of genes related to nematode pattern recognition (e.g. wall-associated receptor kinases), signaling (NLRs), defense-related PR genes (PR1, PR10a, NB-ARC domain-containing genes) as well as a large number of genes involved in secondary metabolites and diterpenoid biosynthesis (*CPS2*, *OsKSL4*, *OsKSL10*, *Oscyp71Z2*, oryzalexin synthase, momilactone A synthase) was observed in *M. graminicola*resistant mutant line-9. It may be suggested that early recognition of invading nematodes triggers plant immune responses mediated by phytoalexins, PR proteins, and other defense proteins and inhibit nematode growth and reproduction. This study provides the first transcriptomic comparison of nematode-resistant and susceptible rice plants in the same genetic background and adds to the understanding of mechanisms underlying plant-nematode resistance in rice.



A model of probable molecular mechanisms and pathways conferring nematode resistance to mutant line-9 as compared to its parent JBT 36/14.

5.3.1.2 The genome of *Anguina tritici*

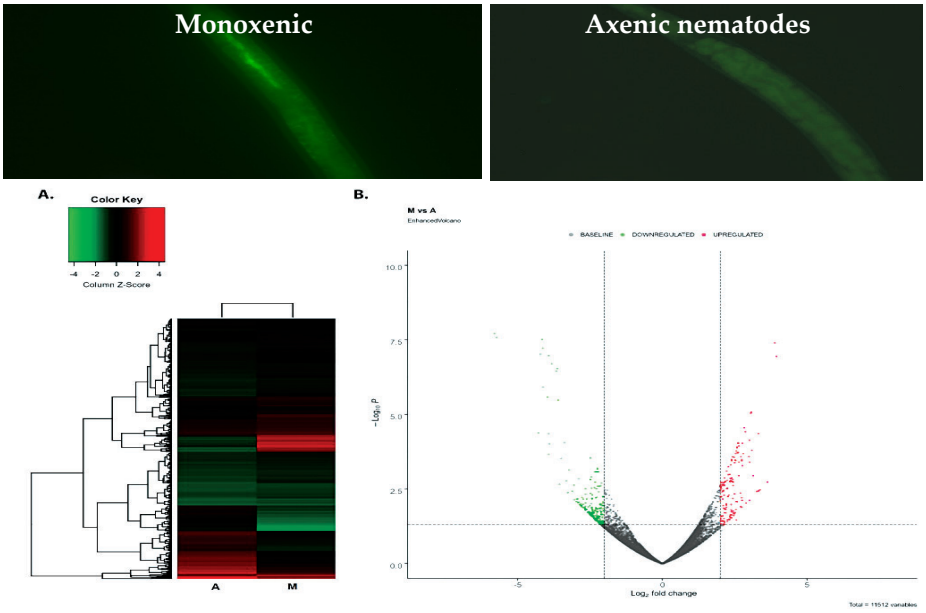
Anguina tritici, the first plant parasitic nematode to be described in literature in the year 1743, is an aerial plant parasitic nematode causing the earcockle (seed gall) and tundu disease of wheat and rye. The nematode juveniles, on discovering the plant host in the soil, move up along with the plant growth, and invade the inflorescence. The nematode has been reported to survive in anhydrobiotic condition for as long as 35 years, in the wheat seed galls. These unique features made us sequence the genome of this nematode. The draft genome of *A. tritici* (using Illumina MiSeq platform) hasan estimated size of 164 MB having 39,965 protein coding genes at 60-fold coverage, and a GC content of 38%. The KEGG analysis revealed the involvement of these genes in 375 different pathways. Comparative genomic analysis showed the presence of 13,497 ortho-groups among *Bursaphelenchus xylophilus, Caenorhabditis elegans, Ditylenchus destructor, Globodera pallida, G. rostochiensis, Meloidogyne hapla, M. incognita* and *A. tritici*. Single copy orthologue based phylogenetic tree showed *A. tritici* and *D. destructor* in monophyletic group, indicating that the two are closely related to each other than any other nematode. The gene prediction studies of the *A. tritici* genome showed presence of 376 tRNAs and 39,965 gene models, with a gene density of 26.57 having an average gene length of 1347 nucleotides. Annotation of 62% genes of the *A. tritici* genome was successful and 38% of the genes did not find any hits in NCBI database thereby suggesting that they might be the genes with novel function which have not been functionally characterized as yet.

Expert functional annotations revealed the occurrence of several gene homologues of developmental, neuropeptide, ageing, anhydrobiosis, parasitism, RNAi, chemosensory and sex determination processes in *A. tritici.* In future, the genome sequence data of *A. tritici*, will help us to understand the process of adaptation to aerial parasitism, anhydrobiotic survival and stress tolerance mechanisms. The genome data will also provide a base for undertaking functional biological studies, w.r.t the genes whose functions are not known today.

5.3.2 Entomopathogenic Nematodes

5.3.2.1 Using transcriptomics to understand bacterial symbiosis in entomopathogenic nematodes

Heterorhabditis nematodes are entomopathogenic nematodes that live in symbiotic association with



Monoxenic nematodes with their symbiont bacteria and axenic nematodes without any symbiont bacteria. Heatmap and volcano plots showing differentially expressed genes between symbiont (M) and non-symbiont (A) states of the nematodes

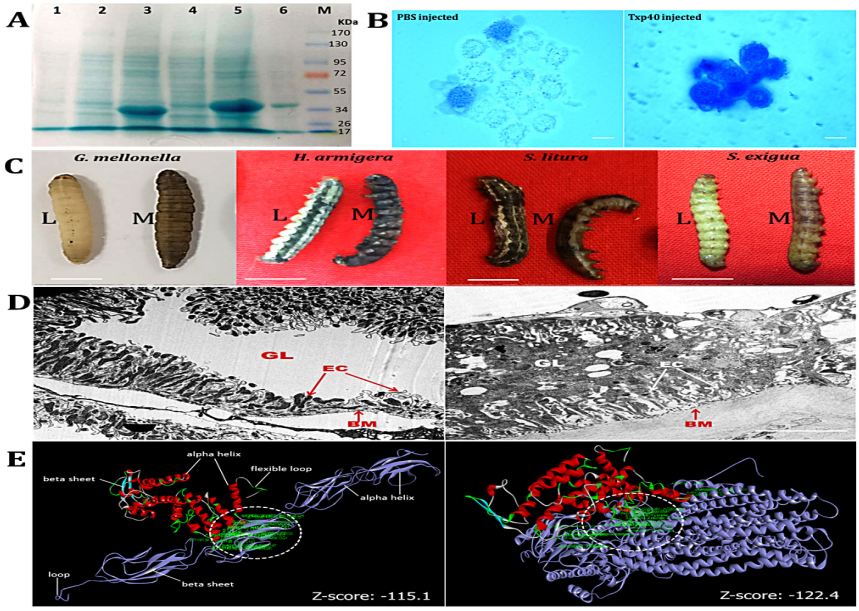
Photorhabdus bacteria. To understand the nematode factors involved in symbiosis with *Photorhabdus luminescens*, the transcriptomes of axenic and monoxenic *H. bacteriophora* nematodes were sequenced at the early adult stage (36-48 h after IJ recovery) when the symbiont attachment and biofilm formation takes place in the posterior nematode intestine. A total of 200 million high quality reads were pooled to generate a 95.7 Mb assembly comprising of 46,599 transcripts. Several differentially expressed transcripts have been identified that are suggested to be involved in cell recognition and adhesion; nematode innate immunity pathways, and carbohydrate-binding. Efforts are on-going to validate the role of these genes in nematode-bacterium symbiosis using functional genomic tools. This study would help in understanding complex animal-microbe associations.

5.3.2.2 Characterization of Txp40 toxin from *Photorhabdus akhurstii*

Photorhabdus akhurstii produces a variety of toxins that aid this bacterium and its mutualistic nematode vector, *Heterorhabditis indica* to kill the insect host. Txp40, a 37 kDa protein, characterized from different *P. akhurstii* strains conferred insecticidal activity against economically important insects *Helicoverpa armigera*, *Spodoptera litura* and *S. exigua* (*Galleria mellonella* used as the reference). Injection of purified Txp40 caused dose-dependent reduction in total circulatory hemocytes and hemocyte viability of test insects. Injection of Txp40 significantly elevated the phenoloxidase activity of insect hemolymph and histological analyses showed extensive damage to midgut epithelium. This explains the access of the toxin from hemocoel to midgut via leaky septate junctions. Txp40 putatively interacts with *H. armigera* midgut receptor proteins cadherin, ATP-binding cassettes, aminopeptidase N1 and alkaline phosphatase, to exert toxicity.Txp40 can be used as an efficient agent for future pest management strategies.

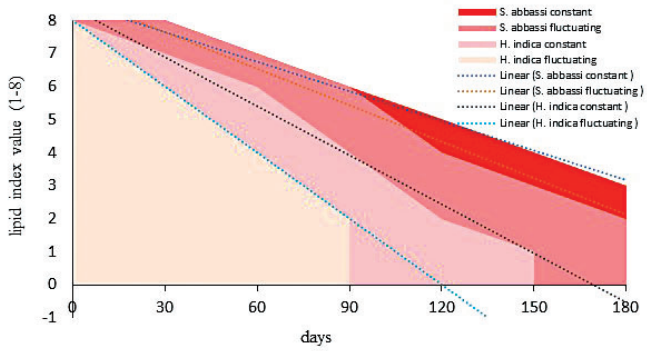
5.3.2.3 Evaluation of the various EPN formulations

The gravimetric moisture content of wet clay-based formulations of *H. indica* and *S. abbassi* was studied at constant (28^{0}C) and fluctuating (28^{0}C to 36^{0}C) storage temperatures. When stored at constant temperature, the initial 20% moisture content remained the same for 30 days and then gradually reduced by 50% 120 days. After 180 days of storage the moisture content reduced to 4.6%. In comparison when stored at fluctuating temperatures, it reduced to 16% within



(A) *In vitro* production of Txp40 protein, (B) Txp40-mediated hemocyte degradation in *G. mellonella*, (C) Melanization reaction in different insects due to Txp40 injection, (D) Txp40 caused severe gut damage in *H. armigera*, (E) *In silico* docking of Txp40 with gut receptors

first 30 days and 50% in 60 days, while after 180 days only 1.03% moisture was available in the formulation. Temperature regulation of wet formulations during storage and distribution is critical for the shelf-life of EPNs. *Steiner nemaabbassi* was comparatively more stable than *H. indica*. Only 54.1% *H. indica* IJs survived after 60 days at fluctuating temperature as compared to 54.4% survival after 90 days at constant temperature. The survival reduced to 3% after 180 days at constant temperature while none survived following the 90 days storage at fluctuating temperatures. In case of *S. abbassi*, 60.6% survival was recorded at 120 days storage at fluctuating temperatures as compared to 62.2% after 150 days at constant temperature, while after 180 days, it reduced to 14.8% and 42.8% respectively. On the scale of 1-8, the stored lipid reserves of *H. indica* declined faster as compared to that of *S. abbassi* and the gradual loss of gravimetric moisture content in the formulation did not induce anhydrobiotic survival in both the nematodes.



Stored lipid reserve index of *H. indica* and *S. abbassi* when stored at constant and fluctuating temperatures. Also, Depletion of stored lipid reserves in *H. indica* and *S. abbassi* after 120 days at constant temperature.

5.3.2.4 Evaluation of the combined application of *B. cereus* and *H. indica* for white grub management

The combined application of *B. cereus* and *H. indica* @ 250, 500, 750, 1000 IJs/3rd instar white grub led to 100% mortality with 5 days which was statistically at par with the two higher doses of *H. indica* alone (500 and 1000 IJs). *B. cereus* alone took 28 days to impart 100% mortality, whereas *H. indica* alone at 250 and 500 IJs caused the mortality within 5 to 10 days and were statistically at par.

5.3.2.5 Evaluation of the compatibility of indigenous EPN with conventional fertilizers

Direct effect on viability and infectivity of IJs of *H. indica* exposed to various inorganic fertilizers i.e., urea, SSP, DAP and sulphate of potash was assessed *in vitro*. All the tested inorganic fertilizers at different doses (except 25 ppm) were lethal to *H. indica* over the 10 days period and urea was least lethal. The incubation time and concentration had a positive correlation with mortality of IJs.

5.3.3 Nematode biocontrol agents

5.3.3.1 Mass multiplication and formulation of *Trichoderma asperellum*

Mass multiplication of a nematicidal isolate of *Trichoderma asperellum* was carried out on organic media and sporulation was enhanced by addition of inorganic salts. The formulation with spore load of 2 x 10^{11}/cc. on soil application @ 6% w/w exhibited a significant reduction in reproduction factor of the nematode and gall index in tomato cv Pusa Ruby with significant enhancement in plant growth characters, compared to untreated control. The shelf life of the formulation based on cfu data indicated higher number of viable spores at 15^{0}C followed by 25^{0}C and 30^{0}C after 6 months of storage.

5.3.3.2 Deciphering the mode of action of the short-listed isolate of *Trichoderma longibrachiatum*

In order to decipher the mode of action, *in silico* protein-protein interaction approach has been performed.

Serine protease protein sequences (total 7 sequences) have been retrieved from *T. longibrachiatum* protein dataset. Similarly target sequences (total 5 sequences) have been retrieved from the protein dataset of *Meloidogyne incognita*. Homology models have been developed for all the protein sequences to study protein-protein interactions. The serine proteases of *T. longibrachiatum* have shown high interaction with all the 5 protein sequences from the *Meloidogyne incognita*. Especially, the subtilisin-like protease with vitellogenin (docking score-25486) and actin (Docking score -18930). Wetlab validation is needed for confirming the interaction. Further, out of these seven serine proteases from *T. longibrachiatum* gene set 5 had shown high level homology with sequences in PHI-Base. Thus, the serine proteases involved in nematode antagonism as per *in silico*protein-protein interaction and homology search in PHI-Database. A tripartite interaction study may give more insights on the role of serine proteases in nematode antagonism.

5.3.3.3 Screening suitable fungal isolate for root-knot nematode management

Isolated fungal endophytes from brinjal roots and screened against root knot nematode. In total 4 fungus isolates namely Br/En/F1, Br/En/F2, Br/En/F3, Br/En/F4 have been isolated and screened against root-knot nematode. Preliminary bioassay results revealed Br/En/F1 exhibited 35% and 60% mortality @ 24 h and 48 h of incubation respectively, followed by Br/En/F3 which caused 28 and 51% mortality for the same period of incubation. While the other two isolates caused <40 % mortality @ 48 h of incubation.

5.3.4 Screening of crop varieties against various nematodes

Fifty five tomato accessions (IC collection s from ICAR-NBPGR, New Delhi) were screened and 54 breeding lines were screned ubder polyhouse cultivation against RKN (*M. incognita*), in *in vitro* on pluronic gel at different temperatures (26, 28, 30 & 32°C) and found some of the lines showing resistance with less or no galls. These lines are also in screening under protected cultivation conditions. Similarly, *M. graminicola* sick plot was developed and further strengthened. Advanced lines (180 in number) of wheat were obtained from division of Genetics, IARI for field evaluation against *M. graminicola*. Lines were sown in *M graminicola* infested field (sick plot) and were evaluated against *M. graminicola* following the standard procedures and protocols in use. Numbers of galls were determined and accordingly plants were rated for their reactions. Out of 180 wheat entries evaluated, only 12 entries showed the attack of *M. graminicola* and developed minute to small galls.

5.3.4.1 Nematode distribution map of Wellington using GIS

The case study was conducted in ICAR-IARI,RS Wellington farm (43.5 acres) to prepare "GIS based Nematode distribution map" using ArcGIS software through basic krigging principle for three seasons. The analysis showed that the abundance of total nematode was higher in summer (861/100cc soil) followed by winter (535/100cc soil) and rainy (183/100cc soil) season. However, the percentage of plant parasitic nematode was high in winter (59%) than in summer (48%) and rainy (34%) season and the percentage of bacterial feeding (40%) and fungal feeding nematodes (16%) were found high in rainy period. The high share of PPN was attributed to presence of susceptible winter crop and or weeds, low soil moisture content, sunny day time and adaptation of nematodes to low temperature and high altitude. This kind of visual depiction when extends to a large area, helps to demarcate the hotspots of potential nematodes and aid in providing a sustainable nematode management in different cropping systems.

5.4 AGRICULTURAL CHEMICALS

5.4.1. Development of active molecules for crop protection

5.4.1.1. Synthesis and bioefficacy evaluation of aldimines against *Rhizoctonia solani*

Pre-assessment of expected antifungal potential of aldimines using important parameters *viz*. molecular

weight, hydrophobicity, H-bond donor, H-bond acceptor, rotating bond and aromatic bond was conducted. Series of 15 aldimines was synthesised by reacting aromatic aldehydes with aromatic amines in methanol. Synthesized aldimines were evaluated (*in-vitro*) for their antifungal activity against *Rhizoctonia solani,* responsible for causing banded leaf and sheath blight disease in maize. The synthesized compounds demonstrated 30-100% inhibition of test fungal growth at 500 ppm concentration. The variation could be attributed to the structural differences among synthesized aldimines because of the presence of various substituents attached to the aromatic rings of the test compounds. The compounds will be screened at lower concentrations.

5.4.1.2 Synthesis and bioefficacy evaluation of chromone derivatives against *Sclerotium rolfsii*

A series of 21 imidazolyl chromones were synthesized by condensation of 2-hydroxy acetophen one derivatives with dimethyl formamide dimethyl acetal afforded enaminones that were cyclized to corresponding 3-iodochromones. The treatment of 3-iodochromones with imidazole in the presence of potassium carbonate gave 2-(1-imidazoly1) chromones. Synthesized compounds were characterized by spectroscopic techniques (^{1}HNMR and ^{13}CNMR and FTIR). *In vitro* screening of imidazolyl chromones against *Sclerotium rolfsii* (ITCC 6474), causing stem rot in tomato, showed good activity and 6,8-Dichloro-2-imidazol-1-yl-chromen-4-one (6r) was the most active (ED_{50} = 8.78 ppm) compound. This compound will be tested for other fungi and *in vivo* evaluation for *S. rolfsii* will be carried out.

5.4.1.3. Essential oils- chemoprofiling and bioactivity assessment

Chemo-profiling and characterization of essential oil and bioactive compounds from *Pogostemon cablin* leaves: Essential oil hydro distilled from leaves of *P. cablin*, collected from Hirisave village (12.9172° N, 76.4563° E), Hassan, Karnataka, during the month of April, 2019, yielded essential oil 1.43% (v/w, fresh wt. basis). GC-MS analysis chromatogram indicated that sesquiterpenes (97.37%), sesquiterpene hydrocarbons (55.87%) and oxygenated sesquiterpenes (41.50%) were the major constituents. Patchouli alcohol (38.67%) was found to be the major sesquiterpene followed by α-bulnesene (18.05%) and α-guaiene (17.69%). Sequential extraction of leaves using hexane, dichlromethane, ethyl acetate, methanol and water resulted in respective yield of 9.66, 6.12, 7.44, 8.82 and 5.6%. GC-MS analysis of hexane extract revealed presence of patchouli alcohol (30.54%), α-guaiene (12.37%) and seychellene (9.68%). Extraction protocol was standardized using three factors at three levels using Box-Behnken response surface methodology to achieve highest extraction yields and patchouli alcohol content (%). UPLC-QTOF-ESI-MS analysis of methanolic extract afforded identification of 13 phytochemicals (salicylic acid, vanillic acid, cinnamic acid, kaempferol-3,7-O,O-diglucoside, luteolin-7-O-glucoside, apigenin-7-O-glucoside, dihydroxy-dimethoxy flavone, apigenin, ombuin, pachypodol, patchouli alcohol, pogostone and hydroxy-3,4,7-trimethoxy flavone) show chromatogram and in box show the chemotyping results.

Nematicidal activity of *Annona squamosal* extracts and essential oils : The citronella oil, geranium oil and extract of *Annona squamosa* and their different combinations were evaluated for their nematicidal activity against J2s of *Melodogyne graminicola* and *M. incognita* in *in-vitro* bioassay. In this assay, all the test solutions showed promising mortality of the J2s of both, *M.graminicola* and *M. incognita*. The mortality of the J2s was found to be concentration dependent. The combination of citronella oil+*Annona squamosa* methanol extract+*Annona squamosa* hexane extract (LC_{50}=13.692) was found more efficacious against *M.graminicola* followed by *Annona squamosa* methanol +*Annona squamosa* hexane extracts (LC_{50}=21.207 ppm), geranium oil+*Annona squamosa* methanol +*Annona squamosa* hexane extracts (LC_{50}=21.778 ppm), Geranium oil+*Annona squamosa* hexane extract (LC_{50}=21.778 ppm) and others. Similarly, Geranium oil+*Annona squamosa* methanol+*Annona squamosa* hexane extracts (LC_{50}=8.0 87 ppm) was found more

efficient against *M.incognita* followed by *Annona squamosa* methanolic extract (LC_{50}=10.564 ppm), *Annona squamosa* methanol+*Annona squamosa* hexane extracts (LC_{50}=11.519 ppm), citronella oil+*Annona squamosa* methanol+*Annona squamosa* hexane extracts (LC_{50}=11.621ppm), geranium oil+*Annona squamosa* hexane extract(LC_{50}=12.161ppm), Citronella oil+*Annona squamosa* hexane extract (LC_{50}=14.118ppm), Citronella oil+Geranium oil (LC_{50}=15.435ppm) and others. The efficacies of many of the test solutions showed better or similar as well as lesser than carbofuran and velum prime, used as control. The pot experiment and field trials of test solutions will be carried out in rice and brinjal.

Mode of action assisted essential oil (EO) selection as nematicidal active principles: Nematicidal bioassay of nine EOs namely, *Citrus sinensis* (OEO), *Myrtus communis* (MTEO), *Eucalyptus citriodora* (CEO), *Melaleuca alternifolia*(TEO), *Acorus calamus* (AEO), *Commiphora myrrha* (MREO), *Cymbopogon nardus* (CNEO), *Artemisia absinthium* (WEO) and *Pogostemon cablin* (PEO) against J2s of *Meloidogyne incognita* revealed OEO, CNEO and TEO as most effective with LC_{50} 39.37, 43.22 and 76.28 µg mL^{-1}, respectively after 72h exposure. The EOs were found having varying compositions of mono- and sesquiterpenes in Gas Chromatography-Mass Spectrometry (GC-MS) analysis. *In silico* screening of molecular interactions of major EO constituents with seven target proteins of the nematode revealed highest binding affinity of geraniol-ODR1 (Odorant Response Gene 1) complex (ΔG =-36.9 kcal mol^{-1}), due to three H-bonding (distance ~ 2 Å) and three hydrophobic and π-alkyl interactions. The intensity of binding affinity followed the order: geraniol-ODR1 >*β*-terpineol-ODR1 > citronellal-ODR1 >*l*-limonene-ODR1 >*γ*-terpinene-ODR1. Taken together, this study provided useful leads on potential of OEO and CNEO as bionematicides.

Evaluation of mustard essential oil (MEO) against pests and diseases of tomato crop: Bioactivity of essential oil of Indian black mustard (*Brassica nigra* L.) was tested against two important pests of tomato namely *Meloidogyne incognita* and *Fusarium oxysporum*. *In vitro* bioassay results suggested that at as low as 1 ppm concentration of MEO, 23% of treated root knot nematodes showed immobilization effect within 6 h of treatment.

The immobilization effect increased up to 73, 82 and 93% at 2.5, 5 and 10 ppm concentration, respectively. Fluorescent microscopy suggested penetration of oil into nematode body. Study also revealed that though the nematodes survived the low dose treatment shock, but only 13% of the treated nematode has re-infectivity potential.

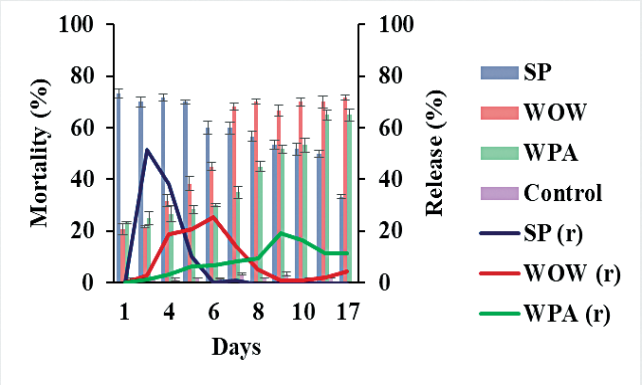
Against *Fusarium*, the MEO showed 100% inhibition of mycelial growth at 25 ppm concentration by poison food technique as compared to commercial formulation Nativo (Tubeconazole 50% + Trifloxystrobin 25%) that showed only 58.7% inhibition in mycelial growth at 1000 ppm concentration. Antibacterial activity of MEO was tested against the bacterial pathogen *Ralstonia solancearum* inciting bacterial wilt of tomato. In poisoned food assay, MEO at 125 ppm showed 100% inhibition in bacterial growth. Further, in volatility assay 100% inhibition in bacterial growth was observed at 50 ppm concentration.

5.4.2. Development of formulations for smart delivery of crop protection inputs

5.4.2.1. Hybrid biopolymeric composite for encapsulation of acetamiprid and its controlled release

Previously, two biopolymers namely, gum arabic and chitosan were selected to encapsulate acetamiprid by a W/O/W double emulsion technique using neem oil. Stability of the emulsion was studied according to CIPAC method (MT 36.1). The study suggested spontaneous emulsification that was stable up to 24 h. The study also demonstrated immidiate release of neem oil. The controlled release property of acetamiprid from the prepared formulation was improved by coating 2% palmitic acid (PA) on the surface of chitosan colloidosome and by solidification of the final formulation. The prepared formulation was characterized using FT-IR, which confirmed formation of amide linkages between the two biopolymers. The average diameter

of the microspheres dispersed in water was around 635 nm with D_{50} and D_{90} values of 409 nm and 1225 nm, respectively. *In vitro* bioassay against white fly suggested that as compared to immediate knockdown (~70% mortality) of commercial SP formulation, the prepared controlled release formulation had executed 25% mortality for first 4 days, which gradually increased to 30, 35, 45, 50 and 65% on 6th, 7th, 8th, 9th, and 16th day, respectively, indicating controlled release. The prepared formulation can be used as an effective controlled release



Release kinetics and bioactivity of prepared formulations (SP = commercial soluble powder formulation; WOW = water in oil in water formulation; WPA = W/O/W formulation with palmitic acid)

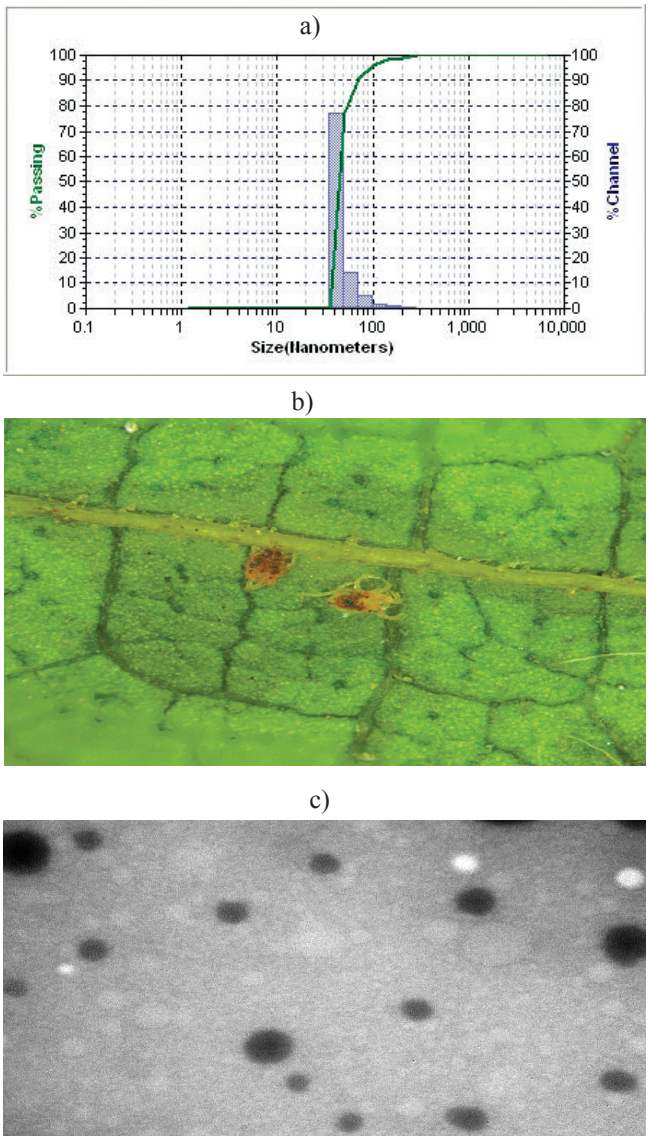
formulation against white fly.

5.4.2.2 Nanoemulsions and acaricial activity of phyto constituents of *Pogostemon cablin*

Essential oil and hexane extract of *P. cablin* were formulated to prepare coarse emulsions (CEs, 1%), further ultrasound assisted emulsification of CEs for 20 min with amplitude of 50 Hz. resulted respective nanoemulsions (NEs). The NEs were characterized for emulsion stability, particle size distribution, poly dispersity index (PDI), TEM for morphology and average droplet diameter. EO-NE $_{Tween\ 80}$ and HE-NE $_{Tween\ 80}$ at 500 µgmL $^{-1}$ concentration exhibited average particle size of 51.7 and 89.9 nm, while, TEM analysis revealed spherical shaped droplets with minimum diameter of 15.3 nm 29.4 nm, respectively. *In vitro* acaricidal activity of EO-NE $_{Tween\ 80}$ and HE-NE $_{Tween\ 80}$ against female adults of *Tetranychusurticae* revealed lethal concentration (LC_{50}) 133.9 and 103.9 µgmL $^{-1}$ after 48 h exposure, respectively.

5.4.2.3. Premix suspension concentrate formulation of tebuconazole and chlormequat chloride (CCC)

A novel premix suspension concentrates formulation (TCS) of CCC and Tebuconazole was developed after due standardization of auxiliaries' composition using suspensibility analysis. Concentration levels of both the auxiliaries were found effective in making a stable formulation were (5.1-5.8%) for surfactant and (0.28-0.5%) for thickener respectively. The active



Preparation, characterization and acaricidal activity of EO-NE $_{Tween\ 80}$ a) average particle size distribution in zeitasizer b) Morphology and droplet diameter as visualized in TEM c) representative plate showing mortality of *T. urticae*

ingredient load in the final SC formulation was (CCC+ Tebuconazole, 40-60%+7.5-15%) SC. The formulation passed all the physicochemical tests prescribed by CIPAC for SC formulation and was found stable under accelerated storage conditions for 14 days and at 0°C for 7 days. The prepared formulation registered superior bio efficacy results in pot (50 and 19.7% reduction in plant height over control and tank mix, respectively) and field conditions (37 and 29.5% height reduction over control and tank mix, respectively). Study on CCC and Tebuconazole residues and persistence in grain and soil showed that after 60 days, ~98% dissipation was there for both the active ingredients. Half-life of CCC ranged from 10.56-12.33 days and that of tebuconazole from 9.8-11.58 days.

5.4.3. Standardization and validation of methods for detection/quantification of contaminants

5.4.3.1.Validation of method for analysis of mixture of contaminants in vegetables/fruits

A lab validated analytical method for detection of 140 pesticides was used for assessment of contaminants in cabbage, brinjal, bhindi, tomato, potato, cucumber, chilli, cauliflower, capsicum, apple and persimmon samples collected from different vegetable markets in Delhi and Himachal Pradesh. Samples were processed as per modified QuEChERS technique and analyzed. A total of 46 pesticides were detected in the selected samples and some of the pesticides were above the quantification limit of the instrument (0.01 µg/g). Most of the samples were found to contain some pesticides within their MRL limit. Since pesticides are inevitable for crop protection, their continuous monitoring in the food commodities is required to ensure consumer safety.

5.4.3.2. LC-MS/MS method for trace level analysis of pesticides in water and evaluation of ground water quality

A method involving sample processing using liquid-liquid extraction (LLE) technique and analysis using LC-MS/MS for simultaneous identification and quantification of 140 pesticides (72 insecticides, 28 fungicides, 40 herbicides), at ppb levels, under Electrospray Ionization (ESI) in +/-ve mode in 20 minutes run was developed using Shimadzu LCMS/MS-8030. Study on effect of pH on extraction of pesticides revealed that 55, 70 and 52% of pesticides showed acceptable recovery (70-120%) and repeatability (RSD ≤20%) at pH 4, 7 and 9, respectively. The developed method with mass confirmation technique is effective in detecting and quantifying the trace level residues of 140 presently used pesticides in water. The method was used for evaluation of water quality from 12 deep tubewells used as irrigation source of iari and it was observed that around 10 to 35 pesticides were detected with varying concentration in different parts of iari. bitertenol, chlorantraliprole, chlorpyriphos methyl, chlorpyrifos, cyphenothrin, diclofop-methyl, esfenvalerate, hexachloro-cyclopentadiene, hexaconazole, imidacloprid, kresoxim methyl, metolachlor, metribuzin, quizalofop ethyl, resmethrin, tebuconazole, transfluthrin and fipronil were detected in the range of below quantification level to 1.37 µg/L. Cumulative pesticide load of pesticide contamination in deep tube wells ranged upto 4.63 µg/L. Periodic monitoring of ground water quality with respect to toxic pesticide residues, especially, in areas where ground water is used for drinking purpose, may help in ascertaining the safety of water to the consumers.

5.4.3.3. Screening of pesticides by LC-MS/MS

A multiresidue method based on modified QuEChERS and LC-MS/MS developed for soil matrix was used for evaluation of quality and health of soils of IARI fields. Soils of 12 different locations across IARI were contaminated with 3 to 8 different pesticides present in the concentration range of 0.01 to 0.55 µg/g. The soils were found to be contaminated with acephate, alachlor, butachlor, carbendazim, chlorpyrifos, cyphenothrin, fenarimol, fenazaquin, fenvalerate, hexaconazole, isopropalin, metolachlor and tebuconazole. Cumulative pesticide load of pesticide contamination in soils ranged upto 0.85 µg/g. Systematic monitoring of pesticide residues in soils of intensively cultivated land is required to determine the safety of the food grain and to ensure soil health from toxic residue point of view.

5.4.3.4. Method development of simultaneous detection of monomers/cross-linkers in crop and soil

LC-MS/MS method was developed for simultaneous detection and quantification of acrylamide, N,N'-methylene-bis-acylamide and acrylic acid in a single run of 5 minutes using LC-MS/MS. Extraction cleanup protocols of the above-mentioned monomers/cross-linker was standardized in plant matrix. The recovery for acrylamide, N,N'-methylene-bis-acylamide and acrylic acid were 44.91, 115.52 and 111.79%, respectively. The instrumental LOD was <0.005 ppm and instrumental LOQ was <0.01 ppm. The method was used for estimation of monomers/cross-linker wheat and ground nut crop, foliage and cropped soil grown using Pusa Hydrogel and its improved variant (SPG 1118). None of the produce or soils were detected with monomers/cross-linker at harvest stage.

5.4.3.5. Colorimetric detection techniques for pesticides in vegetables

Azastilbenes has maximum absorption at 340 nm. When excited at 340 nm, the compound gave emission maxima at 460 nm with a Stock shift of 120 nm. It was found that there is a fluorescence quenching of the chromogenic reagent for pesticides namely edifenphos, quinalphos, dimethoate, imidacloprid and acetamiprid except for λ-cyhalothrin when the concentration gradually increases. The linearity was observed in the range of 0.6-30 µg/ml. The fluorescence was inversely proportional to pesticide concentration. The binding affinity of the pesticides followed the order edifenphos > dimethoate > Imidacloprid > acetamiprid > quinalphos. To find out the applicability of the method for detection of pesticides in cabbage, the sample was extracted and fortified by following standard addition method. The data also followed linearity of fluorescence intensity with pesticide concentration, but the vegetable sample requires matrix matched standard calibration curve for the estimation of pesticides. The chemo sensordid not show any specificity to the chemical group of pesticides.

5.4.4 Management and assessment of contaminants in agricultural commodities and environment

5.4.4.1 Effect of sugarcane trash ash (STA) on pesticides fate in soils

Incubation study on effect of sugarcane trash ash (STA) on fate of fipronil and atrazine, two soil-applied sugarcane pesticides in three soils *viz*., silty clay loam, sandy clay loam and loam from the sugarcane growing region revealed that STA (0.1, 0.2%) enhanced sorption of fipronil in all the three soils, but effect varied with the nature of soil and level of the STA mixed. The Freundlich adsorption coefficient (K_f) values in the control, 0.1% and 0.2% STA-mixed soils were: 1.66, 4.09 and 6.54 (sandy clay loam); 1.94, 2.36 and 2.63 (silty clay loam); 2.37, 5.75 and 5.68 (loam). The K_f values for atrazine in the control, 0.1% and 0.2% STA-mixed soils were: 1.49, 2.16 and 319 (silty clay loam); 2.01, 2.41 and 3.24 (sandy clay loam); 2.68, 2.93 and 3.78 (loam). Leaching studies indicated that the STA resulted in higher retention of atrazine in the 0-5 cm profile. Compared to atrazine, fipronil was fairly immobile in all three soils and pesticide was retained in the surface layer in the control and the STA-mixed soils. Degradation studies suggested that the effect of STA on atrazine and fipronil degradation was statistically insignificant, both in laboratory and field studies.The STA's effect on availability of atrazine (studied by its effect on mustard seedling, a sensitive plant) suggested that the STA reduced herbicide availability and effect can be attributed to higher adsorption of atrazine in the STA-soil mixtures. Higher amount of atrazine was required in the STA-mixed soil to have effect similar to the effect in the control (no ash) soil on mustard seedling.

5.4.4.2. Decontamination studies of pre-mix pesticides in/on Chilli

Field trials were conducted in the fields of ICAR-IARI, New Delhi for the decontamination studies of ethion, profenofos, quinalphos, λ-cyhalothrin, imidacloprid, acetamiprid in/on green chilli (var.

Hybrid NS1701). The crop was sprayed with pre-mix formulations [Mit-505, 50EC, Vazra, 25EC, Rocket, 40EC, Karate, 5EC, Lift; 20SP, Iota-300, 17.8 SL] at fruiting stage at doses @ 2000, 500, 1000, 30, 40 and 100 g a.i./ha. respectively. Samples of green chilli were collected after 48 h of application and decontamination studies were conducted. Washing with warm water could dislodge ~60% of imidacloprid and acetamiprid while washing with $KMnO_4$ was found effective for quinalphos and profenophos. None of the method was found effective for ethion and maximum 22.7% reduction was observed with 5% NaCl solution. The study was conducted under AINP on pesticide residues and is a part of multi-laboratory validation experiment to find simple method for decontamination of pesticide residues from vegetables.

5.4.4.3. Chitosan based magnetic molecularly imprinted polymer for selective detection of tricyclazole

Tricyclazole selective chitosan/Fe_3O_4 magnetic molecularly imprinted polymer (MMIP) was synthesized and characterized. The adsorption equilibrium was achieved in 30 min and the maximum binding capacity observed was 4579.9 µg/g. The Freundlich isotherm model was found suitable for explaining the binding isotherm data (R^2> 0.99). Negative values of thermodynamic parameters ΔG (Gibb's free energy), ΔH (enthalpy), and ΔS (entropy) revealed exothermic and spontaneous nature of adsorption processes. The scat chard plot analysis suggested heterogeneity of binding sites on MMIPs. The molecular recognition selectivity of MMIPs towards tricyclazole was much higher, as compared to its structural analogues, tebuconazole (α = 28.58) and hexaconazole (α = 37.16). The MMIPs were successfully applied to separate and enrich tricyclazole from fortified samples of rice and water, with a recovery percentage of 89.4 and 90.9%, respectively. These reusable imprinted polymers possessing high selectivity and specificity can be utilized as an adsorbent for solid-phase extraction in sample preparation for tricyclazole residue analysis in complex environmental matrices.

5.4.4.4. Assessment of leaching potential of antibiotics in sandy loam soil

Sorption behaviour of sulfamethazine and sulfamethoxazole was investigated in sandy loam soil of Delhi. It was found that when the soil pH is in the alkaline range, both the antibiotics exhibit moderate to high leaching potential (GUS values above 1.8) in sandy loam soil. So these antibiotics need to be used judiciously in order to prevent the ground water pollution.

5.4.4.5. Synthesis of dual-purpose nano metal oxide

TiO_2 and TiO_2 – ZnO hybrid nanoparticles were developed by a new, specific and economical sol-gel process. The prepared sensor probe materials exhibited excellent performance in terms of high sensitivity, good stability, wide linearity over response range, relatively short response time, as well as, remarkable photocatalytic pesticide residue degradation efficiency (UV/ZnO/TiO2 (84.2%)> UV/TiO2 (64.9%)> UV/ZnO (33.3%)). The point of zero charge pH of the hybrid materials was identified to understand the mechanism of photocatalysis of imidacloprid residues in aqueous conditions. The synthesized hybrid nanoparticles' sizes lay in the range of 100-130 nm.

5.4.4.6. Magnetic biochar for pesticide mixture decontamination

Magnetic biochars were synthesized using four agro-waste residues, e.g., rice straw, wheat straw, rice husk and corn cob and their characteristics were investigated. They were used to efficiently and economically remove residues of atrazine, imidacloprid and azoxystrobin (1–20 ppm). Results suggest that the sorption capacity of the magnetized biochar for atrazine significantly decreased in the presence of imidacloprid and azoxystrobin in a binary and ternary solutions, respectively. Atrazine sorption at ≈1 µg/mL single solute system decreased 40% in the presence of imidacloprid (≈1 µg/mL) in binary system. Effect of co-solutes' presence on pesticide sorption was much more at higher pesticide concentration.

5.4.4.7. Hybrid algorithms for pesticide removal optimization

Hybrid prediction models, ANN-SVR, ARIMA-X-SVR, ANN-ARIMA-X were validated for the optimization of biochar-based pesticide removal from water. Validation results showed that ANN-SVR performed as the best prediction model for the optimization of atrazine sorption using biochars. This hybrid prediction model may be used for accurate prediction of pesticide removal using high carbon amorphous materials as sorbents.

5.5 WEED MANAGEMENT

5.5.1 Weed management practices influences soil physical properties under long-term conservation agriculture-based rice-wheat system

A long-term CA-based rice-wheat system is being undertaken for last 10 years. Different weed management options including herbicides were used. After two years of continuous application of herbicides in rice (two seasons) and wheat (two seasons) in fixed plots, it was observed that herbicide treatment, namely, pyrazosulfuron-ethyl 0.025 kg/ha at 1 day after sowing (DAS) followed by (fb) cyhalofop-butyl 0.100 kg/ha at 20 DAS fb bispyribac-Na 0.025 kg/ha at 25 DAS applied to rice, and the tank-mixture of clodinafop-propargyl 0.060 kg/ha + carfentrazone-ethyl 0.02 kg/ha at 30 DAS applied to wheat could reduce weeds significantly in both crops. Soil physical properties studied after two cycles of rice-wheat system revealed that the mean weight diameter was higher, while bulk density was lower under the un-weeded control than the herbicide-treated plots. This indicates that herbicide treatment can lead to deteriorate these soil physical properties. Further investigation may validate this more.

5.5.2 Effective weed management in wheat under a CA-based rice-wheat system

Weed management was studied in wheat under zero-till residue-laden conditions in a 10-year-old conservation agriculture (CA) based rice-wheat cropping system. Four weed control treatments were adopted. Results revealed that the tank mix application of clodinafop-propargyl 0.060 kg/ha + metsulfuron-methyl 0.004 kg/ha at 30 DAS was highly effective towards reducing weed dry weight and increasing weed control index and wheat yield. This herbicide treatment resulted in ~31% higher wheat yields over un-weeded control.

5.5.3 Evaluation of bio-efficacy and selectivity of new low dose herbicide in maize

Different weed control treatments caused significant reduction in total weed density and their dry weight as compared to weedy check, owing the complete elimination of weeds. Season long weed free situation resulted the highest increase in grain yield over weedy check. Tank mix pre-emergence application of atrazine

Effect of weed management on weeds in wheat under CA-based rice-wheat system.

Treatments	Total weed dry weight (g/m^2)	Weed control index (%)	Wheat yield (t/ha)
Un-weeded control	11.35‡	-	4.87
Ready-mix of sulfosulfuron + metsulfuron-methyl @ 0.040 kg/ha (product) 30 DAS	6.08	71.4	5.97
Tank-mixture of clodinafop-propargyl 0.060 kg/ha + metsulfuron-methyl 0.004 kg/ha 30 DAS	2.88	93.9	6.40 (~31%)
Tank-mixture of clodinafop-propargyl 0.060 kg/ha + carfentrazone-ethyl 0.02 kg/ha 30 DAS	3.97	87.9	6.21
LSD(P ≤0.05)	0.54	-	0.27

‡Transformed data through square-root $(x+0.5)^{½}$ method before analysis of variance (ANOVA)

Effect of weed control treatments on weeds and grain yield of maize

Treatments	Weeds (No. /0.25 m²) at 90 DAS	Weeds dry weight (g /0.25 m²) at 90 DAS	Grain yield (t/ha)	Weed index (%)
Atrazine @ 1000 g/ha Pre-emergence	7.36	4.37	4.30	13.48
Pendimethalin @ 1000 g/ha Pre-em.	8.27	4.55	4.21	15.29
Atrazine + pendimethalin @ 500 + 750 g/ha Pre-em.	5.91	3.55	4.78	3.82
Tembotrione @ 120 g/ha at 15 DAS	4.89	2.88	4.75	4.43
Tembotrione @ 180 g/ha at 30 DAS	10.47	5.41	4.19	15.69
1 Hand weeding at 30 DAS	8.77	5.01	4.39	11.67
Weedy check	13.47	6.65	1.73	65.19
Weed Free	1.00	1.00	4.97	-----
Sem.	0.40	0.36	0.15	------
LSD (P=0.05)	1.23	1.09	0.47	-------

and pendimethalin (0.5+ 0.75 kg/ha) and early post-emergence application (15 DAS) of Tembotrione at 120 g/ha were found superior treatments in reducing weeds infestation and in increasing grain yield of maize. Alone pre-emergence application of atrazine (1000 g/ha) and pendimethalin (1000 g/ha) were found equally effective in managing weeds in early stages but inferior to their tank mix application and alone tembotrione (120 g/ha) application at 15 DAS. Weeds suppression through one manual weeding at 30 DAS was not found sufficient to realize potential maize grain yield.

5.5.4 Conservation agriculture-based weed management options for pigeonpea–wheat cropping system

Zero tillage along with residue retention 3 ton/ha in pigeonpea and wheat resulted in highest weed control efficiency, which was 19.28 and 23.61% higher over zero and conventional tillage, respectively. Significantly highest system productivity in terms of pigeonpea grain equivalent yield (3.56 t/ha) was also recorded with zero tillage+residue 3 t/ha. However, highest net B: C ratio (1.48) was obtained under zero tillage followed by zero tillage+ residue 3 t/ha (1.46). Two hand weeding recorded maximum weed control efficiency (78.28%) and system productivity in terms of pigeonpea equivalent yield (3.60 t/ha). However, pre-emergence application of pendimethalin 1.0 kg/ha fb Imazethapyr 60 g/ha at 30 days after sowing in pigeonpea and pinoxaden 50 g/ha fb metsulfuron 5 g (seq. appl.) at 30 DAS in wheat recorded highest net returns and B: C ratio followed by pendimethalin 1.0 kg/ha *fb* one hand weeding at 30 days after sowing in pigeonpea and pinoxaden 50 g/ha+metsulfuron 5 g/ha (Tank mix) at 30 DAS in wheat.

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 nutritional quality of pearl millet, rice, wheat 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

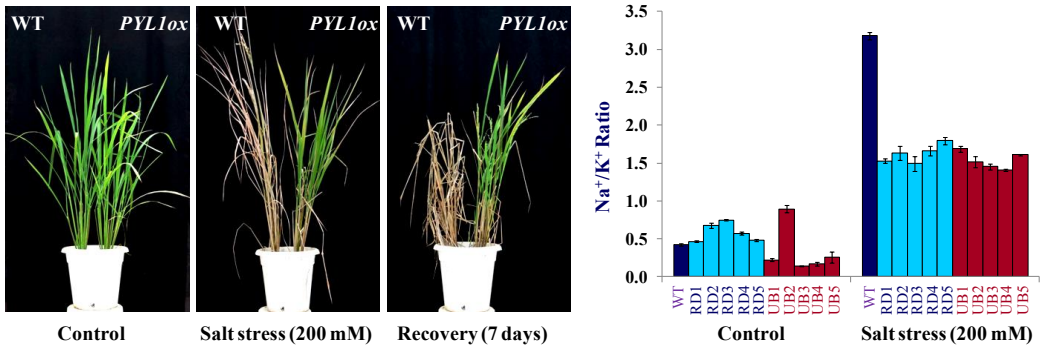
6.1.1 Genetic engineering and genome editing

6.1.1.1. ABA receptor *PYL1* positively regulates abiotic stress tolerance in rice

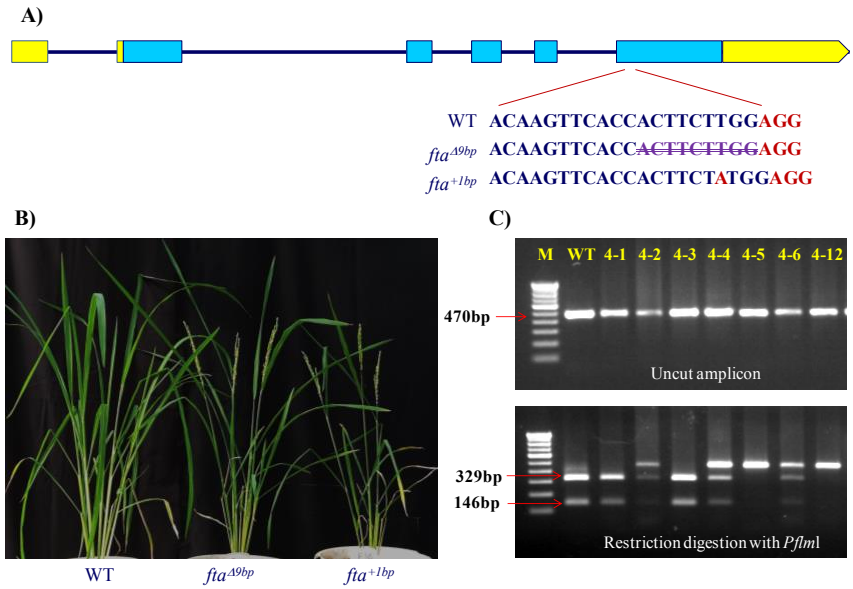
Abscisic acid (ABA) is a key regulator of plant development and stress tolerance. Rice genome encodes at least 11 functional receptors. Transgenic rice cv. MTU1010 over expressing one of the rice ABA receptors, *Pyrabactin Resistance-Like 1* (*PYL1*) was developed to understand its role. Stress-inducible and constitutive over expression of *OsPYL1* conferred enhanced chlorophyll retention in leaf disc assay and seedling survival under PEG and NaCl stresses. *OsPYL1* over expression conferred enhanced tolerance to drought and salt (NaCl 200 mM) stresses at vegetative stage. Although the over expression of OsPYL1 minimized the reduction in the results showed that *OsPYL1* is a key regulator of development and stress tolerance, and fine-tuning of its expression is critical for improving yield and stress tolerance in rice.

6.1.1.2. Gene editing reveals the role of protein farnesylation in rice plant development

Protein farnesylation has been reported to play important role in plant development and ABA signaling mediated stomatal closure and stress tolerance in Arabidopsis. To understand the role of protein farnesylation in rice, CRISPR-Cas9 system was employed to develop gene edited mutants of farnesyltransferase alpha subunit (*FTA*) gene in rice cv. MTU1010. Two different mutant alleles *viz*., 9 bp deletion (fta^{9bp}) and one bp insertion (fta^{+1bp}) in the 5th exon of *FTA* gene were generated, and confirmed by sequencing and CAPS marker. The fta^{9bp} led to in-frame deletion of three amino acids, while fta^{+1bp} caused a frame shift leading to premature termination of the



ABA receptor *OsPYL1* overexpression confers salt tolerance to rice cv. MTU1010. WT, Non-transgenic plant; PYL1ox, transgenic line overexpressing PYL1 under maize Ubiquitin promoterRD1-5, Trans genies expression PYL1 from Stress ? Promoter: UB1-5 Tragenic exprssing PYL1 from constitute promoter ?



Protein farnesyl transferase type-1 alpha subunit (*FTA*) loss of function mutation causes early flowering

protein with only 211 amino acids as compared with 339 amino acid in WT protein. Interestingly, both the mutants showed enhanced sensitivity to ABA during germination, suggesting a conserved function of *FTA* between rice and Arabidopsis. Further, *fta* mutants showed reduced height and flowered about 2 weeks early as compared with WT plants. These results showed the importance of protein farnesylation in ABA signaling and plant development.

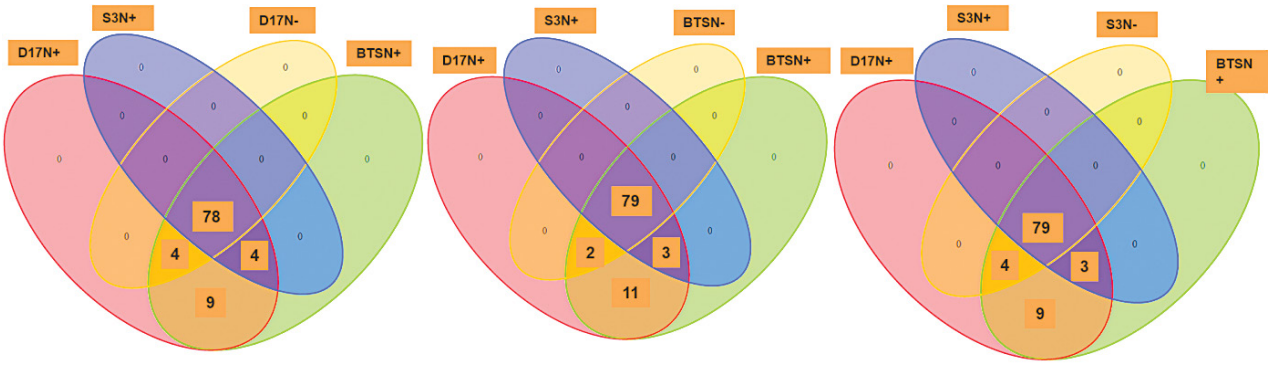
6.1.2. Genomics and gene discovery

6.1.2.1 Cap binding protein 20 (CBP20) regulates miRNA biogenesis in rice

For gene functional validation of *OsCBP20* in micro RNA biogenesis pathway, rice transgenics constitutively overexpressing *CBP20* were developed. There different overexpression line were analysed by transcriptome sequencing. Differentially expressed genes (DEGs) between WT and *CBP20* overexpression lines were identified. miRNAs with a potential to regulate upregulated and highly downregulated DEGs were identified. qRT-PCR validation showed that all five upregulated (Chlorophyll A-B binding protein, FAD dependent oxidoreductase, Expressed protein, protochlorophyllide reductase A and DUF26 kinases) and highly downregulated (SCP-like protein, pathogenesis-related Bet v I family protein, dehydrogenase, cytochrome P450 and AMP-binding protein) DEGs confirmed the RNAseq results. Further, in the *CBP20* overexpression lines, expression levels of miRNAs that potentially target the DEGs were analysed by using qRT-PCR. As compared with target miRNAs, miRNAs showed anti-correlated expression pattern in *CBP20* overexpression lines. This suggests the role of CBP20 in biogenesis of these selected miRNAs in rice.

6.1.2.2 Nitrogen deficiency stress regulated miRNAs and their potential targets in wheat

Forty-one wheat genotypes including bread wheat, synthetic hexaploid, Indian dwarf wheat and emmer wheat were screened for NUE in the field. From this 8 contrasting genotypes were selected and grown in hydroponics for 30 days where seedling stage NUE and N deficiency related traits were assessed. Three genotypes, BT-Schomburgk (BTS), *T. dicoccum* (D17), *T. sphaerococcum* (S3) were selected for miRNAseq analysis based on NUE, anthocyanin content and root traits. Approximately 100 miRNAs were found to be differentially regulated in response to N deficiency in these genotypes. Target genes of N deficiency regulated miRNAs were predicted. The targets belonging to different classes including kinases, N



Venn diagram of differentially expressed miRNAs in different libraries from three different wheat genotypes subjected to high (N+) and low (N-) N treatments. The numbers represent the number of differentially expressed miRNAs.

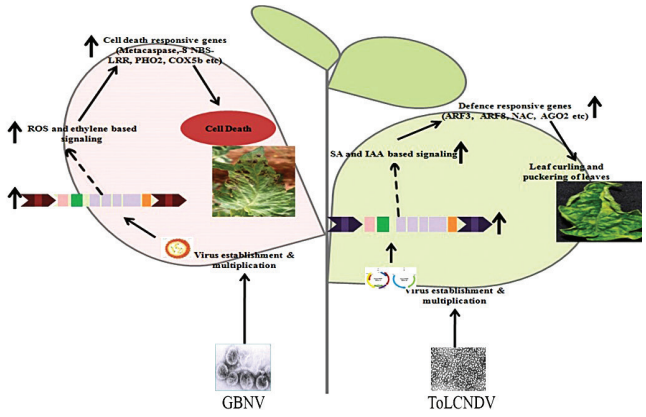
metabolism, secondary metabolism, dirigent proteins and transcription factors, suggesting reprogramming of whole cell metabolism. The results suggest that the members of identified wheat miRNAs and their targets could be a way forward towards genetic improvement of NUE in wheat.

6.1.2.3 Signalling cross talk between osmotic and nitrogen (N) deficiency stresses in wheat

In drought prone areas often, N is also used less, and thus imposing dual stress on the crop. Hence, regulation of genes for N responses under N starvation, osmotic and dual stress conditions in seedlings of a wheat mega variety HD2967 and drought tolerant check C306. The results revealed that HD2967 was more tolerant to short-term N starvation, osmotic stress (OS) and dual stress as compared with C306. Interestingly, it was found that N deficiency stress can also lead to accumulation of ABA in wheat seedlings. Real-time RT-qPCR analysis revealed that nitrate signalling genes (*TaCIPK8*, *TaCIPK23*, *TaNLP4*, *TaSPL9*, *TabHLH1* and *TaNAC4*), HATS gene *TaNRT2.1*, LATS genes (*TaNRT6.5* and *TaNPF7.1*), nitrate and ammonium assimilation genes were also upregulated by OS at least in one tissue of one of the genotypes. Dual stress was found to have significant interaction in regulation genes for nitrate signalling, uptake and assimilation. *TabZIP1* and *TaPIMP1* TF were identified as new players in low N response in wheat. Thus, OS and dual stress modulates the genes for N responses, and genotypic variation exists for this in wheat. Since ABA accumulation was found to be induced also by low N stress, the common pattern of regulation found for N response genes may probably regulated, at least in part, by ABA-dependent pathway.

6.1.2.4 Retro-transposon based gene regulation in tomato during viral infections

Activated retrotransposons, Tnt1 and Tto1, are known to oxidative homoeostasis and hormonal signalling in plant defense pathway. Both the retrotransposons were activated during GBNV (groundnut bud necrosis virus) and ToLCNDV (tomato leaf curl New Delhi virus) infections in tomato, while Tnt1 showed more activation. Similarly expression of programmed cell death (PCD) related genes (*metacaspase* 8, *PHO2*, *COX-5b*, *NBS-LRR*) increased during early stage of GBNV infection and subsequently decreased as necrosis started, suggesting possible co-relations. However, in case of ToLCNDV infection, both the retrotransposons Tnt1 and Tto1 showed similar pattern in activation. Activation of Tnt1 and Tto1 can possibly be co-related with the increased expression levels of genes involved in hormonal signalling like (Auxin Responsive Factors 3/8, NAC transcription factor and MAP kinase) and enzymatic responses involved in oxidative stress such as (CAT, POX, APX, GR and SOD) during ToLCNDV infection. As a host defense response, activation of retrotransposons modulates the expression of PCD responsive genes under GBNV infection and hormonal signaling genes under ToLCNDV infection leading to the necrosis and leaf curl disease, respectively.



Retrotransposons modulated stress responsive changes in phenotypic expression and molecular intermediates during GBNV (necrotic) and ToLCNDV (non-necrotic) infection in tomato plants

6.1.2.5 Epigenomics of drought acclimatization in rice

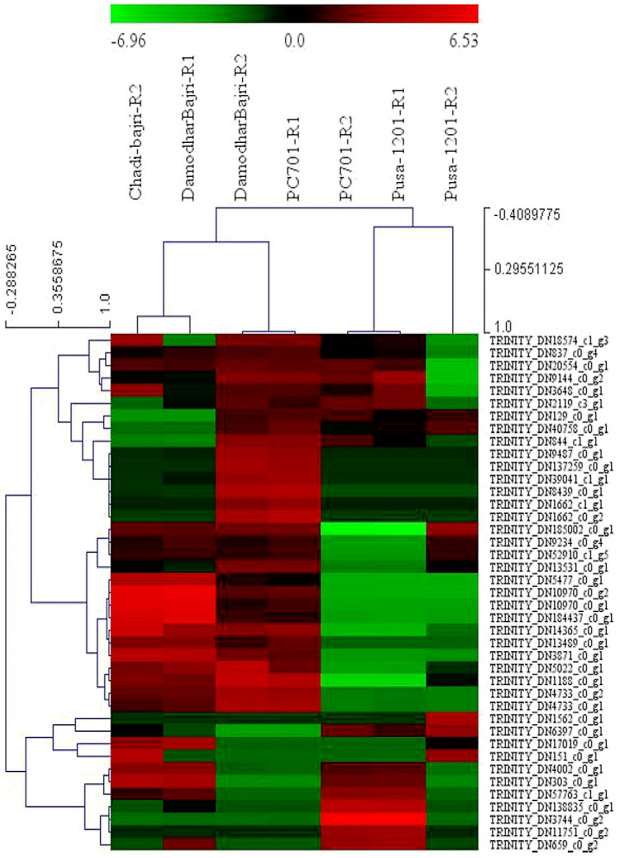
Methylome analysis of roots of the contrasting rice genotypes [Nagina-22 (N-22): drought tolerant, and IR-64: drought sensitive] subjected to reproductive stage drought stress revealed increase in methylation at CG and CHG contexts, while decrease in methylation at CHH context in N-22 as compared to that of IR-64. Further, methylome analysis indicated increased methylation at all the three contexts in the proximal promoter region of the drought tolerant genotype. To understand the effect of changes in DNA methylation in different parts of a gene on its expression, methylome and transcriptome data were analyzed using integrated genomics viewer. The findings confirmed that hypermethylation of promoter causes decreased expression of the gene, while hypomethylation causes increased expression of the gene.

6.1.2.6 Gene expression associated with phosphorus (P) starvation tolerance in rice

Transcriptome data of root and shoot from the contrasting rice cultivatores *viz.*, (Pusa-44 (P-deficiency sensitive) and NIL-23 (P-deficiency tolerant expressing pup 1QTL) genotypes at vegetative stage treated with control (16 ppm Pi) or 0 ppm Pi were analyzed. Comparative analysis of control vs treated shoot tissues of NIL-23 revealed 8515 differentially expressed genes (DEGs), including 5627 up-regulated and 2888 down-regulated. Gene ontology (GO) analysis revealed the enrichment of GO terms associated with metabolic processes, including carbohydrate, lipid, and N metabolism were enriched under the stress to improve nutritional status, energy supply, and cellular protection, particularly in NIL-23 (stress-tolerant genotype). Moreover, the GO terms for phosphorus metabolic process, transmembrane transport, and oxidation reduction were significantly enriched in roots of NIL-23.

6.1.2.7 PearlOmics to dissect candidate genes linked with pearl millet grain quality

To understand the nutritional and keeping quality of pearl millet, a nutri-cereal, *de novo* transcriptome sequencing of developing grains of diverse genotypes namely landraces (Chadi Bajri and Damodar Bajri), hybrid (Pusa-1201) and composite (Pusa composite-701) using Illumina HiSeq-4000 was performed. It was observed that 2623 upregulated and



Top ten differentially expressed gene features within each pairwise comparison based on genes identified in diverse genotypes of pearl millet

2078 downregulated genes in Pusa 1201 as compared to Chadi Bajri. Similarly, 2464 upregulated and 2289 downregulated genes were identified in Pusa 1201 as compared to Damodhar Bajri. Expression analysis of Pusa 1201 over Damodar Bajri showed 1895 upregulated and 1491 downregulated genes. Of these 19 transcripts identified were annotated to be for polyphenol oxidase (PPO), 52 transcripts for lipase, 47 for lipoxygenase and 75 for peroxidase genes. Also, 16 transcripts with homology with starch synthase, 23 with SBE, 8 with SDE, and 17 with AGPase were identified. The PearlOmics experiment was submitted as BioProject in NCBI database (PRJNA625418).

6.2 BIOCHEMISTRY

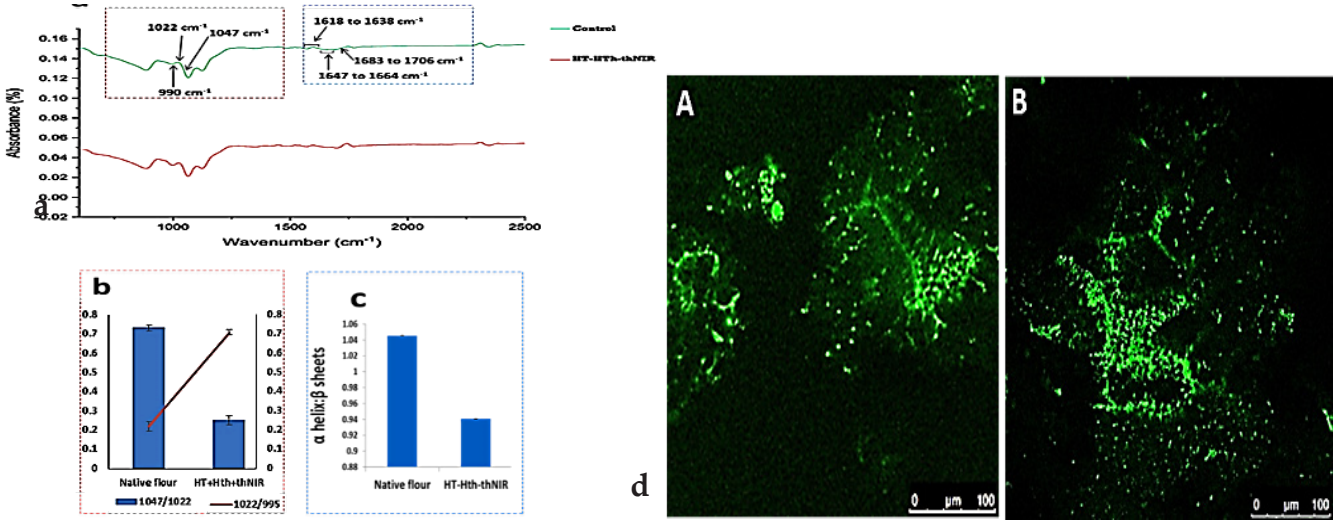
6.2.1 Pearl millet Biochemistry

6.2.1.1 An efficient hydrothermal and thermal-Near Infra-red treatments to limit the rancidity in pearl millet flour

The use of pearl millet is limited due to rancidity and off-odor development in the flour during storage. To solve this problem, an efficient processing technology with "hydro treatment (HT)-hydro thermal (HTh) and thermal near infrared rays (thNIR)" successive treatments was optimized, which was found to be highly effective in reducing the rancidity in pearl millet flour when stored up to 90 days at room temperature. (patent application No. 202011037363). fourier transfer infra-red spectroscopy (FTIR) for protein secondary structures (α-helix and β-sheets), which also regulate protein digestibility, showed non-significant decrease in the ratio of α-helices/β-sheets. Small changes in the ratios and total soluble protein content were also reflected in 1% reduction in protein digestibility. Kinetics of starch hydrolysis showed significant improvement in starch digestibility (upto 10%) in treated flour due to crystalline structure disruption of starch granule and it's packaging which can facilitate amylolytic enzyme attack on starch.

6.2.1.2 NIRS based nutritional profiling of diverse pearl millet germplasm

Near-infrared reflectance spectroscopy (NIRS) was used for evaluating 87 diverse pearl millet genotypes for starch, resistant starch, amylose, protein, oil, total dietary fibre, phenols, total soluble sugars and phytic acid to determine the nutritional diversity and functionality. The usefulness of the NIR models was determined by the RPD (ratio of performance deviation) values along with the R^2 values. Nine NIR models for protein, phenols, amylase, oil, resistant starch, total dietary, phytic acid, total soluble sugars and for starch were successfully developed.



Structural changes in protein and starch molecules: a) FTIR spectra of starch and proteins; b) ratios of 1047/1022 cm^{-1} and 1022/995 cm^{-1} denoting starch crystalline and amorphous region c) ratios of α helix/β sheets. d) Size of starch granules of native flour (A) and thermally treated flour (B) observed under confocal laser scanning microscopy

6.2.1.3 Nutritional superiority of pearl millet landraces

Four landraces of pearl millet (Jafarabadi, Chanana bajra-2, chadi bajri and damodarabajri) were compared for their rancid behavior and nutritional quality with the popular composite variety Dhanshakti. All the four landraces were observed to be less rancid with better keeping quality than Dhanshakti. The superior keeping quality is the lower content of unsaturated fatty acid (21 to 38%) which is more susceptible to oxidation. Linoleic acid, the main substrate for lipoxygenase enzyme, was 23 to 37% less in landraces than Dhanshakti. Due to less availability of the substrate, the LOX activity in landraces was also found to be lower (30-50%) than Dhanshakti. Besides low rancid behaviour, landraces are unique for their sweet in taste mainly due to high content of reducing sugar (2.27% in Jafarabadi) and high glycemic potential (77% in Jafarabadi). Amongst the four landraces, Jafarabadi, also showed higher amounts of Fe (56.66 ppm) and Zn (50 ppm).

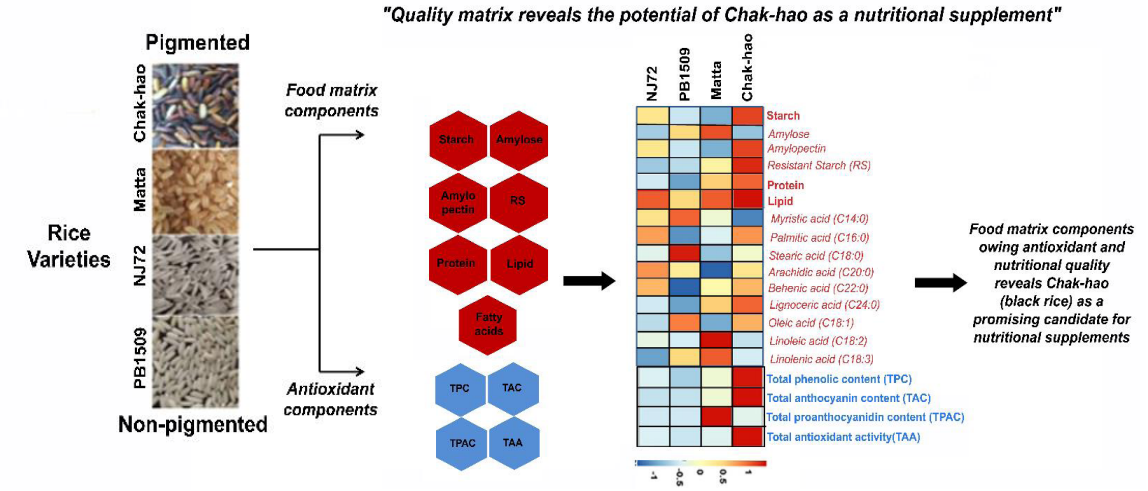
6.2.2 Rice Biochemistry

6.2.2.1 Tailoring the inherent glycemic potential of pigmented rice varieties

Inherent glycemic potential depends on starch bioavailability which is limited by endogenous or exogenous lipid content. The role of various cooking fat types (saturated and un-saturated) on the dynamics of starch hydrolysis in different rice types having varied resistant starch (RS) content under three different cooking conditions ('before', 'during' and 'after') were analysed. Minimal glycemic response was observed when cooking with rice bran oil in all rice varieties. The addition time of oil had a significant effect on white rice (WR) digestibility with 'after' being significantly different to 'before' and during ($P<0.05$). For red rice and black rice the oil added 'during' found the most significant decrease compared to 'before' and 'after'.

6.2.2.2 Chak-hao (black rice) as a nutritional supplement

To promote traditional niche rice varieties, their nutritional and nutraceutical benefits needs to be understood. A study evaluated the natural variability in the inherent matrix composition owing nutritional and antioxidant potential of pigmented niche rice varieties revealed *Chak-hao* (black rice) as a potential candidate. The comprehensive nutritional quality matrix (NQM) developed indicated that *Chak-hao* has stout nutritional makeup in terms of phenolics (2.5 mg/g GAE), anthocyanins (0.65 g/kg), proanthocyanidins (54 mg/100g), antioxidant activity (36 µmol TE/g) and resistant starch (4.13%). The content of high-quality fatty acids like oleic (38.8%), linoleic (29%), and anthocyanin forms like cyanidin-3-glucoside (C3G)- 304 mg/Kg, delphinidin-3-glucoside (D3G)- 220 mg/Kg and peonidin-3-glucoside (P3G)- 120 mg/Kg was



Nutritional quality matrix of non-pigmented (NJ 72, PB 1509) and pigmented (Matta, Chak-hao) rice varieties

also most expressive *Chak-hao*. The correlation between nutritional attributes endorsing antioxidant potential being strongly positive and most significant for *Chak-hao*.

6.2.2.3 Starch biosynthesis during grain filling under drought stress

The starch content increased in developing grains under the drought stress. The increase in the starch content of developing grains was positively correlated with the increase in the activity of ADP glucose pyrophosphorylase and starch synthase (SS) activity, and remobilization of transitory starch from leaves to grains. Comprehensive analysis of transcription levels of ADP-glucose pyrophosphorylase and starch synthase showed a direct relationship with the activity of both the enzymes and starch content of developing grains under the drought. An increase in the activity of AGPase in developing grains was due to induced differential expression of ADP glucose pyrophosphorylase large subunit 3 (*AGPL3*) and ADP glucose pyrophosphorylase small subunit 2 (*AGPS2*) in Nagina 22 and IR 64. Similarly, an increase in the SS activity in developing grains was due to induced expression of soluble starch synthases (*SSIIB*, *SSIVA*, and *SSIVB*) in N22 and SSIVB in IR64.

6.2.3 Probiotics/pre-biotics studies in soybean

Soymilk is increasingly being recognized as an excellent alternative to dairy products by consumers all over the world, as it is not only a good source of complete proteins, dietary fiber but also rich in various phytonutrients such as isoflavones, with diverse biological activities. Despite these health benefits , the consumption of soymilk in India is limited due to the presence of anti-nutritional factors such as phytic acid, limited bioavailability of isoflavones and poor flavour quality. Five promising strains of probiotic *Lactobacillus* sp., having potential to improve bioavailability of soy isoflavones owing to their high β-glucosidase activity, were selected and used for soymilk fermentation, which significantly improved in nutritional and functional properties of soymilk. The level of quality enhancement varied significantly w.r.t. probiotic strain. The *L. plantarum* and *L. rhamnosus* fermentations resulted in an increase in total antioxidant activity, Fe and Zn availability, reduction in phytic acid levels, increase in titratable acidity (0.10- 0.41%) and bioconversion of conjugated isoflavones (daidzin, genistin, glycitin) into more bioavailable aglycones (daidzein, genistein, glycitein).

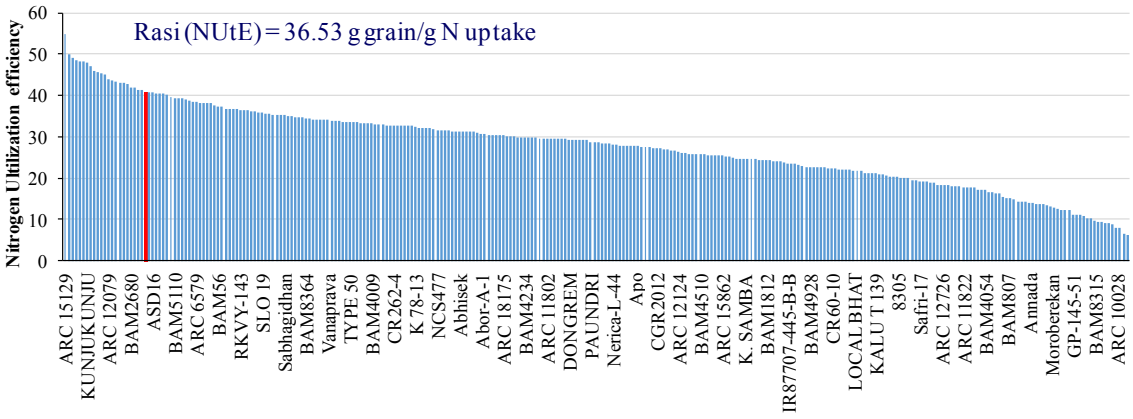
6.2.4 Changes in amino acid profile during terminal heat stress in wheat

Terminal heat stress in wheat resulted in changes amino acid profile causing a decrease in the accumulation of essential amino acids in the grains, ultimately compromising the quality of the grains. Heat stress increased accumulation of glutamic acid and depletion in histidine and valine. Thus essential amino acids though present in very low concentration in grains of wheat, were further depleted during terminal HS; percent decrease was observed more in thermosensitive cv. HD 2329 as compared to thermotolerant cv. Raj 3765.

6.3 PLANT PHYSIOLOGY

6.3.1 Phenomics of water use efficiency and N use efficiency in rice

Precision phenotyping Nanaji Desmukh Plant Phenomics Centre (NDPPC) at with 300 diverse rice germplasm during *Kharif* 2019 to identify donors and QTLs for high NUE and N deficiency tolerance. Rice genotypes were grown under controlled environment condition in two N levels (N120, recommended dose of N; N0 (no fertilizer application). Results revealed that rice plants grown under N deficient condition used more water per unit projected surface area (PSA) as compared with well fertilized (N120) plants. Further, the relative night to day time transpiration was higher in plants grown under N deficit conditions. Genotype with less transpiration and biomass were identified. Based on stress susceptibility index, RPW9-4 (SS1), Kangro, CR60-10, PUSA 44 and Nagina 22 were identified with high tolerance to N deficiency stress. Germplasm lines with N utilization efficiency (NUtE) > 40g grain/g N uptake were identified.



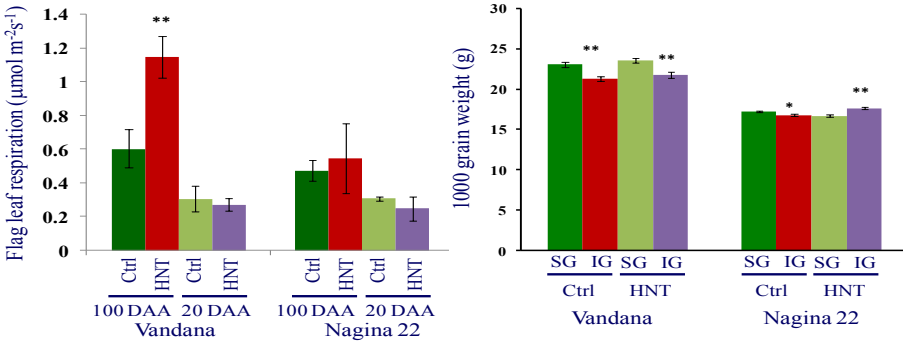
Variation in N utilization efficiency among rice germplasm

6.3.2 Variability in leaf venation and photosynthesis in mutants of rice cv. Nagina 22

Improving photosynthesis is a potential target for enhancing the crop yields and resource use efficiency. The leaf vein density (LVD) may provide an avenue for improving photosynthesis. A portable platform based on mobile phone was developed for rapid imaging of leaf venation and 430 Nagina 22 mutants were phenotyped. LVD of flag leaf ranged from 3.4 to 6.3 veins mm^{-1} compared to the WT (4.3 veins mm^{-1}). The mutants identified with high LVD were M-153-1, SM-M-301-1-1-1, M-N-5, SM-507 and SM67-1. A positive association between leaf photosynthetic capacity and leaf venation was observed in selected mutants. The Nagina-22 mutant SM67-1 with higher photosynthesis capacity (155% over WT) showed higher LVD of 6.0 compared to 4.3 veins mm^{-1} in nagina 22, while the mutant M57 with lower photosynthetic capacity (75% less than WT) showed lesser LVD of 3.7 veins mm^{-1}.

6.3.3 Physiological analysis of high night temperature tolerant Nagina 22

A study was conducted to explain the physiological basis of post-anthesis high night temperature (HNT) tolerance (>3.7°C over ambient) in Nagina 22 and Vandana. A significantly lower test weight of superior and inferior grains was observed in Vandana, while Nagina 22 showed an increased weight in inferior grains under HNT. Poor availability of non-structural carbohydrates for seed filling in Vandana due to 91% increase in flag respiration rates could be responsible for the loss in grains weight. Nagina 22 also recorded a 23% increase in rate of photosynthesis under HNT



Effect of high night temperature on the flag leaf respiration and 1000 grain weight of superior and inferior grains in rice cv. Vandana (susceptible) Nagina 22 (tolerant). Ctrl, Control; HNT, high night temperature; DAA, Days after Anthesis.

to overcome the insignificant increase in rate of respiration of its superior spikelets. Night-time relative infrared thermal temperatures at 10 and 20 days after anthesis revealed that superior and inferior spikelets of Nagina 22 were cooler under HNT than control, most likely due to transpirational cooling of panicles under high night temperatures.

6.3.4 Comparative analysis root system in hydroponics and field conditions in wheat

Twenty contrasting wheat lines (UK germplasm) were grown in optimum (7.5 mm) and low N (0.01 mM) concentration in hydroponics and also in the field at two N levels (N_0 and N_{120}) to analyze the relationship. A significant correlation between root traits measured at seedling stage in hydroponics and root angle at anthesis stage in field grown wheat was observed. The average root diameter at seedling stage may provide a clue on probable growth of roots on the sub-surface that might help in 'top-soil foraging' of nutrients.

6.3.5 Regulation of phosphorous remobilization by abscisic acid (ABA) in wheat

Role of ABA, ethylene and nitric oxide was studied in remobilization of phosphorus (P) from root cell wall under dual-nutrient (nitrogen and phosphorous) deficiency stress (DNDS) in wheat genotypes HD2781 (DNDS-tolerant) and C306 (DNDS-sensitive). Activity of pectin methyl esterase (PME) and pectin hydrolysis was higher in HD-2781 as compared to C306 across the treatments. Reduction in cell wall P content in HD-2781 in root tissue under nutrient stress indicated better P remobilization towards shoot as there was less P retention in cell wall. Endogenous ABA inhibits the activity of PME, thus inhibiting the cell wall P remobilization. The endogenous ABA content was significantly lower in HD-2781 as compared to C-306. The pathway of P remobilization from root cell wall was affected by ABA but it was found to be independent of both NO and ethylene in HD-2781, whereas no such clear relationship was found in C-306.

6.3.6 Endogenous vitamin C and bioregulators for heat tolerance in wheat

Terminal heat stress is a major factor limiting yield in late sown wheat. Plants have developed numerous cellular defense mechanisms including antioxidants such as ascorbate for overcoming the adverse effect of stress. Genotypes high ascorbic content namely, Karim, Chiria 3, Dharwad Dry, GW 322, HD2733, HD2932, HD2967, HD2985, Halna, PBW343 and WR544 were identified. Ascorbic acid content showed high correlation with heat tolerance. Xanthophylls cycle plays an important role in photo-protection under heat stress (HS). Contrasting wheat varieties *viz*. HD 2329 (HS tolerant) and HD 3086 (HS susceptible) were evaluated for xanthophyll cycle under HS. Foliar application of ascorbic acid and $Ca(NO_3)_2$ increased the level of zeaxanthin and lutein under late sown conditions. It was found that xanthophyll cycle activators modulated xanthophyll cycle activity and improved heat stress tolerance in wheat.

6.4 GENETICS

6.4.1 Wheat

6.4.1.1 QTLs and candidate genes for drought tolerance

Drought tolerance was studied in recombinant inbred lines (RILs) derived from the cross between NI5439 × HD2012. Linkage map was constructed using Axiom 35 K Breeder's SNP Array and microsatellite (SSR) markers. A linkage map with 3661 markers comprising 3589 SNP and 72 SSR markers spanning 22,275.01 cM in length across 21 wheat chromosomes was constructed. QTL analysis for leaf rolling trait under drought revealed 12 QTLs on chromosomes 1B, 2A, 2B, 2D, 3A, 4A, 4B, 5D, and 6B. A stable QTL Qlr.nhv-5D.2 was identified on 5D chromosome flanked by SNP marker interval AX-94892575–AX-95124447. Six putative candidate genes were identified based on in-*silico* analysis.

6.4.1.2 Mapping of leaf rust resistance (*Lr*) genes

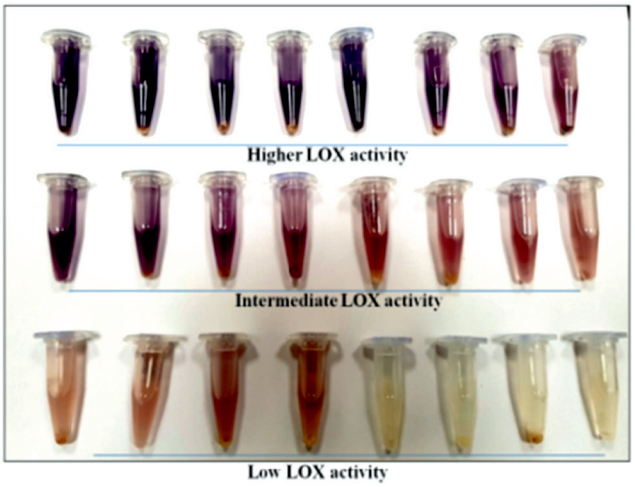
A new leaf rust resistance gene tentatively named *LrM* was introgressed from the diploid non-progenitor

species *Ae. mar*kgrafii (2n = 2x = 14, genome CC) into common wheat using the nulli-5B mechanism. The introgression line ER9-700 showed a high degree of resistance against a wide spectrum of *Puccinia triticina* pathotypes. Genetic analysis showed a single dominant gene for leaf rust resistance. The resistance gene *LrM* was mapped on chromosome arm 2AS using SSR and SNP-based PCR markers. TSD276-2, a wheat genetic stock derived from the cross Agra Local/*T. spelta* 276 showed broad spectrum resistance against leaf rust pathogen. Genetic analysis revealed a single recessive gene for leaf rust resistance, tentatively named as $LrTs_{276\text{-}2}$. The rust reaction and chromosomal location suggest that $LrTs_{276\text{-}2}$ is a new leaf rust resistance gene.

6.4.2 Rice

6.4.2.1 Novel *LOX3* null genotypes of rice for enhancing bran stability and quality

Rice bran oil is a major value-added product from rice bran. Nevertheless, rapid rancidity of rice bran remains a major challenge limiting the realization of complete potential of rice bran oil. Lipoxygenase 3 (LOX3) is the major enzyme that affects bran rancidity by converting fatty acids particularly polyunsaturated fatty acids into their hydroperoxide derivatives. A set of 250 rice germplasm accessions were screened for their LOX3 activity by KI Starch assay method. Genotypes with functional LOX3 produce dark purple color in the assay, while those with non-functional LOX3 give no colour. Ranbir Basmati, Basmati 564, Basmati 802, Basmati 5888, Shah Pasand, Vasumati and Basmati 397 showed absence of the LOX activity. Sequence analysis of *OsLOX3* gene showed a deletion of C residue in exon 2. This led to a frame shift and thus non-functional LOX3 in the nulls. A PCR based functional marker was been developed and validated to track the null allele in the segregating generations. The novel genotypes identified and the marker developed will be helpful in marker assisted introgression of null alleles of *OsLox3* into elite rice varieties for enhancing bran stability and quality.



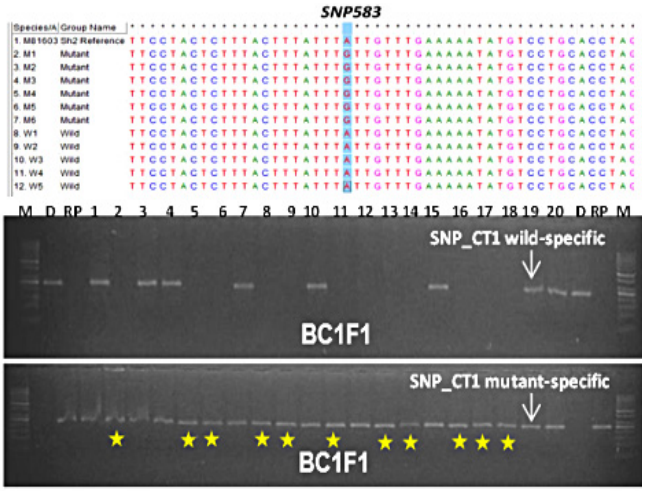
LOX assay depicting genotypes with higher, intermediate and no LOX3 activity

6.4.2.2 Molecular characterization for allelic status of S5 locus in rice germplasm

One of the major problems in inter-subspecific crosses between *indica* and *japonica* is hybrid semi sterility. The S_5 locus is a major locus governing embryo sac sterility in inter subspecific crosses. *Indica* possess $S_{5\text{-}i}$, *japonica* has $S_{5\text{-}j}$ and wide compatible varieties (WCVs) have neutral allele $S_{5\text{-}n}$ at S_5 locus. Analysis of a set of 967 rice genotypes led to the identification of 166 lines as a carrier of neutral allele (*S5-n*), 220 lines as *japonica* allele ($S_{5\text{-}j}$) and 581 lines were identified as carrier of *indica* allele ($S_{5\text{-}i}$).

6.4.3 Development of breeder-friendly markers for *shrunken2* gene in maize

Recessive *shrunken2* (*sh2*) enhances kernel sweetness by six-times, and is abundantly used in the sweet corn breeding programme. *Sh2* gene among five wild- and six *sh2-Ref* based inbreds were sequenced and SNP583 (A to G) and SNP755 (T to C) in 5'UTR, and SNP5112 (C to T) in intron-12 clearly differentiated dominant (*Sh2*) and recessive (*sh2-Ref*) allele. These SNPs were used to develop four gene-based PCR markers and were validated. These markers were further used in genotyping of BC_1F_1 populations leading to successful selection of *sh2-Ref* allele in the marker-assisted breeding.

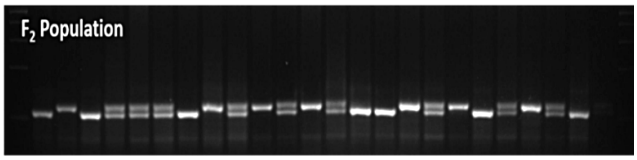


SNP-based marker for *sh2* and its segregation in BC_1F_1 population

6.4.4 Pearl Millet

6.4.4.1 Molecular mapping of fertility restorer gene of A_5 cytoplasm

The mapping population of $ICMA_502555$ / A_5RT-17/8 was used to map the A_5 fertility restorer gene. BSA identified four putatively related SSR markers, IPES0007, IPES0027, IPES0060 and IPES0181 located on chromosome 2, whose likelihood values for a single marker analysis were < 0.001. The linkage map revealed that *Rf5* is positioned at a distance of 5.7 cM and 17.3 cM from the markers IPES0007 and IPES0181 on one side and IPES0027 at a distance of 11.9 cM and IPES0060 at a distance of 25.6 cM from the *Rf5* gene on the other side. A dominant male fertility restorer gene named *Rf5* in 'A_5RT-17/8' has been identified on chromosome 2 between four SSR markers IPES0060, IPES0027, IPES0007 and IPES0181. In the case of marker IPES0027, all B lines display a distinct banding pattern from R lines except for four R lines i.e., A_5RT-17/5, A_5RT-17/6, A_5RT-17/16 and A_5RT-17/19 displayed similar banding patterns to B lines of A_5 CMS system. Each of these three SSR markers, with the exception of IPES0027, distinguished the restorers from the B lines These co-dominant markers can discriminate between three types of genotypes; Rf5Rf5, Rf5rf5, and rf5rf5. Thus IPES0007, IPES0060 and IPES0181 can be useful marker for the identification of A_5 restorers to improve the efficiency of hybrid pearl millet breeding.



Segregation of IPES0007 in F2 population

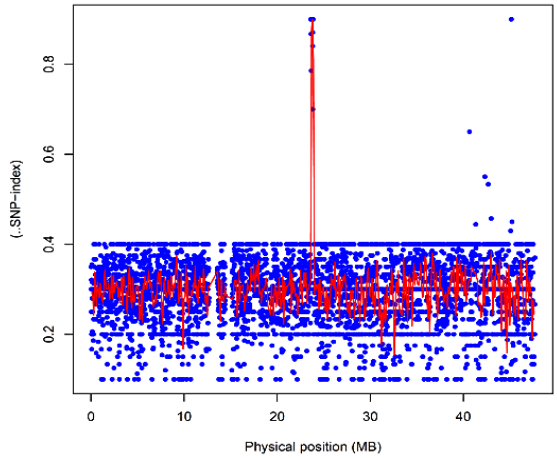
6.4.4.2 Studies on genetic variation for rancidity parameters

The rapid development of rancidity and bitterness in the pearl millet flour is a major problem in its acceptance and utilization. To investigate the rancidity parameters in pearl millet flour, peroxide value (PV) and acid value (AV) were determined in hundred pearl millet genotypes *viz*., landraces, inbreds and hybrids stored; under refrigerated (4-5°C) and ambient temperature (25°C to 28°C) conditions at 0, 10 and 21 days interval. From rancidity profiles of 100 genotypes, five genotypes showing high PV and AV values and five genotypes showing low AV and PV values were selected and profiled for LOX, POX and PPO activity. The genotypes PPMI-1003, PPMI-1239 and IPC-1657 showed less rancid values and low enzymatic activities and thus higher shelf life.

6.4.5 Chickpea

6.4.5.1 Identification of major QTL(s) governing plant height and internode length

F_2 population (241 plants) derived from the cross HC 5 (desi chickpea cultivar with erect growth



QTL governing internode length and plant height on chromosome-5 of chickpea

habit and long internodes) x E 100YM (spontaneous brachytic growth mutant with erect growth habit and short internodes) was phenotyped for plant height and internode length. Resequencing of two bulks (26 individuals each) with contrasting phenotypes (long & short internodes) and the parents was done in 50X coverage. A major QTL (CaqIL5.1) for internode length was identified on CaChr05 (23603436 to 23853931 bp).

6.4.5.2 Identification of molecular markers for determinate/semi- determinate traits

To study the inheritance of semi-determinate growth habit F_1, F_2 and $F_{2:3}$ of the cross BG362 x BG3078-1 along with the parental lines were evaluated. The semi-determinate stem growth habit of BG3078-1 line is controlled by a single dominant gene *Dt2* and its genotype assigned as *dt1dt1Dt2Dt2*. Three SSR markers Ca_GpSSR00560, TA42 and H3DO5 were found to be associated with stem growth habit.

6.4.5.3 Mapping of QTLs for BGM

A RIL population from an inter-specific cross (GPF2 x *C. reticulatum* ILWC292) was genotyped with GBS approach and phenotyped for BGM resistance for two years. Three consensus QTLs (*qbgm-4.1*, *qbgm-4.2 &qbgm-5.1)* for BGM resistance were identified in both the years.

6.4.5.4 Mapping of salt tolerant QTLs

Extensive analysis of the phenotyping and genotyping data by Axiom®Cicer SNPArray identified a total of 28 major effect and minor effect QTLs explaining up to 28.40% phenotypic variance. QTL clusters on CaLG03 and CaLG06 each harbouring major QTLs for yield component traits under salinity were identified. Also retrieved 763 predicted genes from QTLs region (~3.3MB) from CaLG03 and 156 genes from ~0.1Mb QTL region in CaLG06.

6.4.6 Genetics of wilt resistance in pigeonpea

192 germplasm lines of pigeonpea and the mapping population of the cross between ICP 2376 and ICP 8968 were phenotyped at Agricultural Research station, Kalburgi, Gulbarga for studying the genetics of wilt resistance. The F2 population segregated into 3R:1S genetic ratio indicating a single dominant resistance gene controlling the resistance to Gulbarga isolate of *Fusarium* wilt in this cross. The disease reactions observed in the BC1F1 populations with ICP 2376 as a recurrent parent confirmed the single dominant gene model detected in the F2 populations.

6.4.7 Phosphorus use efficiency in mungbean

The root architectural traits of 153 mungbean genotypes were compared under optimum and low phosphorus (P) conditions. Total root length was positively and significantly correlated with total root surface area, total root volume, total root tips and root forks under both optimum P and low P. IPM-288, TM 96– 25, TM 96–2, M 1477, PUSA 1342 were found to be the best highly efficient genotypes. 144 diverse mungbean genotypes were evaluated for phosphorus use efficiency (PUE) traits under hydroponics with optimum and low phosphorus levels. Genome wide association study was conducted using 55,634 SNPs obtained by genotyping-by-sequencing method. In total, 71 protein coding genes were identified, of which 13 genes were found to be putative candidate genes controlling PUE associtated with nutrient uptake and root development pathways.

6.4.8 Lentil

6.4.8.1 Aluminium stress tolerance

The Al accumulation and callose depositions in roots increased under 148 µM Al^{3+} stress condition. Lower Al content was detected in root tips of tolerant genotypes (L-4602, and ILWL-15) than in Al sensitive (BM-4) genotype. The Al-tolerant genotypes L-4602 and ILWL-15 visualized less callose in the root tip than Al-sensitive BM-4 in response to Al stress. Antioxidant enzyme (SOD, APX and GPX) activities and proline increased in roots under Al stress in all the genotypes. Pathway analysis of top 135 DEGs in all six comparison groups revealed 63 unique and uncharacterized Al stress related proteins. Pathway analysis showed that these genes belonged to organic acid synthesis and exudation,

phytohormone responsiveness, ROS detoxifying enzymes and alternate pathway genes along with callose synthesis genes. In tolerant genotype, genes for several organic acid transporters were significantly up-regulated when compared to its control *viz*. ALMT 7, 9, 12, 14. When compared to sensitive genotype, MATE was found to be significantly up-regulated in tolerant genotype. This alternate pathway has commissioned Metacaspase- 1, 4, 9 to induce programmed cell death in tolerant genotype. In phytohormone signalling pathway, Auxin responsive protein SAUR72, Auxin efflux carrier component 3, Abscisic acid receptor PYL4, Ethylene responsive transcription factors 9, ERF095, 1B, etc. were significantly up-regulated. In transporters group, putative multidrug resistance protein, ALMT 7, 12 were up-regulated. For organic acids synthesis pathway, genes for enzymes which were significantly up-regulated in wild genotype included Aconitatehydratase (Aco), Acetyl Co-A carboxylase, Succinate dehydrogenase, Acetyl Co-A acetyl transferase, Enoyl- Co A hydratase, etc.

A F6 recombinant inbred line (RILs) population derived from a cross between L-7903 (Al-resistant) and BM-4 (Al-sensitive) was phenotyped for variation in secretion levels of malate and was combined with genotypic data obtained from 10 Al resistance linked SSRs markers. A major QTL was mapped for malate (*qAlt_ma*) secretion with phenotypic variation of 60.2%. SSRs associated with this QTL were found to be located in a previously identified Al -resistance QTL on linkage group 1. The validated SSRs associated with this QTL will be useful for marker assisted improvement of Al resistance in lentil.

6.4.8.2 Salinity tolerance

Transcriptomic scanning by Illumina Hi-Seq 2500 platform revealed a total of 17,433 significant-differential expressed genes (DEGs) in all combinations between PDL-1 (salt tolerant) and L-4076 (Salt sensitive) genotypes. The differentially expressed transcripts were functionally characterized by Gene ontology (GO) analysis and assigned to metabolic pathways using Mapman analysis tool. The DEGs were found to be significantly associated with phyto-hormone mediated signal transduction, cellular redox homoeostasis, secondary metabolism, nitrogen metabolism as well as cellular stress signaling.

6.4.9 Mustard

6.4.9.1 MAS for white rust and quality traits

Molecular markers linked to white rust and oil quality traits were screened in thirty-five backcross populations for introgression of white rust resistance, low erucic acid and/or glucosinolate traits in different promising Indian mustard varieties *viz*., Pusa Mustard 21, Pusa Mustard 22, Pusa Jagannath, and PM 30. Based on genotype data for the three traits *viz*., white rust, erucic acid and glucosinolates, backcrosses and generation advancement were carried out.

6.4.9.2 Transfer of powdery mildew resistance to popular Indian mustard cultivars

Three backcrosses were attempted from BC_1F_1 to BC_2F_1; four back crosses from BC_2F_1 to BC_3F_1 and nine back crosses from F_1 to BC_1F_1 for transferring powdery mildew resistance from PMW 18 to popular Indian mustard cultivars *viz*. Pusa Mustard 25, Pusa Mustard 28, Pusa Mustard 29, Pusa Mustard 30, Pusa Mustard 31, NRCDR 02, NRCHB 101 and Giriraj.

6.4.9.3 Mutation breeding

Twenty-nine single plants were selected from 17 progenies of mutated PM 30 for high oleic acid, tocopherol, yellow seed coat colour, oil content and other agronomically important traits. To develop short statured and bold seeded version of heterotic genotype Heera, 18 & 23 progenies representing M4 & M6 generations, respectively, were raised and 34M4 and 35M6 plants were selected as per objectives.

6.4.10 Speed breeding in soybean

For speed breeding, a three-pronged strategy was adopted: i) Growing the crop under elevated CO_2 concentration (> 400 ppm) and higher temperature; ii)

Pre-mature pod harvesting, and iii) oven drying of the immature pods. The experiment was conducted with a set of early and late maturing soybean genotypes in the National Phytotron Facility. The early genotypes matured in 55-60 days, while the late maturing genotypes matured in 75-80 days. With this approach, at least 4 generation of soybean would be feasible to grow under controlled condition.

6.4.11 DWnt4 mutations in Drosophila

Next Generation Sequencing of seven DWnt4 mutant alleles has been done using Illumina HiSeq 2500/Next Seq 500 system. Genome analysis was done using the software SnpEff Genomic variant annotations and functional effect prediction toolbox version 4.1. Non-synonymous SNPs resulting in transcript variation were identified through *in silico* structural annotations. The recessive mutations of the gene DWnt4 are maintained against balancer chromosomes which carry a GFP marker. Non GFP embryos are collected as homozygous null alleles of the respective mutations to study gene interactions in loss of function alleles of DWnt4. Wingless LacZ balancer (*wgLacZ)* is being used in order to screen the embryos by staining the embryos with β galactosidase (X-Gal staining). The embryos which do not stain for β galactosidase will be recessive homozygous mutations. The expression of genes like engrailed, patched, armadillo will be checked in these embryos.

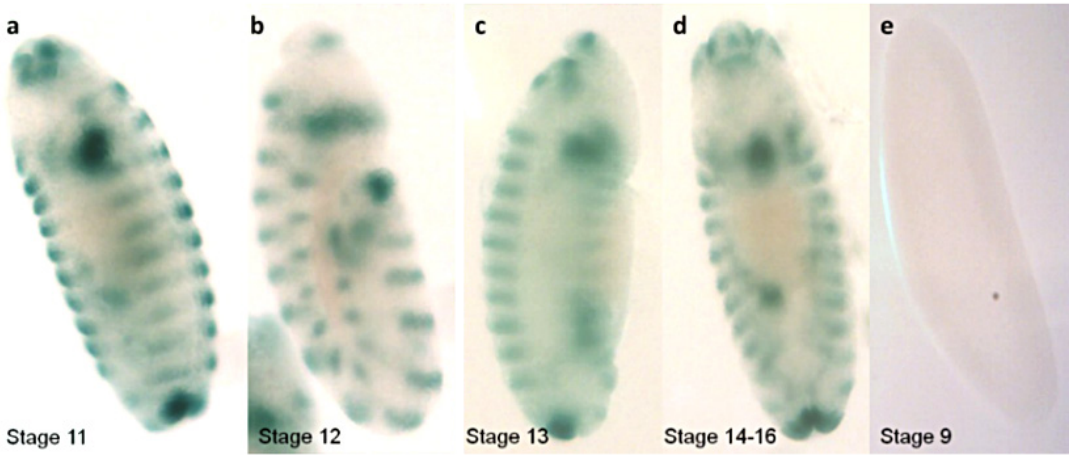
6.4.12 QTLs fruit bearing in Brinjal

Four QTLs have been identified on 4 genomic regions with one each in Ch 4, 10 and two in Ch 11 by using whole genome re-sequencing of the two bulks (cluster bulk and solitary bulk) obtained from the segregating F_2 population of Pusa Safed Baingan 1 (cluster bearing) and Pusa Hara Baingan 1 (solitary bearing). A total of 300 new SSRs have been identified from the genome sequence of brinjal which will be used for polymorphism survey.

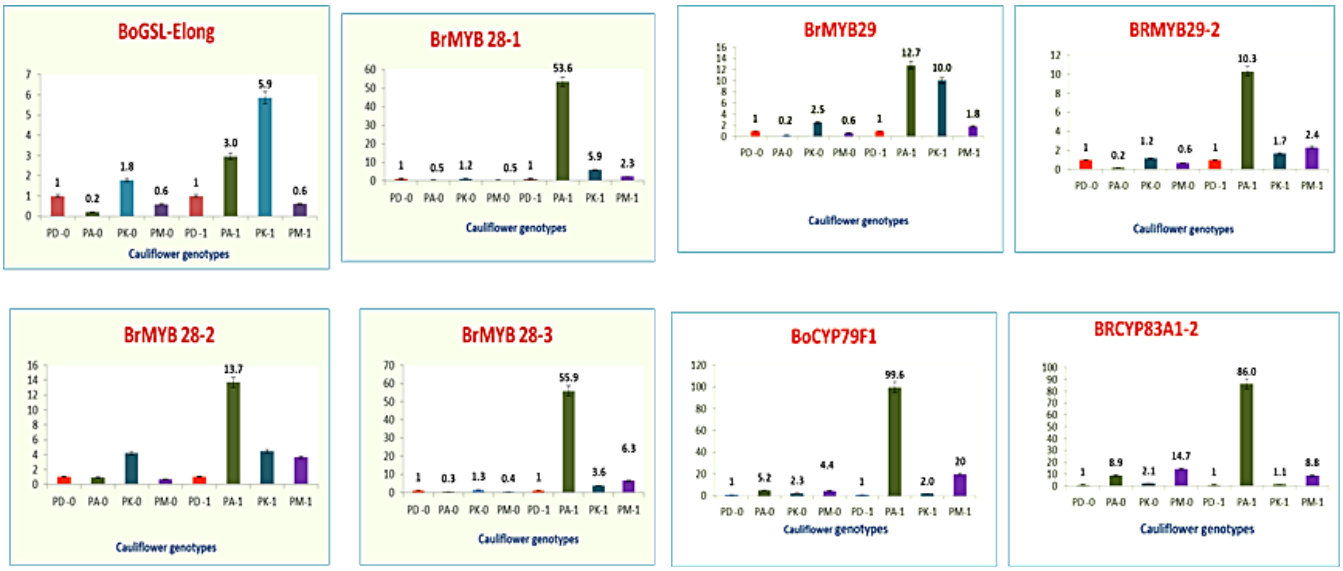
6.4.13 Cauliflower

6.4.13.1 Aliphatic glucosinolates

A study was conducted to correlate the content of aliphatic glucosinolates to the expression of genes involved in their synthesis in four varieties of *Brassica oleracea* namely Pusa Deepali (PD), Pusa Ashwini (PA), Pusa Kartiki (PK) and Pusa Meghna (PM). Expression of nine different genes *viz. BoGSL-Elong, BrAOP-2-2, BrMYB 28-1, BrMYB 28-2, BrMYB 28-3, BrMYB 29, BrMYB 29-2, BoCYP79F1, BRCYP83A1-2* was studied in the test genotypes. It was observed that there was no difference in the expression of different glucosinolate pathway genes in different varieties during October, however when the samples were taken in the month of November there were critical differences in the expression of different genes in different varieties. Highest expression of all the genes except *BoGSL-Elong*



X-Gal staining to detect wingless expression in *wglacZ* line. a, b, c, d showing pattern of *wg* expression at different embryonic stages, e showing non *LacZ* embryo



Expression of genes for glucosinolate biosynthesis in *Brassica oleracea*

was observed in Pusa Ashwani while highest expression of *BoGSL-Elong* was observed in Pusa Kartiki.

6.4.13.2 Genotyping by sequencing (GBS) and QTL for curding

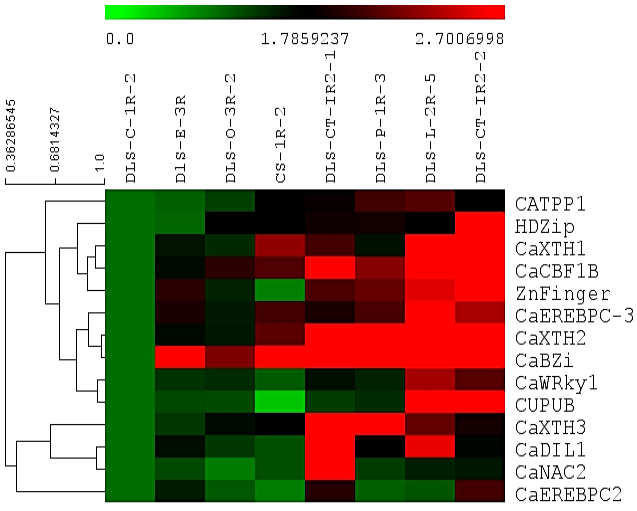
GBS was performed using 92 genotypes of cauliflower and two each of broccoli and cabbage. It generated ~302 million reads (9.1226E+10 bp) and identified 35381 SNPs. STRUCTURE analysis revealed five sub-populations and population admixture. In total, 121 SNPs were detected including 38 from Delhi and 83 from Barapani. Twelve QTLs were detected for traits associated with curding traits.

6.4.13.3 Pyramiding of black rot and downy mildew resistance

Through marker assisted breeding, black rot resistance gene (*Xca1bo*) and downy mildew resistance gene (*Ppa*[3]) were successfully transferred to Pusa Sharad background and 6 double gene homozygous backcross derived lines were evaluated. Out of which one line was found to have high curd weight of 720 g and was resistant to both black rot and downy mildew disease.

6.4.14 Cold tolerance in Chilli

Four cold tolerant hot pepper genotypes have been identified namely DLS-CT-IR2-1, DLS-P-1R-3, DLS-L-2R-5, DLS-CT-IR2-2 which exhibited better agronomic performance during the cold winter conditions of Delhi. These genotypes had strong antioxidant defense and ROS (reactive oxygen species) scavenging system and lower levels of lipid peroxidation in response to cold stress in comparison to the cold sensitive genotypes. Further, expression of fourteen cold inducible genes *viz. CaXTH1, CaXTH2, CaXTH3, CaCBF1B , HDZip, CaBZ1, CaWRKY1, Zn finger, CaTPP1, CaDIL1, CaPUB1, CaNAC2, CaEREBP-C2 and CaEREBP-C3* were analysed in 4 genotypes. Twelve of the fourteen



Heat map of cold inducible genes in cold susceptible and tolerant hot pepper genotypes

genes tested had significantly higher expression in cold tolerant genotypes. The confirmation of existence of innate cold tolerance mechanism in test genotypes can pave a way for future utilization of these genotypes in cold stress breeding.

6.4.15 QTL-seq analysis for the identification of genes associated with fruit length and gynoecy in bitter gourd

QTL-seq analysis was carried out for mapping genomic region associated with fruit length using the segregating populations ($F_{2:3}$) of a cross DBGS-2 (large fruit; 22-26cm long) × Pusa Purvi (small fruit; 4-5cm). Based on graph of sliding window analysis with delta-SNP Index distribution in each chromosome, the peaks were observed in the chromosome 2 and 9 those were considered to be the major QTLs and wider/flatter peak in chromosome 7 denoted multiple minor QTLs.

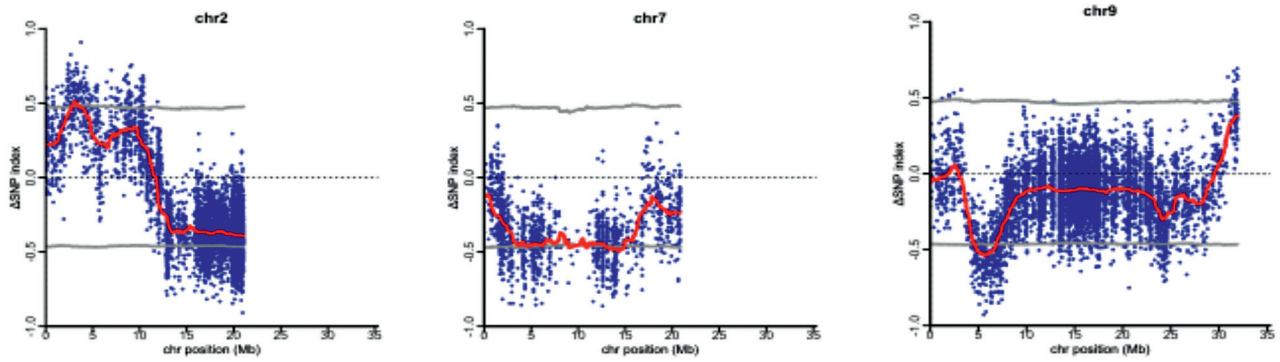
Similarly, QTL-seq analysis was also done for gynoecy trait in bitter gourd using the segregating populations (F2:3) of a cross PVGy-201 (gynoecious line) × Pusa Do Mausami (monoecious). The study revealed that a major QTL–region (23.4 to 24.7 mb region) of chromosome 1 was identified in harbouring putative candidate gene for gynoecy. On aligning the sequence reads of chromosome 1 of gy-1 (source of the gene) to OHB-3 (reference genome), a total of 8574 SNPs were detected and out of which 1008 SNPs were present in the candidate region (23.4 to 24.7mb region). These SNP were further filtered and based on functional annotation 3 putative candidate SNPs were identified with high phenotypic effect.

6.4.16 Cucumber

6.4.16.1 Comparative transcriptome analysis for extended shelf-life

Comparative transcriptome analysis of a natural variant, DC-48, having extended shelf life with a contrasting genotype, DC-83, gave molecular insight for this extremely useful economic trait. Total 1364 DEGs were identified and a large number of them were associated with cell wall degradation, chlorophyll and ethylene metabolism as revealed through KEGG analysis. Gene regulatory networks revealed the role of the major metabolism associated with a wide variety of the biological process for enhanced shelf life. Large numbers of SSRs, SNPs and InDels identified through the whole genome RNA-seq. These markers will be instrumental in linkage mapping, identification of DNA based markers and fine mapping of economically important traits in cucumber.

Fruits at 15 DAP



QTL-Seq analysis

6.4.16.2 Optimization of protocol for development of haploids

In cucumber, four genotypes (DC-48, DC-83, DC-43 × DC DC-48 and Gycl-15 × DC-48) were studied for their response to gynogenesis. Effects of developmental stages of un-fertilized ovary, temperature stress treatment and sucrose concentration were studied for direct and indirect regeneration. It was observed that the F_1 hybrids DC-83 × DC-48 and GyCl-15 × DC-48 responded better as compared to the open pollinated genotypes, DC-48 and DC-83. Among the 4 different developmental stages, the unfertilized ovaries cultured at one day before anthesis were most suitable. Temperature stress treatment for 4 days at 9.0ºC combined with 2 days treatment at 32.0º and 2% sucrose concentration was found to be most suitable for effective gynogenesis.

6.4.17 Development of SSR markers in garlic

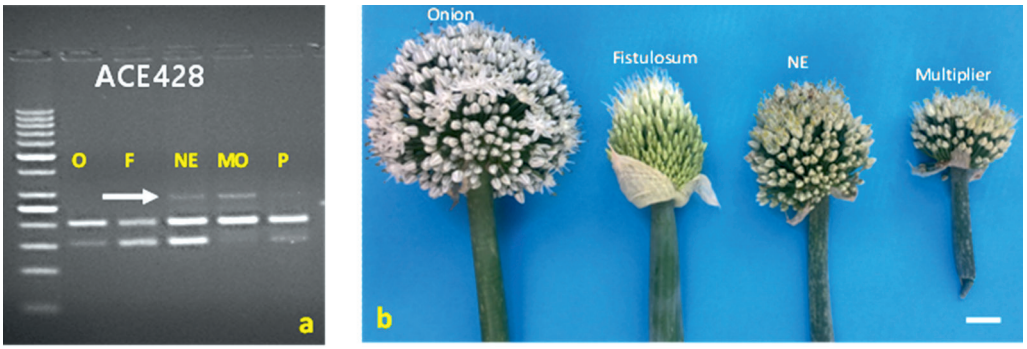
To develop SSR 97 EST-SSR primers from onion database and 39 SSR markers from garlic were analyzed. It was observed that 24 SSR markers (24.7%) from onion and 24 garlic SSR (61.5%) markers showed amplification in the preliminary examination. Different SSR markers and DNA barcodes *viz.*, ITS, *rbc*L, *trn*H-*psb*A, *tab_rps* and *Rpo*C were used for identification of a semi cultivated *Allium* genotypes collected from North East. A total of 30 SSR markers were used to elucidate the parentage of this semi cultivated species. Based on the SSR markers, it appears that this species is a cross between *A. fistulosum* and multiplier onion. This was is also supported by DNA barcoding using rbcL gene.

6.5 AGRICULTURAL PHYSICS, REMOTE SENSING & GIS AND METEOROLOGY

6.5.1 Soil Physics

6.5.1.1 Temperature sensitivity of soil organic carbon decomposition in maize-wheat system

Soil samples were collected from 0-5 and 5-15 cm depth from an ongoing field experiment on tillage, residue mulch and nitrogen interaction in maize-wheat cropping system in a sandy loam soil at Indian Agricultural Research Institute, New Delhi. It was observed that soil organic carbon mineralization increased with increase in incubation temperature but decreased at 5 to 15 cm depth than that of 0-5 cm depth. The cumulative CO_2 emissions increased under NT and crop residue mulching than that of CT and no-mulching but the percentage of total organic carbon mineralized was less under NT and crop residue mulching that of CT and no-mulching, respectively. This was attributed to higher total organic carbon concentration in soil under NT and crop residue mulching than that of CT and no-mulching, respectively. With the increase in N level cumulative CO_2 emissions increased. Temperature sensitivity (Q_{10}) values increased with soil depth. Q_{10} values under NT and crop residue mulching was more than that of CT and no-mulching. Higher content of recalcitrant pool (Less labile and non labile pool) of carbon under NT and CT may be responsible for higher Q_{10} values in these treatments. Activation energy (Ea) theory indicated that the temperature sensitivity of SOM decomposition is determined by SOM quality, namely, the molecular weight, molecular structure complexity, and chemical bond stability.



SSR marker characterisation a) SSR primer ACE428 for identification of onion (O), *A. fistulosum* (F), North East species (NE), multiplier onion (MO) and Pran(P) b) Floral morphology of different Allium species

Overall results suggest that NT with crop residue mulching may be followed in maize-wheat system for facilitating carbon sequestration in sandy loam soil of Indo Gangetic Plain region.

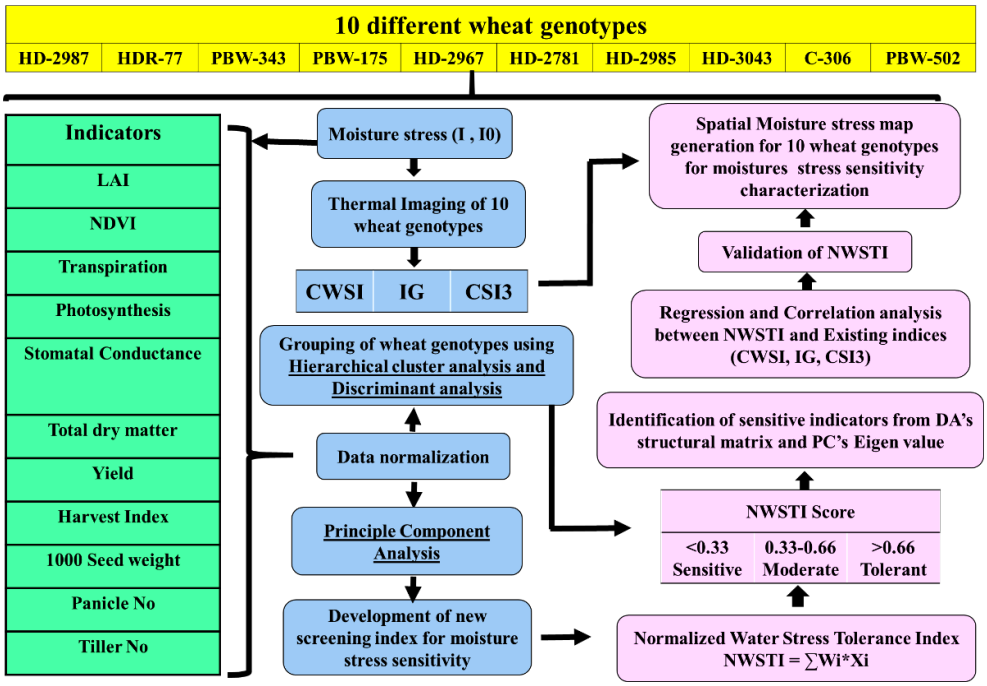
6.5.1.2 Prediction of soil health indicators using machine learning approaches

For prediction of hydraulic conductivity (HC), soil water content at field capacity (SWC_{FC}) and mean weight diameter (MWD) based on the performance evaluation of four Kernel functions, Radial basis Kernel function based SVM were found to be best for training and testing data, respectively. Performance of ANN was best among the three models for prediction of SWC_{FC}. ANN can capture non-linear functions and perform better than MLR. SVM models could probably predict the HC and MMD with more satisfactory performance owing to their more flexibility and capability to model non-linear relationships. SVM was best model with lowest RMSE (0.103 and 0.12 for training and testing) and MAPE values (10.96 and 16.91% for training and testing data) in prediction of MWD. The results showed that machine learning approaches can be useful for the prediction of MWD from very easily measurable soil parameters. Soil texture, OC, and BD can be used to predict soil structural stability effectively using SVM. Similarly, SVM will provide a novel technique for prediction of hydraulic properties like saturated soil hydraulic conductivity and field capacity moisture content.

6.5.2 Bio-Physics

6.5.2.1 Thermal imaging and multivariate techniques based Normalized Water stress Index (NWSTI) for characterizing wheat genotypes under water deficit stress

A study was undertaken to understand the combination of thermal imaging and multivariate techniques to characterize and screen different wheat genotypes under deficit water stress condition. Ten wheat genotypes namely HD-2987, HDR-77, PBW-343, PBW-175, HD-2967, HD-2781, HD-2985, HD-3043, C-306 and PBW-502 were grown under two irrigation conditions. Wheat genotypes were characterized thermo-graphically using canopy temperature-based stress indices, namely crop water stress index (CWSI), stomatal conductance index (IG) and stomatal resistance index (CSI3). Simultaneously, biophysical parameters like normalised difference vegetation index



Thermal imaging and multivariate techniques based NWSTI

(NDVI), leaf area index (LAI), transpiration, stomatal conductance and photosynthesis, were measured at vegetative stage while yield and its components were recorded at harvest. These parameters were analyzed using multivariate techniques namely PCA, hierarchical cluster analysis (HCA) and discriminant analysis (DA) to develop a new index called normalized water stress tolerance index (NWSTI), to group wheat genotypes depending on their ability to tolerate water deficit stress. Based on these multivariate analysis, wheat genotypes were classified as tolerant (C-306, HD-3043, HD-3987 HD-3985 and HD-2781), moderately tolerant (HDR-77, PBW-175 and PBW-502) and sensitive(HD-2967, PBW-343) to water stress with NWSTI score of > 0.66, 0.33-0.66 and < 0.33, respectively. A significantly higher correlation (R^2, $p<0.001$) between NWSTI and the thermal image-based stress indices prove the usefulness of NWSTI as stress index.

6.5.2.2 Application of AI based Image analysis technique to detect yellow rust in wheat

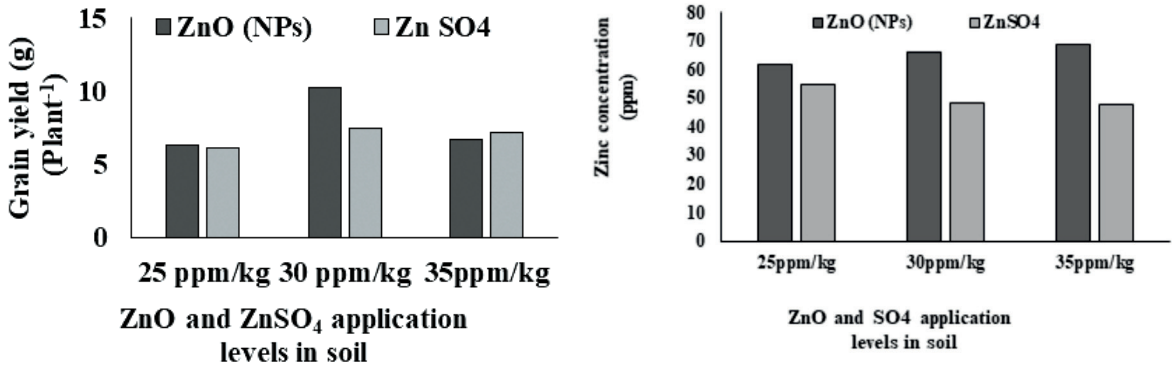
A methodology was developed for early detect on of yellow rust in wheat using diverse image processing techniques and artificial neural network (ANN). The ANN classifier for disease classification showed better results and recognition rate up to 91%. ANN based classifier is adopted which combined color and texture features to recognize and classify different levels of yellow rust in wheat. The ANN based approach could significantly classify the wheat cultivars based on the different levels of disease incidence into resistant R, mildly resistant MR, Mildly Susceptible MS, 10S, 20S, 30S, 60S and 100S. Experimental results showed that classification performance by ANN taking feature set is better with an accuracy of 71%.

6.5.2.3 Nanocomposite of carbon nanotube and hematite nanostructures for the fabrication of biosensor for nitrate detection

To achieve the aim of nutrient sustainability in food chain, an effort was made to fabricate a biosensor for nitrate detection using nanocomposite of carbon nanotubes and hematitie nanostructures. Carbon nanotubes were functionalized using boiling acid treatment method. Then the hematite nanostructures were synthesized using microwave assisted solvothermal process. The characterization studies of the nanoparticles using UV-Visible spectroscopy, FTIR, SEM and TEM revealed the morphology and confirmed the shape and size of nanoparticles synthesized. Then the nanocomposite of CNT and α-Fe_2O_3 nanostructures was prepared by optimizing their ratio. Using the nanocomposite the biosensor was fabricated.

6.5.2.4 Impact of zinc oxide nanoparticles (ZnO-NPs) on wheat

A pot experiment was conducted on wheat (HD2967) with metallic zinc oxide nano- particles (ZnO-NPs) vis-à-vis equivalent amount of zinc sulfate



ZnO-NPs impact on wheat

(ZnSO4) applied in the soil @ 25, 30 and 35 ppm/kg. ZnO-NPs increased grain yield (g plant^{-1}) significantly ($p<0.05$) over the conventional $ZnSO_4$ fertilizer. The efficiency of ZnO –NPs production in terms of biomass was higher (223-342%) over the conventional $ZnSO_4$ fertilizer application. This might be due to drastically increased surface area of ZO-NPs and their slow release in the soil. The concentration of zinc (ppm) in the grains was significantly more (12.2-44.7%) in wheat grown across the ZnO-NP applied soil over the conventional $ZnSO_4$ applied soil and it was maximum under the 35 ppm/kg ZnO-NPs.

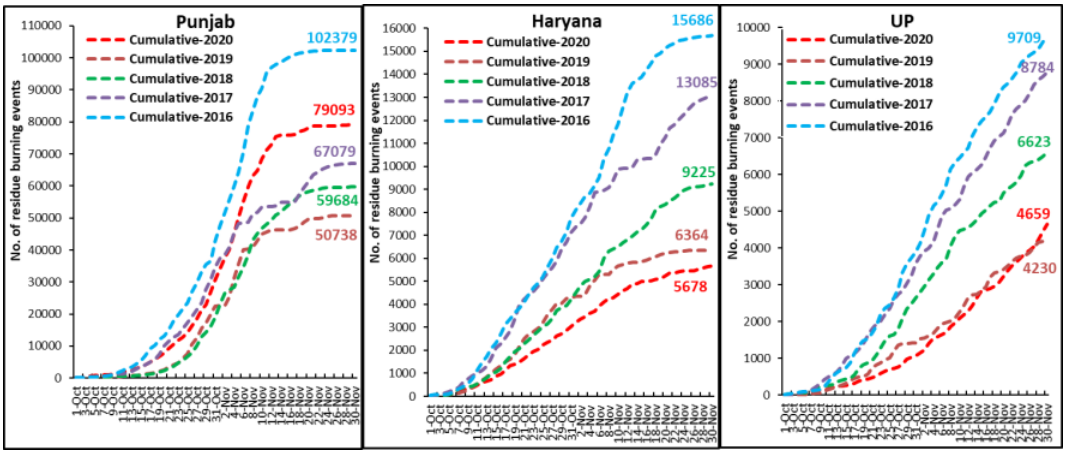
6.5.3 Remote Sensing and GIS

6.5.3.1 Monitoring rice crop residue burning by satellite remote sensing

Using thermal satellite images, spatio-temporal monitoring of the active fires due to paddy residue burning was carried out in real-time for the three states of Punjab, Haryana and UP from 1-Oct to 30-Nov 2020 on daily basis and their comparison was made with events during 2019, 2018, 2017 and 2016. Daily bulletin of fire events were prepared and fire locations were put on CREAMS Geoportal (http://creams.iari.res.in) for visualization as maps. Total paddy area burnt was also estimated for Punjab and Haryana using moderate resolution satellite imageries. The analysis clearly brought out a 46% increase in rice residue burning in 2020 as compared to 2019 in the three States. The burning events increase by 56% in Punjab and by 10% in UP, while it decreased by 11% in Haryana. Developed a model based on remote sensing detected of fire power and estimated emission of pollutants (particulate matter) and Green House Gases (CO_2, CO, NOx, CH_4) from residue burning. The study scope was expanded by undertaking satellite based monitoring of crop residue burning across India on daily basis and maps were uploaded on ICAR KRISHI Geoportal (https://krishi.icar.gov.in).

6.5.3.2 Mapping of burnt area due to paddy residue burning in Punjab and Haryana using sentinel-2 satellite dataset

The burning of residue events 2019 were compared with those monitored during 2016, 2017 and 2018. Total 61332 burning events were detected in the three States between 01-Oct-2019 and 30-Nov -2019, which are distributed as 50738, 6364 and 4230 in Punjab, Haryana and UP, respectively. Overall, the total burning events recorded in the three states were 18.8% less than in 2018. UP recorded 36.1% reduction, Haryana recorded 31.0% reduction, and Punjab recorded 15.0% reduction, respectively, in the 2019 than in 2018. Sentinel-2 MSI high resolution (20 m) image were used for paddy burnt area mapping during Oct-Nov 2019. The threshold cutoffs for differences in NBR (delNBR) and NDVI



Graph showing date-wise active fire events in Punjab, Haryana and UP detected from satellite images between 1-Oct to 30-Nov in 2016, 2017, 2018, 2019 and 2020

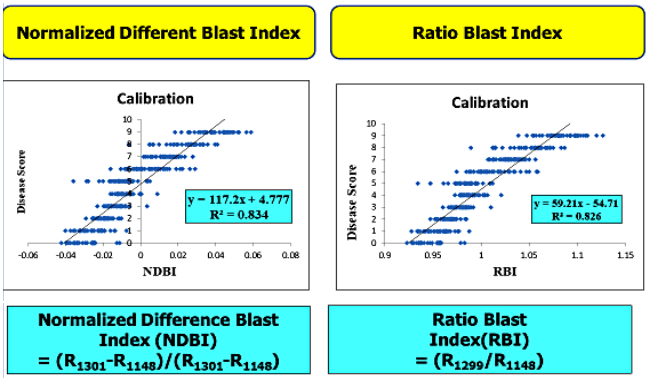
was used for estimating rice burnt area. In Punjab, the percent area burnt was 37.42% in the 2019 as compared to 49.39% in 2018. So about 12.0% reduction in paddy area burning was estimated as compared to 2018. In Haryana, the percent area burnt was 17.70% in the 2019 as compared to 16.96% in 2018. Almost no change in paddy area burning in percent term was estimated as compared to 2018.

6.5.3.3 Improved index insurance product for wheat using satellite remote sensing inputs

Satellite remote sensing derived indices could explain higher variability in wheat yield as compared to the weather indices. Among the remote sensing indices, vegetation health index (VHI) of sensitive crop stage showed best performance. The relationship between yield loss and pay-out (r=0.7 to 0.9) improved in all the districts for remote sensing based index insurance as compared to the weather based index insurance. Satellite remote sensing based index insurance products lowered the basis risk i.e. the mismatch between index and crop yield significantly and VHI based product showed the lowest basis risk. The study provides a robust methodology for designing of scientific index based crop insurance product.

6.5.3.4 Detection of rice blast disease using remote sensing

A field experiment was conducted at Almorah district of Uttarakhand (hotspot area) with the collaboration of ICAR-VPKAS to detect the different levels (0-9 scale of IRRI) of rice blast disease using

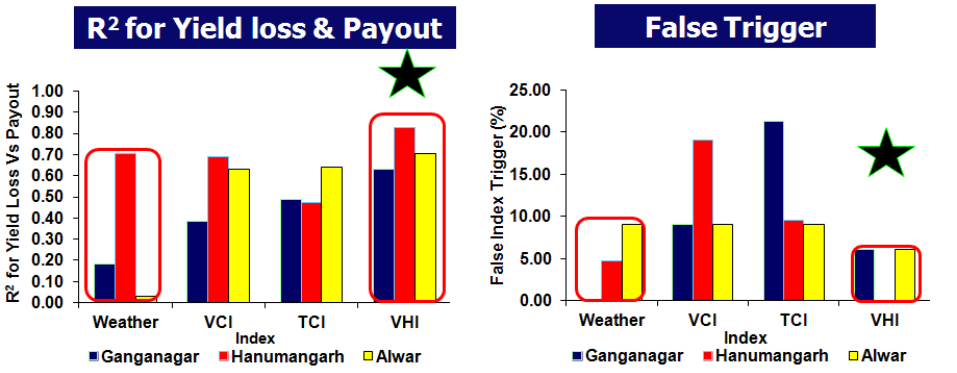


Rice blast detection using remote sensing

hyper-spectral remote sensing techniques. The bands at 650 nm (red) and 750-1150 nm (NIR) were found to be useful for this purpose. Disease levels were distinguished better for low land irrigated condition than that of upland rainfed condition. Two indices, namely, Normalized Difference Blast Index (NDBI) and Ratio Blast Index (RBI) were developed.

6.5.3.5 Assessing soil properties from air borne airborne visible near-infrared (VIS-NIR) spectroscopy

Laboratory-based VIS-NIR has already proved its potential as an effective alternative technique to traditional laboratory-based chemical analysis. Upscaling same methodology to field scale using imaging spectrometer on air borne platform for soil fertility assessment has many fold benefits. Team at IARI in participated with the science campaign of AVIRIS NG (Airborne Visible Infra Red Imaging Spectrometer



Remote sensing derived VHI based index insurance products has highest correlation between yield loss to payout and lowest ratio of false triggers for three districts of Rajasthan in case of wheat

- Next Generation) through collaborative experiment of ISRO and NASA, todevelop spectral models for estimating soil fertility parameters in the farmers' fields at different locations of country. Geotagged soil sampling, spectral signatures were collected using ground sensor in collaboration with team from NBSS & LUP, Nagpur. Models developed were evaluated for both ground and air borne sensors for parameters like pH, EC (dS m^{-1}), SOC (%) and available P and K (kg ha^{-1}).

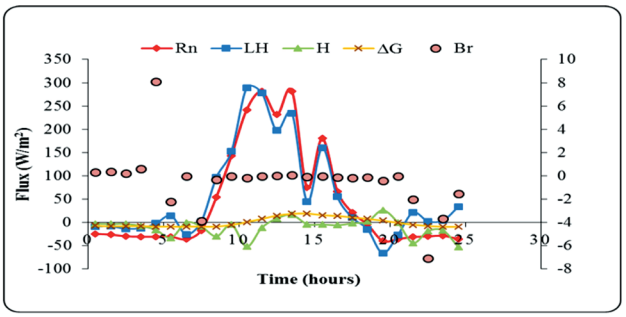
6.5.4 Agricultural Meteorology

6.5.4.1 Weather based wheat yield prediction using machine learning

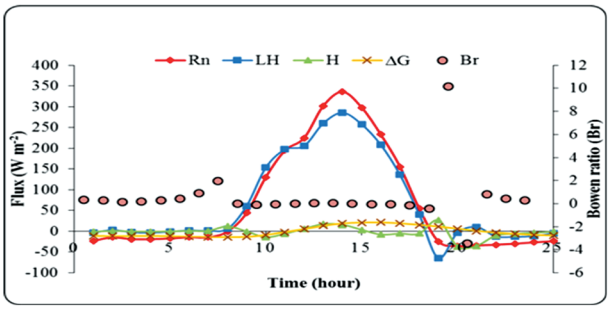
Weather based models using machine learning were developed and validated so that reliable prediction of wheat yield can be obtained. Wheat yield and weather data during crop growing period (46th to 15th SMW) for last 35 years were collected from IARI, New Delhi, Hisar, Amritsar, Ludhiana and Patiala. The wheat yield prediction model was developed using stepwise multi linear regression (SMLR), support vector regression (SVR), least absolute shrinkage and selection operator (LASSO), variable section by LASSO and SVR (LASSO-SVR), variable section by SMLR and SVR (SMLR-SVR) techniques. LASSO modal performed excellent for yield prediction at tillering, flowering and grain filling stage having nRMSE value ranged between 0.02 at grain filling stage for IARI, New Delhi to 8.36% for Hisar at flowering Hisar stage. Based on percentage deviation of predicted yield done at tillering, flowering and grain filling stage by observed yield, LASSO model performed best for all the station having value <6% except at tillering and flowering stage it was 12.07 and 14.44% respectively. The model performance of SVR is increased if hybrid model in combination with LASSO and SMLR is applied. Hybrid model LASSO-SVR has shown more improvement in SVR model compared with SMLR-SVR.

6.5.4.2 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



(a)



(b)

Trend of energy balance and Bowen ratio for (a) a cloudy day and (b) cloud free day over maize crop during kharif, 2020

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*, 2020 and *rabi* 2019-20. During *rabi* 2019-20, the partitioning of Rn into LE was 81.6%, H was 5.5% and G was 5.7%. Moist soil contributes more LE compare to H and G. The soil moisture availability also reduced the H value. The contribution G was low due to higher LAI. The highest value of Rn recorded was 336.5 W m^{-2} and its partitioning into LE, H and G was 48.2%, 21.3% and 15.9%, respectively. The sensible heat flux reached a peak at 13.30 hrs and the value was 97.7 W m^{-2}. In a cloudy day at silking stage all the components of energy balance were varied through the day. The initial stage of wheat crop recorded the lowest ETc (0.50 mm day^{-1}) followed by development stage (1.77 mm day^{-1}) at 40-70 DAS and end stage (1.7 mm day^{-1}). The mid stage at 70 to 120 DAS recorded the highest ETc (4.69 mm day^{-1}). G/Rn was lowest when crop LAI was highest in both the crop.

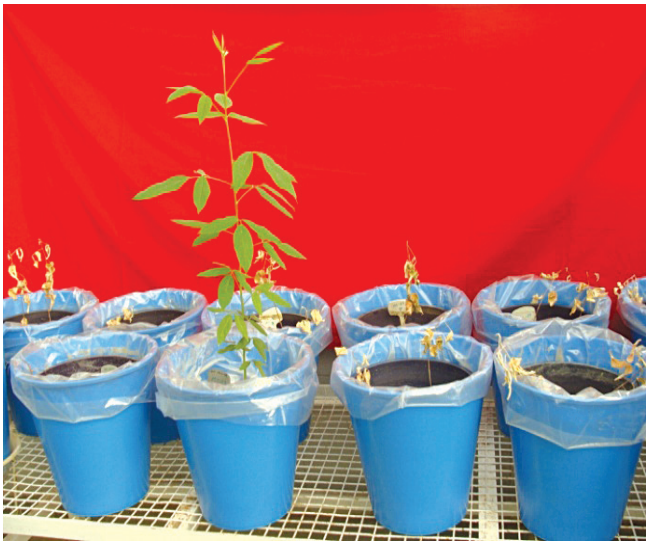
6.5.4.3 Weather based Agromet Advisory

Weather based agromet advisory bulletins were prepared on every Tuesday and Friday in both Hindi

as well as in English. These bulletins are sent through electronic media for wider dissemination among farmers and stake holder. These advisories along with crop status were sent to IMD for preparation of national bulletins and uploaded on IMD website (www.imdagrimet.gov.in) in both Hindi and English. These bulletins along with daily weather data and medium range weather forecast were uploaded on the Institute website (www.iari.res.in). During 2020, total 104 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 are fruitful for farmers, through this they can select high yielding varieties of different crop and vegetables and other farming practices such as sowing, weeding, irrigation, fertilizer and pesticides spray (time & doses) can be done at right time. Through this they can benefited from the monsoon, its status and day to day weather conditions which is helping to do proper farm practices at proper time. Feedback received from the farmers from different villages of NCR Delhi showed that agromet advisory bulletin is useful since they receive advises on appropriate field operations and management practices depending on suitability of weather conditions. It helps in reducing cost of cultivation, saving of input resources and increases in net profit. Farmers who followed the agromet advisories are able to reduce the input cost by reducing the irrigation, based on the rainfall forecast, number of spray, seed rate and timely management practices based on agromet advisories.

6.6 NATIONAL PHYTOTRON FACILITY (NPF)

The National Phytotron Facility has been serving the plant scientific community since 1987. The facility has been used to conduct experiments on various subjects including genetics, physiology, plant protection, biochemistry, plant-environment interaction and future climatic conditions. Besides various experiments on crop development, recombinant DNA technology, nutrient use efficiency, bio-fortification, gene expression studies, etc., critical observations were made on optimization of thermo- and photoperiod conditions for speed breeding of soybean and wheat. As part of using microbes for environmental protection, efficiency and interaction of the microbes with biodegradable plastics was also studied to gain useful insights on it. During 2020, the users from ICAR institutes, IIT Delhi, JNU, etc. conducted more than 60 experiments besides the on-going previous experiments. The facility has been supporting and providing required experimental conditions all the time. Even during the corona pandemic, the NPF was running 24 x 7 supporting the critical experiments without fail.



Identification of pigeonpea genotype with tolerance to water logging in seedling stage

7. SOCIAL SCIENCES AND TECHNOLOGY TRANSFER

Agriculture has been the backbone of Indian economy and primary source of livelihood for about 58 per cent of India's population. Food and nutritional security, rural employment, institutions, improved and environmentally sustainable technologies are important for the progress a nation. Keeping this in view, the school of Social Sciences focused its research on various important aspects such as assessing improved IARI technologies, developed a model linking macro-economic variables, empirically evidenced relationship between farm size and productivity, assessed current status of e-NAM, assessed the functioning performance and supply dynamics of FPO, analyzed the effect of market information on bargaining power of farmers, analyzed the impact of protected cultivation of horticultural crops, studied the impact of new technologies and new approaches, developed innovative extension models, assessed climate resilient technologies, farmer led innovations, gender empowerment, entrepreneurship developmen and reached aspirational districts with improved agricultural technologies. Pusa *Krishi Vigyan Mela* 2020 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 Development of model linking macro-economic variables

As part of policy analysis, an effort was made to estimate important macroeconomic variables *viz.* rural poverty, non-farm employment, agricultural income, and agricultural wages and its determinant with the help of structural equation modelling. Analysis suggested that on an average one percent increase in non-farm employment will reduce the rural poverty by 0.18 percent. It was also found that 1000 rupees per ha. increase in agricultural income will reduce the rural poverty on an average by 0.3 per cent. Agricultural wages strongly influence income and which indirectly affects poverty. Road density and per capita power availability have positive influence on non-farm employment. Further, an in-depth examination of data clearly depicted that there has been an overall decrease in labour force participation rates (LFPR) over the years, particularly in 2017-18 mainly due to decline in female LFPR in rural labour market. However, LFPR in urban labour market increased marginally for both male and female. The employment rates as measured in terms of work force participation rates (WFPR) has declined for both male and female over the years mainly in rural areas. The decline was significantly higher in case of females. Even though there is a marginal decline of WFPR for both gender in urban areas the decline in rural area is much higher. The other important indicator of rural labour market is unemployment rates, which were observed to have increased more for males in both rural and urban areas as compared to females. Agriculture is still the major employer for both the genders, although shows a steady decline over the periods. Manufacturing sector witnessed a slight decrease in terms of employment by both males and females. Based on unit level data of NSSO 2017-18, the impact of rising non-farm employment opportunities on consumption expenditure and poverty levels for North Eastern regions were estimated through Inverse Probability Adjustment Regression approach. The results showed a positive and significant impact of non-farm employment on consumption expenditure while having a negative impact on poverty levels.

7.1.1.1 Farm size and productivity relationship

The farm size and productivity relationship were examined by using primary data collected from the famers. In the first study in semi-arid region

of Karnataka, primary data were collected from 303 sample households and a total of 419 maize cultivating plots. Cobb-Douglas production function was employed using farm size in one model and dummy variables for farm sizes *i.e.*, small and large farms in second model along with other explanatory variables. The negatively significant coefficients of farm size in first model and significant coefficients of dummies for small and large farms in second model confirmed inverse relationship between farm size and productivity in maize cultivation. In the second study, the farm size and productivity relationship and access to irrigation water in paddy cultivation was also investigated using primary data collected from 102 farmers belonged to Eastern Yamuna canal command area of Western Uttar Pradesh (WUP). Of the total selected farmers, 37 and 27 per cent farmers owned electric and diesel operated tube wells respectively and 36 per cent farmers were water buyers from electric (21%) and diesel (15%) operated tube wells. Although, the study area is a canal command area, only one-thirds farmers practiced conjunctive use of canal and ground water. The average cost of water extraction was quite high (₹100/hour) in diesel operated tube wells than that of electric operated tubewells (₹ 43/hr) mainly due to diesel cost. Further, the cost of water extraction was quite high for small farmers (₹ 53/hr) in comparison to large farmers (₹ 35/hr) in case of electric tubewells. The water markets were found to be inefficient in WUP, as selling price were quite high in electric (₹ 60/hr) as well as diesel (₹ 164/hr) operated tubewells than that of the cost of water extraction. However, there is a welfare effect of water markets on buyers as well as sellers as tubewell owners spread their overhead cost and realize some returns, while resource poor buyers are having access to irrigation water. Although, use of irrigation water in paddy cultivation was significantly higher for electric operated tubewell owners than that of buyers and diesel tubewell owner farms, the yields and gross returns were not found to be significantly different in paddy cultivation. It was also observed that the farmers were applying excessive irrigation water in paddy cultivation in this region. Further, a neutral farm size and productivity relationship was observed in paddy cultivation in WUP.

7.1.1.2 Valuation of ecosystem services

A study was conducted to understand and evaluate paddy ecosystem services and disservices, and assess if incentivizing farmers through eco-compensation or payments for ecosystem services could help in conserving fragile and important agro-ecosystems. The Wayanad district in Kerala was selected for the study and around 225 paddy farmers were surveyed in February, 2020. In the study, Markov chain analysis indicated greater stability in area under banana and plantain in Wayanad and Kerala reflecting a shift in cropping pattern towards these crops. As observed from structural break analysis in the study, the 'Kerala Conservation of Paddy Land and Wetland Act, 2008' prohibiting the conversion of paddy fields in the state, could significantly arrest annual reductions in area under paddy to an extent of 11,253 ha in Kerala and 129.4 ha in Wayanad. However, rising area of fallow lands indicate a possible trend of abandoning paddy cultivation and leaving fields fallow. Farmers of Wayanad grow paddy landraces mainly for self-consumption, due to which they perceive consumption aspects of landraces to be most important among varietal traits, as revealed by Friedman rank test. Farmers also grow landraces as part of their tradition and for conservation, and are highly aware of paddy ecosystem services and probable ecological effects of paddy land conversions. Using market price, replacement cost and benefit transfer methods, it was estimated that the paddy ecosystem of Wayanad generates ₹ 6,26,919 per ha worth of ecosystem services annually, of which 77 per cent is non-marketed. Thus, paddy farming in Wayanad brings in externalities worth ₹ 4,82,711 per ha to the region. 'Wayanad Package Scheme 2018' was aimed at financial assistance of farmers growing indigenous paddy in Wayanad, but only around 10 per cent farmers were aware of the scheme. However, around 95 per cent of farmers showed willingness to enrol in eco-compensation programmes as payments for preserving ecosystems would augment farm income and also incentivize conservation. Single bound contingent valuation analysis found a mean compensation of ₹ 7,933 per ha

required for cultivating paddy landraces, which was lower than that proposed by Government. But these amounts are extremely low in comparison to the annual value of services generated by the ecosystem. Thus, the value of ecosystem services needs to be accounted for in eco-compensation framework and farmers should be duly recognized and paid for the invisible fruits of their toil.

7.1.1.3 Performance of e-NAM

A study has been conducted for analyzing current status of e-NAM trading across the states and challenges in e-NAM process with special reference to two selected markets of Tamil Nadu. It was found that in total about 7.2 million tonnes of quantity of commodity are traded in e-markets across the country, since the launching of e-NAM to December 31, 2019. The state-wise analysis indicates that Haryana is the leading state in e-trading with the share of 32% followed by Madhya Pradesh (11%), Punjab (10%), Telangana (9.5%), Uttar Pradesh (9%), Andhra Pradesh (7%), Tamil Nadu (6%), Maharashtra and Rajasthan shares about (5%) each and rest (15%) shared by other eight states and UTs which are linked in e-NAM. As far as the commodities concerned, about 59% of the total traded commodity are cereals, 11% are cash crops, 9% are vegetables, 7% are oilseeds, 6% are pulses and rest of 8% are other crops. In terms of value of trade, about ₹ 21,750 crores are traded in e-NAM in the above-mentioned period. Haryana tops with 34 per cent share of total trade, Andhra Pradesh secures second place with 13 per cent share followed by MP(10.5%) and Punjab (9.7%). Cereals (45%) and cash crops (11%) occupy top two positions in value of trade. For the purpose of analyzing the challenges in e-NAM process two e-NAM markets namely Ammoor and Madurai in Tamil Nadu during February 2020. The licensing is cumbersome process, after a long wait of more than one year after application the trader's licenses are given for inter market transaction. The share of online payment is just 0.05% of total all-India traded value of ₹ 1,00,000 crores as on 4th May in All-India. The prices are quoted per bag and each bag quantity is different across the region/markets for example 65 kg/bag in Madurai for paddy, while 70 kg bag in Ammoor. In general, in Tamil Nadu licenses have been given to traders to purchase outside the market yard (98%) and pay the mandi fees monthly by traders, it also effectively prevents farmers to come forward to e-NAM. The mobile App and desktop App are different features, in the mobile App simultaneously you cannot view all the lots. Therefore, the intermarket transactions are minimum or nil, only e-trading is happening with in the e-NAM.

7.1.2 Performance of farmer producer organizations (FPOs) in Maharashtra

The primary survey conducted in the villages of Yavatmal district of central Marathwada region of Maharashtra to assess the functioning performance and supply dynamics of FPO/FPS's. The members were selected from a number of villages and were facilitating the marketing of red gram through FPO making a supply chain. The members of FPOs gained from the FPOs in terms of better price realization and having access to credit and niche markets. Farmer Producer Organizations (FPOs) were started in 2013-14 with the help of SFAC and NABARD at the national level. There are FPOs in the Yavatmal district of Maharashtra, four FPOs, of which 136 farmers were randomly selected with the help of a pre-tested schedule for primary data collection to examine the performance, determinants, and constraints. About 97 per cent of the members of FPO have at least one extension visit to their fields by the extension agents supported by the FPO. Whereas, 87 percent of the non-members had no extension visits. Besides, around 98 percent of the members have received training on marketing activities, in the case of non-members, was just 2 per cent. Three or more extension visits in a season increase the chance of getting membership by around 50 per cent. Similarly, undergoing training on market activities increases the probability of becoming a member by 63.5 percent. The result of logit regression reveals that extension visits and training given by the NGOs encourage farmers to enroll themselves as a member of FPOs. Lack of awareness among the farmers, marketing risk, less Government support, and nexus between mandies and village traders are the major constraints in the FPOs.

7.1.2.1 Market information and its effect on bargaining power of farmers

The research question in this study was to see if the knowledge of MSP will have on the bargaining power, which should reflect in the final prices' farmer would get in the farm gate negotiation. The expected effect can be called as anchoring effect, which has been found to be a robust effect in different negotiation settings. In the last year, Impact of MSP awareness was estimated on the price received by the farmers in Eastern India. To strengthen the evidence, a similar analysis using nationally representative data, NSSO's situational assessment survey of farmers was performed. The data was collected from 35200 rural households across India in two rounds. From the dataset only subset of farmers who grow rice was selected. The final sample size is 7671 rice farmers, who sold the produce to channels other than the APMC mandi. Out of this, only 2601 farmers were aware about MSP. We tested whether those who are aware about MSP derive higher price than those who are not aware. Coarsened Exact Matching and Nearest Neighbour Mahalanobi's matching methods were used to estimate the impact. The results indicate that the farmers who are aware about MSP don't get a better price than those who aren't aware of MSP in the farm gate negotiations. This could be due to low bargaining power of farmers not only with respect to asymmetric information, but due to immediate cash requirement which impose disproportionately higher cost of waiting for the farmers.

7.1.2.2 Financial feasibility of protected cultivation

This study was undertaken to analyse the status and impact of protected cultivation of horticultural crops in the Pune and Nasik districts of Maharashtra based on primary survey of 200 farmers comprising 120 protected and 80 open field during 2018-19. It was observed that the cumulative area achieved under protected cultivation during the period 2005-06 to 2017-18 under NHM in India was 2.15 lakh ha, of which 88 per cent under plastic mulching and only 4 per cent is under greenhouse/shade net house. While in Maharashtra it was about 0.16 lakh ha, of which 65 per cent under plastic mulching and 17 per cent under shade net house and 10 per cent under naturally ventilated polyhouse. The total establishment cost under protected cultivation was higher in case of rose about ₹ 16.15 lakh followed by gerbera (₹ 13.79 lakh), carnation (₹ 12.99 lakh) and capsicum (₹ 10.05 lakh) for the polyhouse size of 1000 sq. m area. The total cost of cultivation under protected cultivation was higher in case of carnation about ₹ 4.60 lakh, followed by gerbera (₹ 4.59 lakh), rose (₹ 4.49 lakh) and capsicum (₹ 3.14 lakh). While the yield obtained from protected cultivation were 2.22, 2.07 and 1.99 lakh numbers in gerbera, carnation, and rose. Whereas 11325 kgs of capsicum yield were obtained for 1000 sq.m area. The net returns received from protected cultivation were highest in case of carnation (₹ 2.22 lakh), followed by rose (₹ 1.64 lakh), gerbera (₹ 1.63 lakh) and capsicum (₹ 1.04 lakh). The factors like years of education, household income, access to subsidy and risk orientation index were the major determinants in the choice of adoption of protected cultivation technology. About 60 per cent of the farmers are regularly paying loan and factors such as low prices, high input costs and high-interest rates were said to be the main reasons for the non-repayment of loans.

7.1.3 Impact of CFLD on pulse programme in Uttar Pradesh

To assess the impact of cluster front line demonstration (CFLD) the two-year preceding period (2013-15) and two-year recent data (2016-18) on area, production and yield of pulses were taken and analysed. During the period 2016- 18, 23 per cent increase in area under pulses and 29.06 per cent in production was observed. The average demonstration yield of chickpea variety JAKI-9218 is 16.19 q/ha, whereas, the average farmers existing yield is 10.17 q/ha. Thus, by adopting the demonstrated technology 59 per cent increase in yield is expected. The technology gap for chickpea crop variety JAKI 9218 raised during 2015-16 ranges from -4.20 to 12.25. The extension gap ranges from 2.25 to 14.2 and the average for the whole state is a bit on higher side at 6.02. The technology index was much low for many districts while it was high for Banda, Varanasi, Allahabad, etc. The technology index shows

the feasibility of technology under farmer's field. The lower the technology index higher is the feasibility.

7.1.3.1 Impact of mustard variety Pusa Mustard-25

The total economic surplus generated from Pusa Mustard 25 is estimated at ₹ 44694 crores (at 2018 prices) during the period of past 10 years (2010-2028), and was distributed between producers and consumers in ratio of 51:49. The annual average total income for TE 2018-19 is estimated at ₹ 2919 crores and the producer surplus is ₹ 1499 crore and consumers surplus is ₹ 1420 crores. Impact of BGA bio-fertilizer on use of chemical inputs, cost of cultivation, yield and farmers' income in North Western Indo-Gangetic Plains. The use of BGA biofertilizer has led to decrease in urea consumption by 25 per cent, DAP consumption by 17.6 per cent, and potash by 9 per cent. It has led to increase in yield by 3.8 per cent and income by 3.9 per cent.

7.2 AGRICULTURAL EXTENSION

7.2.1 Development of innovative extension model

Assessment of the socio-economic impact of IARI-Post Office Linkage Extension Model revealed that the information source preference 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 were improved satisfaction on extension service, changes in cropping pattern and yield, change in seed management practices, increased social status of post master and increased social security. The visibility of extension interventions conducted by BPMs like on-farm demonstrations and training has increased significantly.

The improved IARI technologies of rice (PS-5), mustard (PM-26, PM 30 and Pusa vijay) were promoted in Darjeeling and Jalpaiguri district of West Bengal. The average yield was ranged between 32-42 q/ha for PS-5 variety of paddy. The performance of mustard variety Pusa Vijay was highly satisfactory and farmers reported an average yield of 12-18 q/ha.

Demonstrations (Nos. 20) of climate resilient technologies (direct seeded rice, zero-till wheat, IPM in cotton) were carried out at village Sangel in Mewat, Haryana. A significant difference ($P<0.01$) in knowledge, skill and adoption of among the farmers. The farmers secured higher benefit cost ratio under direct seeded rice system with varieties Abhishek (1.24) and Sahbhagi (1.21) as compared to conventional transplanted system in Gaya district of Bihar. It instilled conviction among the farmers for adoption of direct seeded rice technology.

Different climate resilient technologies (Nos. 31) like short duration rice variety (PS-5), pheromone trap to control yellow stem borer, brinjal fruit and shoot borer, zero tillage, DSR, mulching techniques, raised bed panting, line sowing, intercropping of jute and moong *etc.* were promoted in 3 adopted villages of Jalpaiguri districts. The findings revealed that the PS-5 was the most popular technology as it is adopted by more than 80 per cent of the farmers. The cultural practices were adopted by 56 per cent, soil fertility management by 37 per cent, and irrigation management by 24 per cent. Seemingly unrelated regression (SUR) was used to identify the predictors of adoption of climate resilient technologies. The important variables determining the adoption of climate resilient technologies were the cost of technology, availability of knowledge, complexity of technology, labour availability, observability, organizational linkage, leadership, scaling up the technology by organization, communication strategy, number of communication channel used *etc*.

The digital content on package of practices of rice was developed and disseminated *via.* mobile phone. Digital agro-advisory services on Darjeeling mandarin was provided through whatsapp group namely "Darjeeling Mandarin" covering the farmers of Darjeeling and Kalimpong hills.

7.2.2 Maximizing farm profitability through entrepreneurship development and farmer led innovations

Innovation generation practices of farm households may also be making impact in poor people's livelihoods

and might form the basis for food security. Farmers being creative are evolving innovations under specific agro-climatic and socio-economic conditions. Farmers' innovations incorporate farmers' wishes, makes use of cheap and locally available material and the technology is easy to adopt and to spread. Farmer led innovations (FLIs) having advantage to tackle second generations' problems require different set of capacities on the part of farm innovators to scale their innovations in addition to be innovative. It can empower individual farmer and rural communities, strengthens link between farmers, extension worker and researcher in such a way that farmer experimentation directs the research agenda and the participatory technology development ensures sustainability of technology. Provision of comparative experiences through knowledge management systems, conflict management approaches, facilitation of multi stakeholder negotiations, building alliances with private sector, marketers and NGOs need to be stressed upon. Farmers need to initiate group action in production process, the mechanism for better remuneration need to be ensured for the extra efforts and the institutional arrangements for networking of stakeholders need to be devised to translate the challenges into opportunities.

In order to develop the model for making farming a business venture and replicating farmers' innovations, following options were prioritized for action interventions in selected project locales.

- Identification prioritisation and implementation of IARI technologies for agri-enterprise ventures uptake based on location and farmers' needs in a participatory mode.
- Six focus group discussions for taking up specialty agriculture production, value addition of selected fruits and vegetable were conducted.
- One farm innovators meets in collaboration with respective ATARIs at Raipur was organised to share the experiences of farmers-led innovations in the field of agriculture and allied sector and to set the ground for networking of farm innovators, research institute and research policy makers for dissemination of farmers' innovations among larger population.
- The lessons learnt from Interaction meets include: the requirement for establishing and maintaining a database of available technologies and innovations, establishing and maintaining a meta-database of agricultural information, facilitating the database to act as a platform for exchange of information and experiences, developing and disseminating theme-based knowledge, publishing lessons learnt from development and adoption of innovation activities., undertake an analysis of partner institutions to assess their potential as participants in maximizing farm profits as primary information centers and building capacity of partner institutions (both human and infrastructure).
- Farm innovators have been involved in IARI led extension programmes and dissemination of IARI technologies through CATAT, IARI, New Delhi.
- ICT based social networking of the farmers through WhatsApp group for sharing of agricultural information is actively maintained and agricultural messages are being shared. On an average 7.88 relevant messages per week are being shared by members. Social networking of farm innovators has proved to be potential to construct knowledge.
- Two training courses (one each in two villages) were conducted for promotion of secondary agriculture.
- Facilitated participation of farmers and farm women in Pusa *Krishi Vigyan Mela* 2020 held at IARI.
- Perceived determinants of entrepreneurial and innovative behaviour were assessed and were found that middle aged farmers belonged to innovative behaviour and financial support translated innovations into income generating activities.
- Three farm women groups formed in earlier years were handheld for income generating activities.

- One farmer already linked with IARI for commercial seed production through participatory seed production programme has been facilitated to continue the programme.

7.2.3 Enhancing nutritional security and gender empowerment

Indian Agricultural Research Institute, New Delhi has developed a low erucic acid (<2% erucic acid of total fatty acids) mustard variety Pusa Mustard-30 to reduce the risk of consumption of high erucic acid related disorders. The results about adoption of PM 30 revealed that among 160 farmers in the study, 63.75 percent of farmers adopted while 36.25 percent of farmers did not adopt the variety. It was also observed that among aware groups, only 35.71 per cent of the farmers adopted whereas among knowledge group, 73.72 per cent of them adopted the variety. There was an adoption gap of 38.01 per cent between both the groups. It clearly showed that knowledge about the health benefits of the variety influenced farmers to adopt that variety. Farmers' preference for a mustard variety results revealed that yield was the most considered attribute in selection of a mustard variety (58%) followed by oil content (22%), taste of the mustard oil (8%) and resistance to pests and diseases (5.5%).

The distribution of households based on food consumption (FCS) shows that majority of households (50.0%) belonged to the borderline (28-42) followed by acceptable (38.00%; >42) and only 12 per cent belonged to the poor category (<28). Further FCS of beneficiaries was slightly higher score than non-beneficiaries. It was observed that number of beneficiaries in borderline and acceptable FCS category were more than non-beneficiaries. The determinants analysis to find out the factors which influenced farmers to adopt nutri rich varieties revealed that for male headed households, level of education, membership of associations and access to credit; whereas for female headed households, access to credit and membership of associations were the important factors which influenced them to adopt new varieties.

The propensity to score matching (PSM) impact model findings indicated that positive and significant differences among nutri-rich variety adopting households (45 HHs) and non-adopting households (55 HHs) in selected food and nutrition security proxy variables like food consumption score (FCS). Farmers cultivating nutri rich variety were found more secure than non-cultivators in terms of food and nutritional security.

Under Agri-Nutri (A2N) Smart Village model, various capacity building activities are carried out. Nutri-rich seeds of IARI variety (under A2N Village Model) *i.e.* 500 kg of Wheat (WB 02 & DBW-173) from IIWBR, Karnal, 288 kgs of Summer moong (Pusa Vishal), 547 Pusa kitchen garden kit were demonstrated farmer's field.

Kitchen garden in Lachoda village

7.2.3.1 DBT project -expansion activities of biotech kisan hub in three aspirational districts of Rajasthan, one aspirational district of Haryana and three aspirational districts of UP

The project interventions were made in 7 aspirational districts (Dholpur, Karauli and Baran in Rajasthan; Mewat in Haryana; and Shrawasti, Balrampur, and Bahraich in Uttar Pradesh). A total of 185 demonstrations of improved varieties of wheat (HD 2932, HD 2967, and HD 3086) and mustard (Giriraj), bio-fertilizers (PSB,VAM, *Azotobacter, Trichoderma*, Pusa Sampoorn (NPK), ZNSB), and carrot (Pusa Asita and Pusa Rudhira) were laid out in Dholpur aspirational district of Rajasthan. Vegetable kits for homestead nutri-gardens (Poshanvatika) were provided to 100 households and 194 farmers were educated about the improved cultivation practices. The demonstrations of improved varieties of wheat (HD 3086 & HD 2967),

bio-fertilizers (PSB, *Azotobacter* and Pusa Sampoorn) and vegetables were conducted covering 137 farmers in the Karauli aspirational district of Rajasthan besides providing kitchen garden kits to 100 households for nutritional security and capacity development of 110 farmers in improved crop management practices through training, *kisan gosthies* and field visits. During the *kharif* season, demonstrations of paddy variety Pusa-1121 and BGA bio-fertilizer were conducted in 10 hectares engaging 20 farmers, while 155 farmers were trained in improved cultivation practices and 286 farmers were benefitted through *kisan gosthies* and field visits in Baran aspirational district of Rajasthan. The orchards of papaya variety (Red Lady) were laid out in 5 hectares engaging 15 farmers. The demonstrations were also conducted during the *rabi* season for the improved varieties of wheat (HD 3086, HD 2967), mustard (Pusa 28), Garlic (G 282), bio-fertilizers (Pusa Sanjeeni, Pusa Sampoorn, and VAM), and Pusa decomposer covering 77 farmers, while 150 farmers were trained in improved crop cultivation and 280 farmers were benefitted with *kisan gosthies* and field visits. The interventions in Mewat aspirational district of Haryana included demonstrations of improved varieties of paddy (Pusa Basmati 1121, Pusa Basmati 1509 and Pusa Basmati 1718), wheat (HD 3086, HD 2967, and HD 3226), vegetable crops (Carrot –Pusa Vasudha and Radish –Pusa Chetki), bio-fertilizers, and Pusa Decomposer for in-situ crop residue management, engaging 113 farmers. Demonstrations of improved varieties of wheat (HD 3086 and HD 3226), mustard (Pusa Mustard 28), marigold (Pusa Narangi), vegetables and bio-fertilizers were laid out in the fields of 85 farmers in Shrawasti aspirational district of Uttar Pradesh. Nutri-garden kits were provided to 100 farmers for household nutritional security. Orchards of tissue cultured banana (cv. Grand Nain), litchi (cv. Poorvi and China) and guava (cv. L-49 & Allahabad Safeda) were established in the fields of 10, 15, and 7 farmers, respectively. Training on crop diversification with vegetables and flowers; wheat and mustard cultivation, homestead nutri-garden; management of pest of vegetable crops, use of bio-fertilizers, crop residue management were organized, which benefitted 290 farmers. In Balrampur aspirational district, demonstrations of improved varieties of paddy (Pusa 44, PNR 381, Pusa 2511, Pusa Samba 1850), bio-fertilizers (PSB, BGA and *Azotobacter*), improved varieties of vegetable like lobia (Pusa Dharni), sponge gourd (Pusa Sneha), bottle gourd (Pusa Santusthi), cauliflower (Pusa Ashwini & Pusa Kartik) were organized with 81 farmers. The orchards of mango (cvs. Mallika, Chausa, and Dussehri); Litchi (cvs. Chinaand Shahi), and tissue cultured banana (cv. Grand Nain) were established in 3 acres. Through capacity building interventions 159 farmers were benefitted. Demonstrations of improved varieties of wheat and mustard as well of bio-fertilizers were laid out in 115 acres in Bahraich aspirational district of Uttar Pradesh, while nutri-garden kits were provided to 25 farmers for household nutritional security.

National agriculture women day celebrated on October 15, 2020 at KVK, Bahraich,UP

7.2.3.2 Establishment of Biotech-KISAN Hub at Chitrakoot

Engaging 326 farmer beneficiaries, demonstrations of improved varieties of paddy (Pusa Sugandha-5, Pusa Sambha 1850), pigeonpea (Pusa 16), greengram (Pusa 9531), Sesame (Pragati), Okra (Pusa Sawani) and cowpea (Pusa Komal) were laid out in 205.5 acres; while demonstrations of use of bio-fertilizers and improved varieties of vegetables were laid out in 29 acres and in 9.2 acres, respectively during *kharif* season. Fruit orchard of guava and mango were established in 0.8 acres. Fifteen trainings and six *Kisan -Gosthies* and 25 field days were organized during *kharif* season for enhancing the knowledge and skills of the farmers and a total of 333 farmers were benefitted. Kitchen

Distribution of IARI-kitchen garden seeds

Demonstration of bio-fertilizer at farmers' field

garden kits containing vegetable seeds were provided to 190 farmers to promote vegetables' consumption and nutritional security through their cultivation in homesteads. Three training programmes on value addition of agricultural produce; Integrated disease management, and use of bio-fertilizers were organized in which 47 farmers participated.

7.3. TECHNOLOGY ASSESSMENT AND TRANSFER

7.3.1 Outscaling agricultural innovations for enhancing farm income and employment

During *rabi* 2019-20, the project was in operation at four villages namely Khajurka (Palwal, Haryana), Kutbi (Muzaffarnagar, U.P), Rajpur (Aligarh, U.P) and Beenjpur-Raghunathpura- Ramchandrapura cluster (Alwar, Rajasthan). The performance of location-specific improved varieties of wheat, mustard, lentil, onion, gram, pea, palak and marigold were assessed through 455 trials over an area of 142.68 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 villages.

At Rajpur, wheat varieties HD 2967 (6.02 t/ha), HD 3086 (5.65 t/ha), HD 3059 (4.62 t/ha), HD 3237 (5.86 t/ha), HD 3226 (5.78 t/ha) and HD CSW 18 (6.07 t/ha) yielded higher than local check (5.0 t/ha). Net profitability was the highest for HD 2967 (92789 ₹/ha). Mustard demonstrations of Pusa Jagannath (2.73 t/ha) reported 9.40 percent increase in yield with net profitability of 86900 ₹ /ha. In pulses, Lentil demonstration of varieties L 4076 (1.46 t/ha) and L 4717(1.53 t/ha) yielded 17.2-22.8 per cent higher to local check.

In Khajurka, Palwal (Haryana) six wheat varieties were assessed. Among timely sown varieties, the highest average yield was obtained for HD 3237 (5.86 t/ha). The average yield of late sown wheat variety HD 3059 was (5.27 t/ha). The varieties HD 3226, HD 3086 and HD CSW 18 have good chapatti making quality. Lentil variety L-4076 preferred for bold grains, higher average yield of 1.28 t/ha with an economic gain of ₹ 41,750/- per ha as compared to local check yield (1,25 t/ha) and economic gain (₹ 31,000/-.)

At Beenjpur, among five timely sown wheat varieties, the highest average yield was recorded in HD CSW 18 (6.97 t/ha) followed by HD 3226 (6.48 t/ha), HD 2967 (6.35 t/ha) and HD 3086 (6.24 t/ha) compared to local check WH 711 (5.55 t/ha). Mustard variety Pusa Jagganath 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 Jagganath (1.91 t/ha).

At Kutbi, 35 wheat demonstrations covering 35 acres area of high yielding varieties *i.e.* HD CSW 18 (3 acres), HD 3086 (20 acres), HD 3237 (2 acres), HD 3226 (5 acres) and HD 3059 (5 acres) were laid out at farmers field. The performance of IARI wheat varieties was found superior as compared to local check however, lodging was observed in wheat variety HD CSW 18. The highest yield of HD 3086 (4.67 t/ha) was recorded with 33.57 per cent yield gain over local check.

7.3.1.1 Results of *Rabi* Crop Demonstrations (2019-20)

Village	Crop	Variety	Yield Demonstrations (t/ha)	Average . yield of local Check t/ha	(%) Increase in yield over local check	Average net return, (₹/ha)	
						Demonstration plot	Local Check plot
Khajurka Palwal (Haryana)	Wheat	HD2967	5.85	5.00 (HD2851)	17.12	88833	73125
		HD3086	5.49		9.88	82190	73125
		HD3237	5.86		17.32	89015	73125
		HD CSW - 18	5.34		6.80	79370	73125
		HD3226	5.60		12.10	84231	73125
		HD3059	5.27	4.65 (Raj3765)	13.44	78174	66703
	Lentil	L-4076	1.28	1.05 (Local)	2.24	41750	31000
Rajpur, Aligarh (UP)	Wheat	HD2967	6.02	5.0 (HD2967)	20.56	92789	76250
		HD3086	5.65		13.16	85766	76250
		HDCSW-18	5.72		14.36	86396	76250
		HD 3237	5.86		17.30	89751	76250
		HD 3226	5.78		15.70	87861	76250
		HD3059	4.62	4.0 (PBW373)	15.63	69181	59500
	Mustard	Pusa Jagannath	2.73	2.5 (Pioneer)	9.40	86900	80000
	Lentil	L 4076	1.46	1.25 (Deshi)	17.20	48680	40000
		L 4717	1.53		22.80	52320	40000
Beenjpur, Alwar (Rajasthan)	Wheat	H.D-2967	6.35	5.55 (WH-711)	14.46	15360	90087
		H.D-3086	6.24		12.54	105965	90087
		C.S.W-18	6.97		28.59	123522	86935
		H.D-3237	6.50		19.92	112125	89360
		H.D-3226	6.48	5.32 (Raj- 3765)	21.80	111640	84510
	Mustard	Pusa Jagannath	1.91	2.35 (coral-432)	-18.72	50540	70900
Kutabi, Muzaffarnagar (UP)	Wheat	HD3086	4.67	3.5 (PBW 226)	33.57	62164	42700
		HDCSW-18	3.95		12.85	48340	42700
		HD 3237	3.85		10.0	46420	42700
		HD 3226	4.5		28.57	58900	42700
		HD3059	3.55		1.42	43160	42700
	Mustard	Pusa Jagannath	1.65	1.2	37.50	47500	29500

During *Kharif 2020*, a total of 91 assessment trials were conducted at village Nidana, Rohtak (Haryana) and Village Bhagwanpur, Meerut (UP) on paddy varieties (PB-1121, PB-1509 and PB-1718) and Moong Bean (Pusa 9531, Pusa Vishal and Pusa 1431) covering an area of 35.30 ha. An assessment of the spread of IARI wheat varieties as a result of regular demonstrations from 2014-15 to 2019-20 are presented as under:

7.3.1.2 Assessment of horizontal spread of wheat varieties

Total area spread (ha) of different wheat varieties over the years in the project villages

Wheat varieties	Location	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
		Total area spread (ha)					
HD 2967	Khajurka	6	51.6	250	282	418	468.2
	Rajpur	6.4	55.52	251.33	300.79	317.03	383.2
HD 3086	Khajurka	2 .0	21.2	102.5	203.6	124.6	158
	Rajpur	2.0	20.72	97.23	220.67	143.38	166.01
HD 3059	Khajurka	2	9.9	25	33	34	33.2
	Rajpur	3.6	18.11	39.14	35.51	25.9	30.56

7.3.1.3 Interventions on kitchen gardens

Based on the assessment of nutritional status, awareness level and consumption pattern of rural households on nutritional food and dietary pattern were assessed and nutri-garden were promoted at farmers' field by providing vegetable kits for promoting crop diversification and enhancing nutritional security.

Vegetable	Variety	Village
Onion	Pusa Red	Rajpur, Khajurka, Beenjpur
Onion	Pusa Ridhi	Rajpur, Beenjpur
Palak	Pusa Bharti	Rajpur
Palak	P- all Green	Khajurka
Carrot	Pusa Rudhira	Rajpur, Beenjpur
Methi	PEB	Rajpur, Beenjpur
Pea	P-Pragati	Khajurka
Vegetable Kits	Assorted vegetables	Kutbi

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 project 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 climatic based Agro-advisory from the Institute. Exposure visits of farmers from project villages during *Krishi Vigyan Mela* 2020 at IARI was conducted.

From *Kharif* 2020 Two new villages have been selected under the project, namely Nidana, Block Mahem (Rohtak, Haryana) and Bhagwanpur Chittawan (Meerut, U.P). The analysis of existing farm production system was carried out through participatory tools and techniques involving farmers. The benchmark survey and participatory agro-ecosystem analysis was conducted to identify the resources and agricultural related problems in the area. In Nidana village, on analyzing the farmer's categories based on size of their landholding, it was found that majority of farmer (53.3 per cent) were landless, followed by small landholder (have one to two hectare of lands) (32.6 per cent) . The total cultivable land is 920 ha and 75 per cent of the households are engaged in agriculture.

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 crop trials of 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 and promoted through demonstrations, training, field days *etc.* by the partner organizations.

During *rabi* 2019-20 under NEP collaborative program with ICAR institutes and SAUs,197 demonstrations involving 22 varieties of 9 crops were conducted covering an area of 34.16 ha. 79 Wheat demonstrations on IARI varieties HD 2967, HD 3059, HD 3086, CSW 18, HD 2932, HD 3237 and HD 3226 was carried out in an area of 23.46 ha in 10 locations. 25 demonstrations on Mustard Pusa Jagannath, Pusa Tarak and PM 31 variety was conducted in 6.4 ha. The lentil (Var. L 4076, L 4147), Onion (var. Pusa Red, Pusa Riddhi), Gram (var. Pusa 3022, Pusa 372 and Pusa 547), Palak (var. All green, Pusa Bharti), Pea (var. Pusa Pragati), Marigold (var. Pusa Basanti and Pusa Naragi) were also demonstrated to the farmers in 36 locations. During *rabi* 2019-20, 433 demonstrations covering 28 varieties of 13 crops in an area of 102.80 ha were conducted in collaboration with voluntary organizations. The wheat varieties *viz*., HD 2967, HD 3086, HD CSW 18, HD 2932, HD 3118, HD 3226, HI 1620 and HD 3059 were demonstrated in 206 ha. A total of 227 demonstrations of mustard (var. Pusa Jagannath and Pusa Tarak) was conducted in 104 ha. The lentil (var. L 4076 and L 4147), onion (var. Pusa Red, Pusa Riddhi), gram (var. Pusa 3022 and Pusa 372), palak (var. All green and Pusa Bharti), pea (Var. Pusa Pragati), marigold (var. Pusa Basanti and Pusa Naragi), carrot (var. Pusa Rudhira) and fenugreek (var. PEB). The feedback on IARI varieties from the various institutions was as follows:

The wheat variety HD 3086 was found to be highly suitable under timely sown irrigated condition and high grain yield and manifested resistance to yellow rust. Its area increased from 5.67 per cent in 2017-18 to 14.38 per cent in 2019-20 (KVK, Kathua). In the hilly terrain of Kangra, the CSKHPKV, KVK reported satisfactory performance of wheat HD 2967. This champion variety of IARI performed well consistently with 4.35 t/ha yield and 55.36 per cent increase over local check (PRDF, Gorakhpur). There the variety saturated 70 per cent of the mandate area. At the site of FARMER, Ghaziabad and HESCO, Dehradoon, also, HD 2967 recorded 5.53 t/ha yield. At Varanasi, the FAARD foundation recorded 25 per cent yield increase in HD 2967. ISHARA, Deoria also reported 13.15 per cent yield increase of the variety with an average yield of 5.04 t/ha. At HESCO the wheat HD CSW also performed well. The wheat variety HD 2932 excelled in farmers' field with 4.15 t/ha average yield which was an increase of 14.64 per cent over the yield of local check. It was liked due to high yield, resistance to water stress, low pest and disease incidence (MPKV, Rahauri). At MPUAT, Udaipur, HD 2932 recorded 6.57 per cent increase in yield. The variety recorded average yield of 2.44 t/ha and a net economic gain of ₹ 19,470/- per ha in dry region Jhansi (RLBCAU, Jhansi). Vidya Bhawan KVK also reported good yield performance of HD 2932 with 98 cm plant height, 55 grains per ear and good ear length of 9.3 cm.

At DRMR, Bharatpur HD 2967 and HD 3086 was highly preferred due to strong stem, long spikes, more tillering with high production potential. Wheat variety HD 2967 also performed well with 29.9 per cent increase in yield over local check at KVK, Bhadohi. The non lodging character was also preferred. There is a demand for nutrient rich wheat varieties e.g. Pusa Malvi and Pusa Poshan of Indore centre of IARI from MPUAT, Udaipur to address the malnutrition problem of their area.

The mustard varieties Pusa Tarak and Pusa Jagannath performed well with 1.62 and 1.88 t/ha yield and 3.85 per cent and 4.4 per increase in yield, respectively at KVK, Bhadohi. SHDA, Kushinagar reported 1.22 t/ha average yield of Pusa jagannath. Pusa Jagannath was liked due to profuse branching and Pusa Tarak was for short duration and higher (40 per cent) oil content. At RLBCAU, Jhansi the mustard varieties PM 31, PM 28 and PM 26 recorded economic gain of ₹ 9811/-, ₹ 13,087/- and ₹ 10,369/-, respectively. The farmers preferred bold seeded high yielding mustard varieties.

Lentil L-4076 and Pusa Shivalik along with gram variety P-3022 performed satisfactorily at the sites of KVK, Kangra and L-4076 recorded 23.53 per cent higher yield than local check at KVK, Bhadohi. PRDF, Gorakhpur also reported 36.11 per cent yield increase

in L-4076 over local check and that in case of gram P 3022 was 60.54 per cent.

The vegetable varieties also performed satisfactorily in different parts of country. At Hamirpur, Himachal Pradesh, the farmers appreciated for vegetable demonstration in kitchen garden. Pea variety Pusa Pragati recorded 11.28 per cent yield increase with 7.79 t/ha of average yield of green pod at HESCO, Dehradun. The onion varieties Pusa Riddhi and Pusa Red were preferred by many farmers. Both the varieties were highly preferred in Odisha, as reported by NRRI, Cuttack for their long shelf life and flavour. Pusa Red yielded 23.0 t/ha at SHDA, Kushinagar. KVK Chomu reported the large scale spread of Pusa Madhavi among farmers. The Palak variety Pusa Bharati was liked for high nutrient and Pusa All green was liked for its multi-cut trait at Odisha. KAU, Thrissur also reported good performance of Pusa All green. CIARI, Port Blair reported that Pusa All Green and Pusa Bharti recorded yield increase of 86 to 106 percent over that of the local check. The green leaves fetched higher market price.

Group formation and production of value added products and seeds are going at various partner organizations. PRDF, Gorakhpur and YFA, Rakhra, Punjab are already involved in seed production. PRDF Gorakhpur has produced 303 q of TL seed. Under the program, a women farmers group '*Mahila Sahbhagita Jaivik Utpadak Samooh*" has been formed at village Sirrora, Salempur, Ghaziabad for small scale value addition enterprises by VO partner FARMER, Ghaziabad. The five FPOs developed by NRRI, Cuttack also have started paddy seed production. MPKV, Rahauri has planned to develop seed bank in collaboration with NSC and Maha Beej.

During *Kharif* 2020, under NEP, 200 demonstrations on 7 crops with 16 varieties covering an area of 51 ha were conducted at 11 locations of ICAR Institutes/ SAUs. Under paddy crop, 129 demonstrations were carried out with the paddy varieties *viz.*, Pusa 2511, Pusa 1850, PB 1728, PB 1509, PB 1121 and PB 1401 in an area of 38.5 ha. Also 71 demonstrations of other crops like arhar (var. Pusa 16, Pusa 991 and Pusa 992), Moong (Pusa Vishal, Pusa 9531 and Pusa 1431), Bottle gourd (Pusa Naveen, Pusa Santusthi), Sponge Gourd (Pusa Sneha) and Amaranths (Pusa *Lal Chaulai*) were conducted. In collaboration with voluntary organisations, 190 demonstrations on 6 crops with 17 varieties covering an area of 80 ha were conducted at 17 locations of voluntary organizations. Under paddy crop, 247 demonstrations were carried out with the paddy varieties *viz.*, Pusa 2511, Pusa 1850, PB 1728, PB 1509, PB 1121, PB 1401 and P 44 in an area of 65 ha. Also 118 demonstrations of other crops like arhar (var. Pusa 16, Pusa 991 and Pusa 992), moong (Pusa Vishal, Pusa 9531 and Pusa 1431), bottle gourd (Pusa Naveen, Pusa Santusthi), sponge gourd (Pusa Sneha) and Amaranthus (Pusa Lal Chavlai) were conducted.

7.3.2.1 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 selected villages to climatic variability and climate change through strategic research on adoption and mitigation. During the reporting period, 140 demonstrations of wheat HD 2967 and HD 2733 were laid which shows an average 8-10 per cent increase in yield. For crop diversification, chickpea P 256, mustard Pusa Tarak, moong Pusa Vishal and Sunhepm (*dhaincha*) as green manure crops were also introduced in 145 acres of farmers' field. Besides, 10 demonstrations on IPM and 160 demonstrations on bio-fertilizers were also conducted. In *Kharif* 2019, 100 demonstrations on paddy PNR 381 was laid at the location and the variety proved better performer than the local.

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* 2019-20, 26.1 t of HD-2967 and 4.2 t of HD 3118 wheat seed was produced at PRDF Gorakhpur, and 7.13 t seed of wheat HD 2967, 11.6 t of HD 3086, 15 t of HD 3226 and 6.2 t of HI 1620 were produced at YFAP, Rakhra.

During k*harif* 2020, 5.7 t of PB-1509, 38.2 t of Pusa-44 and 2.2 t of PB-1121 and 6.2 t of PB-1718 seed were produced at Rakhra.

7.3.4 Front line demonstrations on wheat

During *rabi* 2019-20, 18 FLDs of wheat were conducted at the villages Prangarh and NaglaTasi in Bulandshahar and Meerut districts of Uttar Pradesh in collaboration with IWBR with newly released wheat variety HPBW- 01 and variety HD 3226 with zero tillage and use of bio-fertilizer (*Azotobacter* + PSB). The zero-tillage practice saved ₹ 4500/ha. the cost of ploughing, gave 3% 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* 2019-20, 400 demonstrations on wheat varieties (HD 2967, HD 3086 and HD CSW 18) and 350 demonstrations on mustard (Pusa Mustard-28 and Pusa Mustard-31) were conducted at 82 and 73 locations in an area of 80 ha and 140 ha, respectively.

7.3.6 *Pusa krishi vigyan mela 2020*

Pusa *krishi vigyan mela* 2020 on the theme "IARI Technologies Towards Achieving Sustainable Development Goals" was organised at the IARI *mela* ground from March 1-3, 2020. The *mela* was inaugurated by Shri Narendra Singh Tomar, Hon'ble Union Minister of Agriculture and Farmers Welfare, Panchayati Raj and Rural Development, Government of India. The inaugural function was presided over by Honorable Minister(s) of State for Agriculture and Farmers Welfare, Sh. Parshottam Rupala and Sh. Kailash Choudhary. Dr. Trilochan Mohapatra, Secretary, DARE & Director General, ICAR, was the Guest of Honour. During the inaugural session, other dignitaries present on the dais were Dr. T.R. Sharma, DDG (Crop Science), Dr. A.K. Singh, DDG (Agri. Extn.), Dr. A.K. Singh, Director IARI, Dr. J.P. Sharma, Jt. Director (Extension) and Dr. J.P.S. Dabas, I/C, CATAT.

Farm technologies developed by the Institute for sustainable agricultural development were displayed in a huge thematic *pandal*. Besides, live demonstrations on improved crop varieties, vegetables production technology, IFS Models, farm machineries were conducted to provide first-hand experience to farmers and were the major attractions of *mela*. Farmers were provided free of cost 'Farm Consultancy Services' including soil and water testing at the *mela* site by the agricultural scientists. In all, 950 farmers got benefitted through these consultancy services. About 400 soil samples and 110 water samples brought by the farmers were also tested. Health camp 'One Health' was also organised first time provided 769 registrations, 403 advisories and 440 eye checkup was an additional highlight of the *mela*.

A total of 270 stalls were put up by ICAR Institutes (53), SAUs (4), public sector organization (11), private organizations (116), NGOs (8), farm entrepreneurs (68) and Flower show (10) from across the country through which they displayed their technologies and products. The *mela* also provided a platform to many organisations and progressive farmers to directly sell their agri-products to the consumers.

More than 80,000 visitors from different parts of the country including farmers, farm women, extension workers, entrepreneurs, students and others visited the m*ela*. Farmers from 24 States *i.e.*, Uttar Pradesh, Delhi, Haryana, Rajasthan, Kashmir, Jharkhand, Chhattisgarh, Nagaland, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Gujarat, West Bengal, Maharashtra, Kerala, Bihar, Orissa, Uttarakhand, Himachal Pradesh, Karnataka, Assam, Arunachal Pradesh, Mizoram, Tripura and Manipur visited the *mela*. About 4000

farmers from institute's project and MGMG villages in UP, Haryana and Rajasthan were also mobilized to visit the *mela.*

Four technical sessions were organised on different themes of agricultural importance. The technical session 1 on "Agricultural Technologies for Sustainable Production and Nutrition Security" was chaired by Dr. T.R. Sharma, DDG (Crop Science). On the second day- 2nd March, there were two technical sessions. In the forenoon, the technical session 2 "Sustainable Development Goals and Gender Equality" was co-chaired by Dr. R.B. Singh, Chancellor, CAU, Imphal and Dr. Shridhar Dwivedi, Senior Consulting Cardiologist, National Heart Institute. The technical session 3 "Natural Resource Management for Eco-Friendly Development" was chaired by Dr. A. K. Singh, Secretary NAAS and former VC, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior. On the third day- 3rd March, in the forenoon, session 4'Innovative Farmers Meet' was organized. Dr. K. V. Prabhu, Chairperson, PPVFRA was the Chief guest In this session, the awardees Innovative Farmers and Fellow Farmers shared their rich experiences of farming and innovations practiced by them.

Seeds of high yielding varieties of different crops worth ₹ 46.80 lakhs and bio-fertilizers worth ₹ 1.20 lakh were sold through Pusa Seed Sale Counter during the *mela* period. Revenue generated through advertisements in m*ela* souvenir was ₹ 47000. 70 STFR meters were also purchased/booked during *mela* time.

Fourteen publications useful for farmers and agri-entrepreneurs including *mela* souvenir, *Prasar Doot, Pusa Surbhi*, Fellow and Innovative Farmers: 2020, Crop Cultivars for farmers' prosperity, *Phal evam sabjiyon ke mulyavardhan ki saral vidhiyaan, Khadyann evam udhyan phasle,* Carrot Pusa Rudhira: A Success Story, Yes, You can Launch Your Own Enterprise: Beginners Guide, Impact of cluster frontline demonstration on pulses in northern India, Insecticides for pest management in agricultural crops, *Khadyann bhandaran ke pramukh keet evam unka prabhandan, Swasth ke liye poshan* and *phasal utpadakta badhane hetu krishi bhautikiy taknikiyaan* were released.

The valedictory function was graced by Sh. Kailash Choudhary, Honorable Minister of State for Agriculture and Farmers Welfare. Prof. Ramesh Chand, member, Niti Ayog, Dr. Trilochan Mohapatra, Secretary, DARE and Director General-ICAR, Dr. A.K. Misra, Chairman, ASRB and Dr. R.C. Aggarwal, DDG (Education), ICAR were the Guests of Honour. IARI Fellow and IARI Innovative Farmers' Awards were bestowed to 5 and 39 farmers respectively. The awarded farmers included 5 women entrepreneurs and they belonged to 26 States/UTs of the country

7.3.7 Participation in off-campus exhibitions

CATAT organised/participated in one national agricultural exhibition for display /sale of IARI technologies, products, services and publications.

Participated in *Krishi Mela* 20 organised by University of Agricultural Sciences, Dharwad from January 18-20, 2020.

7.3.8 Agricultural Technology Information Centre (ATIC)

Agricultural Technology Information Centre (ATIC) was established in IARI is providing a single window delivery system for the Institutes' products, services and technologies to the farmers/entrepreneurs etc. During Covid-19 lockdown period, ATIC sale window was opened from April 11, 2020 for the benefit of the farmers.

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-PRI line), 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 & advisory needs of the visitors

are also being catered through touch panel *kiosks*, revolving scrollers, LED display boards, information museum, plant clinic, farm library and exhibits related to agriculture implements, seed samples, bio-fertilizers displayed at the centre. In ATIC crop *cafeteria*, laid out live demonstrations of *kharif* Paddy varieties and *rabi* live demonstrations of wheat varieties were showcased for the benefit of the farmers.

A total number of 24,590 farmers/entrepreneurs, development department officials, students, NGO representatives etc. from 15 states of India visited ATIC during the year for farm advisory, diagnostic services, purchase of technological inputs/ products.

Pusa seeds of worth ₹ 25, 81, 115/- and farm publication for ₹ 22, 530/- 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 350 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.

7.3.9 *Krishi Vigyan Kendra* (KVK), Shikohpur, Gurugram

7.3.9.1 On farm trial (OFTs) and Frontline Demonstrations (FLDs)

OFTs on Integrated nutrient management in pearl millet: Low productivity and profitability of Pearl Millet was observed in Gurugram district (19.5-29.5 q/ha) due to low level of organic carbon and imbalance application of nutrients by farmers, so an OFT was organized on Integrated nutrient management in pearl millet was assessed at Sakatpur village in 4 ha area of Gurugram district involving 10 beneficiaries. Farmers are using fertilizers as 60:40:0 NPK kg/ha whereas recommendations are 60:30:30 NPK kg/ha. Intervention was 10 t FYM + soil test based NPK + NPK liquid fertilizers@ 10 ml/kg seed as seed treatment. Results revealed that pearl millet grain and fodder yield under intervention group increased by 17.08 and 13.91% over farmers practice respectively with B:C ratio of 2.34. Adoption of INM in pearl millet increased soil fertility also.

OFT on Integrated nutrient management in pearl millet

Frontline Demonstrations on pearl millet: FLD under AICRP on pearl millet was organized for 14 ha area, where in 4 ha area under fortified variety HHB-299 which is high in iron and zinc and rest 10 ha area is under improved hybrid, benefitting 24 farmers of the district.

Frontline Demonstrations on Pulses: FLD under NFSM pulses was organized for 50 ha area, where in 20 ha area under pigeon pea (variety Pusa Arhar -16) and 20 ha area under Summer moong (variety MH-421), chick pea 10 ha (CS-J515) benefitting 85 farmers of the district.

Frontline Demonstrations on oilseeds: FLD under NFSM oilseeds was organized for 75 ha area in Gurugram where in 50 in Mewat under *Krishi Kalyan Abhiyan*- III. The mustard variety PM-31 was demonstrated in 60 ha area and 25 ha area under RH 749 and RH 725 was under 40 ha, a total of 273 demonstrations were benefitting 273 farmers of the Gurugram and Mewat districts of Haryana.

Frontline Demonstrations on wheat: FLD on wheat was organized for 7.6 ha area, benefitting 19 farmers of the Gurugram district for wheat varieties HD- 2967 and HD- 3237.

7.3.9.2 Training under KKA-III

Training under KKA-III: Twenty four trainings on Diversified Agriculture was organized for 861 farmers

Vocational Training Programmes for rural youth

Sl. No.	Training title	Participants	Duration (Days)	Dates	Sponsored
1	Protected Cultivation	16	21 days	Feb 24 to March 15, 2020	ARYA
2	Dairy Farmer/Entrepreneur	20	25 days	Feb 24 to March 21, 2020	ASCI
3	Floriculturist (Protected Cultivation)	20	25 days	Feb 24 to March 21, 2020	ASCI
4	Mushroom cultivation	36	14 days	Sept 18-24, 2020 Oct 6-12, 2020	ARYA

of Aspirational district Nuh of Haryana under *Krishi Kalyan Abhiyan* phase III.

Farmers Training: Thirteen day-long trainings on weed management, seed production, INM and plant protection measures of *rabi* crops, drudgery reduction technologies income generation activities for women empowerment, minimization of nutrient loss in processing were organized benefitting 269 farmers and farm women.

7.3.9.3 Agricultural extension activities

Awareness on *Meghdoot* App: Seven awareness programme for "*Meghdoot* App" under *Gramin Krishi Mausam Sewa*, a collaborative project of IMD and ICAR being implemented by KVK, Shikohpur, Gurugram were organized in the district at Sakatpur, Basunda, Tajnagar, and Sanpka, Raiseena village of Sohna block, Tripadiand Farrukhnagar of Gurugram district in March and August 2020 wherein a total of 245 farmers and farmwomen had participated.

Field days: Five field day programmes were organized as field day cum farmers' training were organized on different aspects.

Direct Webcast of Global Potato Conclave: The PM Shri Narendra Modi had directly addressed the Global Potato conclave on 28th January 2020, which was webcasted at Kakrola village of Gurugram district, where in 32 farmers of village had been benefitted. A *kisan gosthi* was also organized to solve the farmer's problems.

Celebration of International women's day: KVK celebrated International Women's Day on March 08, 2020 at KVK campus in which 64 women from Shikohpur and nearby villages had participated including *AaganWadi* Workers

Celebration of world environment day: KVK celebrated World environment day on June 05, 2020 at KVK campus by planting 130 fruit (Mango, Aonla and Guava) and 30 plants of Kinnow, Guava and Aonla were given to farmers of Tirpadi village of Farruknagar block of Gurugram district for development of Vatika.

Scientific advisory committee meeting: 34th SAC meeting of KVK Gurugram held on 28th August 2020 thorough Zoom cloud meetings at 11.00 AM to 1.30 PM.

***Parthenium* awareness week:** *Parthenium* Awareness Week (August 16-22) was observed August 16-22, 2020. Two awareness programmes were organized on 17th and August 22, 2020 at Raiseena village of Sohna block and Tripadi village of Farrukh Nagar block where in 45 farmers have participated.

Soil health campaign and world soil day: 18 soil health campaigns were organized in 18 different villages of

Celebration of World soil day

Gurugram and Nuh district of Haryana benefitting 784 farmers. World soil day was organized on December 5, 2020.

7.3.10 Transfer of technologies through IARI regional stations

7.3.10.1 Regional Station, Indore

Wheat frontline demonstrations: Total of 18 demonstrations of 5 varieties were conducted in 10.20 ha area conducted in 4 villages of Indore and Dewas Districts in M.P. Overall average increase in yield was 13 q/ha or 30% in these demonstrations.

Wheat demonstrations in tribal area (TSP): Total of 27 demonstrations of 5 varieties were conducted in 11.40 hectares area. These demonstrations were conducted in 4 tribal villages of Dhar District in M.P. Overall average increase in yield was 18 q/ha or 46% in these demonstrations.

Soybean and wheat demonstrations in collaboration with IISR in M.P.: Soybean: 10 demonstrations of variety (JS 20-69) were conducted in Sehore District, M.P. Wheat: 10 demonstrations of three varieties (HI 8759, HI1605, HI1544) were conducted in Sehore District, M.P.

Extension Activities during 2019-20 by Regional Station, Indore

Particulars/Activity	Number
Preparation of display exhibits *viz*. posters and banners *etc.*	70
Farmers group meetings organized (Field)	21
Kisan mela / Field days organized	6
Field visits	61
Short trainings for farmers/ extension officers and NGO's *etc.*	31
Visitors groups (Farmers/ Extension officers and NGO's)	17
Extension literature distributed to farmers, visitors & trainees.	12000
Participation in agricultural exhibitions / *Krishi mela*	7
Number of farmers trained in "Wheat Production Technology"	3100
Answered farmers' phone calls	1650
Sent answers and literature to farmers on Whatsapp	250
News articles in National papers	7
TV/ Radio programmes/ Bytes	6
Popular articles	11
Answered wheat queries on M krishi mobile application	70
Sent alerts and crop calendar messages through m krishi to M.P. farmers	20

7.3.10.2 Regional Station, Pusa (Bihar)

Front-Line Demonstrations– Wheat: To reduce the yield gap between lab-to-land, 25 front line demonstrations were laid out during 2019-20 under report in the different villages Dwarkanathpur and Mahmadpur Khaje of Muzaffarpur districts of Bihar. The demonstrations conducted were latest variety DBW 187 wheat varieties on the use of new improved wheat variety (5) and HD 3086 on the use of bio-fertilizers-*Azatobactor* and PSB (15) and zero-tillage technology (5). The performance of different demonstrations conducted was very encouraging.

Exhibition and participation in *Kisan mela*

- Actively participated in three days *Kisan Mela* on February 16-18, 2020 at Dr. Rajendra Prasad Central Agricultural University, Pusa Bihar.
- Also participated in one day *Kisan Mela* on 19th February, 2020 at *PARIVARTAN* Siwan, Bihar.

7.3.10.3 Regional Station, Karnal

Basmati Beej Diwas: '*Basmati Beej Diwas*' was organized on March 3, 2020. *Pusa Beej* of popular varieties of Basmati rice *viz*., PB 1509, PB 1121, PB 1718, PB 1637, PB 1728 and non-Basmati variety Pusa 44 was sold to hundreds of farmers from Haryana, Punjab and Western Uttar Pradesh.

7.3.10.4 Regional Station, Amartara Cottage, Shimla

Front Line Demonstrations

Wheat Front Line Demonstrations: Five front line demonstrations on wheat variety HS542 were

organized in different villages of Himachal Pradesh for its popularization among the hill farmers.

Barley Front Line Demonstrations: Twelve front line demonstrations were organized in different villages of Himachal Pradesh for popularizing newly released rust resistant barley varieties (BHS400 and BHS380) among the hill farmers.

Eight field/farmer's day on cultivation of fruit crops, nursery techniques & wheat and barley cultivation and thirteen trainings on production technology of temperate fruit, nursery management for temperate fruit, pruning of temperate fruit crops, propagation techniques, and cultivation of apple, pear, kiwi, pomegranate, stone fruits and strawberry *etc* were conducted in different location of Himachal Pradesh.

7.3.10.5 Regional Station, Kalimpong, West Bengal

Mera Gaon Mera Gaurav: The Station is engaged in transfer of improved technologies among the agrarian societies for economic upliftment. Keeping this view, total 8 training programme, 10 demonstration and 12 awareness programme covering 200 farmers were conducted. Improved technologies of Darjeeling mandarin (Nucellar seedling, grafted planting materials, mulching technique to control fruit fly), healthy sucker of Varlangey cultivar of large cardamom, seed of major vegetables (brinjal, cabbage, cauliflower, tomato, chilli, green peas, bottle gourd, Bitter gourd etc) and growing rootstock of Darjeeling mandarin were promoted under the programme.

Tribal sub-plan (TSP): Two awareness cum workshop was organized on doubling the farmers' income with the tribal farmers of Jalpaiguri, and Kalimpong districts. Inputs like improved varieties of paddy, fish tank, tomato hybrid seed, chilli hybrid seed, micro-nutrients, vermi-compost units and bio-fertilizer were distributed for demonstration.

Scheduled Caste Sub-plan (SCSP): Under this programme 10000 Arecanut seedling, 2000 Bay leaf, 500 lemon, 500 avocado and 5000 coffee seedlings were distributed among the SC farmers in Darjeeling, Kalimpong, Jalpaiguri, and Coochbehar district of North Bengal.

8. EMPOWERMENT OF WOMEN IN AGRICULTURE AND MAINSTREAMING OF GENDER ISSUES

Women in agriculture play a greater role in promoting sustainable food production, enhancing household food security and protecting the environment. Considering this, many programmes are designed to empower them in all spheres of life. Despite this, still they are most vulnerable, because of number of barriers and other issues. But, their role cannot be ignored and continuous coordinated efforts are needed. Hence, capacity building in improved technologies, producing diverse, nutritious food, vocational trainings *etc.* is very much essential.

8.1 A nutrition led extension model of community agri-nutri security centres (CANSCS) for nutrition security of women

Community agri-nutri security centres (CANSCs) were established in Mukari and Lehchoda villages of Baghpat district of U.P. by the Division of Agricultural Extension, ICAR-IARI in collaboration with DST under the project titled "A nutrition led extension model of community agri-nutri security centres (CANSCS) for nutrition security of women". A total number of 5 trainings were conducted. In this project, Pusa nutri kitchen garden was promoted to ensure their nutritional security. The vegetables in surplus production were processed through machineries like solar dryer, microwave oven, spice coating pan and a small packing machine set up under CANSC. It also focused on social and behavioral change principles to inculcate good nutrition practices (GNP).

- Designed and organised 06 trainings (of 3 days duration) in Bassi & Sunnehda villages of Baghpat district and Hasankala and Jagdishpur villages of Sonepat district of Haryana covering 300 rural women in the area of Nutrition Sensitive Agriculture.

8.2 Processing and value addition hub established at kvk chitrakoot by IARI, New Delhi

Under Department of Bio technology (DBT) Biotech KISAN hub project, an agri-horticulture micro-processing unit was established on Dec. 16, 2020 at krishi vigyan kendra (KVK), Chitrakoot. The

Nutrition sensitive agriculture centre beneficiaries

Hallur bajra cookies prepared by beneficiaries of nutrition

Demonstration of Agri- Horticulture processing technologies in the training programme at Chitrakoot

Training on value addition to rural women at Chitrakoot

equipment like hydraulic press, pulper, flour mill, spice mill, mixer cum grinder and other accessories have been provided in the hub from the project for use by the local farmers for agri-horticulture produce processing and value addition purpose at farming community level. A three-day training programme was also conducted on processing and value addition of agri-horti produce for the farm women of the area.

8.3 Enhancing nutritional security and gender empowerment

KVK, Gurugram celebrated *poshan maah* were organized from 1st to 30th September, 2020 during which 5 days long, 5 trainings cum awareness programme during on September, 09, 2020 at Khwaspur village, September 14, 2020 at KVK campus, September 28, 2020 at Garhi Harsaru village, September 29, 2020 at Sakatpur village and September 30, 2020 at village Bhorakalan- Chitrasenki Dhani on "Balanced diet, poshan thali and establishment of nutria-garden".

8.4 Effectiveness of (SHGS) for gender empowerment

A total of 9 women SHGS were formed by KVK, Gurugram, Haryana and given hands-on training on "Food processing, preservation and value addition". Initially they were supported with some machines, utensils and basic packaging machines to motivate them to start their entrepreneurial work. They were also guided regarding packaging, marketing and getting FSSAI registration/license. All the SHGs were maintaining their enterprise and trying to expand their horizons in number of products as well as range of marketing. During 2020, the Kshitiz SHG of Chandu village has got orders from HAFED (Haryana State Co-operative Supply and Marketing Federation Limited) and their products will now be available on HAFED stores also. Although, the year 2020 proved to be a slowdown for all the SHGs entrepreneurial activity especially the newly formed groups but they all maintained their enterprises. The net income of all the SHGs during the year 2020 is shown in the table below:

During lockdown in the country due to Covid-19 pandemic, the processing work of all the SHGs was affected. During that period, some of the SHGs utilized the opportunity of stitching masks and sold through the stalls provided by Haryana Government at various places of Gurugram.

Awareness campaign and capacity development programs were also organized for health and safety issues and improved agricultural technologies to mitigate drudgery.

Income of women SHGs during 2020

Name of SHG	Address of SHG	No. of women	Products prepared	Annual Net Income (₹)
Kshitiz SHG	Chandu village	10	Soynut, soy health powder, Variety of nutritious cookies, soybean-bajraladoo etc.	3.5 lakhs
Arzoo SHG	Sakatpur village	10	Pure spices and other mixture of spices like.	4.5 lakhs
NaiPahal SHG	Shikohpur village	10	Aonla products, pickles of seasonal fruits & vegetables, papad of moong dal and rice	65,000/-
Naya Din SHG	Harinagar village	08	Bajraladoo, soy ladoo, besanladoo, soynut, Pickles of aonla, chilli, carrot, cauliflower, mango	55,000/-
Nari Shakti SHG	Khwaspur village	12	Pickles of seasonal fruits & vegetables, Varieties of ladoos, potato chips, aonla products, soynut	80,000/-
Muqabala SHG	GarhiHarsaru village	09	Aonla products; Squash of mango, lemon, guava and pineapple-papaya; varieties of ladoo	45,000/-
Prajapat SHG	Tajnagar village	05	Ladoo, juice, squash, pickle, powder, candy, supari of aonla, varieties of pickles and ladoos	40,000/-
Ekta SHG	Tajnagar village	05	Ladoo, juice, squash, pickle, powder, candy of aonla, varieties of pickles and ladoos	50,000/-
Pragati SHG	KherkiMajra village	01	Jam, candy, pickle, squash, powder, murabba, juice from seasonal fruits (aonla, mango, karonda, papaya)	30,000/-

9. POST GRADUATE EDUCATION AND INFORMATION MANAGEMENT

The Indian Agricultural Research Institute (IARI) has a rich legacy of excellence of more than 116 years in research, teaching and extension. The post graduate (PG) school of IARI continues to provide national and international leadership in human resource development by awarding PG degrees in 26 disciplines. So far, 4306 M.Sc., 63 M.Tech. and 4974 Ph.D. students have been awarded degrees including 478 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).

9.1 POST GRADUATE EDUCATION

9.1.1 Admission during the Academic Session 2020-21

The PG school continues to attract students seeking admission to twenty six disciplines in all five streams of admission, namely, Open competition, Faculty upgradation, ICAR in-service nominees, Departmental candidates and Foreign students. The admissions to the M.Sc./M.Tech./Ph.D. programme are based on an AIEEA (PG) – 2020 and AICE-JRF/SRF (Ph.D.)-2020 conducted by the NTA/ICAR. The foreign students are admitted through DARE and are exempted from the written test. During the academic year 2020-21, 245 students (including 10 physically challenged; 2 under departmental technical scheme; and 3 under CWSF) were admitted to M.Sc./M.Tech. and 265 students (including 10 physically challenged; 5 ICAR in-service; 1 under Faculty Upgradation scheme and 6 under departmental technical scheme and 2 under CWSF) were admitted to Ph.D. courses. For PG outreach programme at sister institutes, 5 students in CIAE, Bhopal; 8 students in IIHR, Bengaluru; 9 students in NIBSM, Raipur; 7 students in NIASM, Baramati; and 10 students in IIAB, Ranchi were admitted. In addition, 3 international students (1 M.Sc. & 2 Ph.D.) from 3 foreign countries were admitted. At present, the total number of students on roll is 1597 (408 M.Sc., 30 M. Tech. and 1159 Ph. D.), which include thirty four international students (9 M.Sc. & 25 Ph.D.) from foreign countries.

9.1.2 Convocation

The 58th Convocation of the Post Graduate school of the Indian Agricultural Research Institute (IARI) was held on February 14, 2020. Hon'ble Vice-President of India, Shri M. Venkaiah Naidu was the Chief Guest and delivered the Convocation Address. Shri Narendra Singh Tomar, Hon'ble Union Minister of Agriculture and Farmers Welfare & Rural Development & Panchayati Raj, Govt. of India presided over the function and Shri Kailash Choudhary, Hon'ble Minister of State for Agriculture and Farmers Welfare, Govt. of India graced the function as Guest of Honour. Dr. T. Mohapatra, Secretary, DARE & Director-General, ICAR, former Director-Generals of ICAR; former Directors & 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.

During the Convocation various publications and a total of 34 varieties/hybrids released which included 9 varieties of wheat, 4 of maize, 2 of chickpea, and one each of lentil, mungbean and soybean. Eleven varieties/ hybrids of vegetables (brinjal-1, cucumber-1, summer squash-1, ridge gourd-1, cauliflower-3, tomato-1,

spinach-1, and muskmelon-2) were released for better nutrition as well as higher yield and income. Four new varieties of fruit crops were also released which included two in mango and one each in pummelo and grape. One variety of gladiolus, Pusa Shanti released for timely sown conditions of NCR, Delhi.

In his Convocation address, the Chief Guest, Shri M. Venkaiah Naidu, Hon'ble Vice President praised the agriculture as the basic culture of India and the backbone of the Indian economy. He applauded the scientific, technological and industrial advancements made in the field of agriculture and allied sciences. He highlighted about the contributions of ICAR-Indian Agricultural Research Institute for bringing about the Green Revolution in the country. Shri Naidu stated that it is the result of the Institutions' regular researches and advancements in the varieties that have led to enhanced production of food grains to about 283.37 mt in 2018-19. The Hon'ble Vice President mentioned about the predomination by the Pusa Basmati rice varieties over the rice cultivation in the country. The Wheat varieties HD 2967 and HD 3086 have played a vital role in enhancing the wheat production and productivity in the country. He urged for finding out the ways to make the country 100% hunger free. Shri M. Venkaiah Naidu also stressed on achieving the nutrition security along with food security in the country. He emphasized to prioritize the home grown food security. The Hon'ble Vice President urged to address the ever increasing problems and challenges of hidden hunger among the adolescents as it affects the socio-economic growth of the country. The Hon'ble Vice President also highlighted about the various central government's schemes like pradhan mantri kisan SAMPADA Yojana (Scheme for agro-marine processing and development of agro-processing clusters) that are aimed at enhancing the income and livelihood of the agricultural and farming communities.

Dr. Ashok Kumar Singh, Director, IARI presented the Director's Report on the significant research achievements of the Institute during 2019, while Dr. Rashmi Aggarwal, Dean & Joint Director (Education), IARI presented the Dean's Report and proposed a formal word of thanks.

During this Convocation, 242 candidates (144 M.Sc., 9 M.Tech. and 89 Ph.D.) including 15 (11 M.Sc. and 4 Ph.D.) International students were awarded degrees. One student each in M.Sc. (Mr. Arkaprava Roy, Discipline of Soil Science & Agricultural Chemistry) and Ph.D. (Mr. Mahawar Himanshu Ravi, Discipline of Microbiology) were awarded the Best Student of the Year Awards. Five students each in M.Sc. and Ph.D. received IARI Merit Medals. Dr. Neera Singh, Professor of Agricultural Chemicals received the Best Teacher Award in Agricultural Higher Education 2019-20 for her achievements in academics. The twenty-ninth Sukumar Basu Memorial Award for the biennium 2017-18 was awarded to Dr. S.V. Sai Prasad, Head, IARI Regional Station, Indore for his outstanding research contributions towards "Developing durum wheat varieties". The twentieth Hari Krishna Shastri

Shri M. Venkaiah Naidu, Hon'ble Vice President distributed Awards and degrees to the students during 58th convocation

Memorial Award for the year 2019 was awarded to Dr. T.K. Behera, Professor, Division of Vegetable Science, IARI, New Delhi for his outstanding research contribution in the field of "Vegetable Breeding". The fifth Dr. A.B. Joshi Memorial Award for the biennium 2019-20 was awarded to Dr. G.P. Singh, Director, ICAR-Indian Institute of Wheat and Barley Research, Karnal for his outstanding research contributions in "Genetics and Plant Breeding". This year, IARI instituted an "Best Agricultural Extension Scientist Award" biannually to the Scientist/Academician of Indian nationality from all branches of Agricultural Sciences. The first Best Agricultural Extension Scientist Award for the biennium 2019-20 was awarded to Dr. J.P. Sharma, Joint Director (Extension), IARI, New Delhi for his outstanding contributions in the field of "Agricultural extension, education, communication and management".

A cultural programme was organized in the evening of Convocation Day *i.e.* February 14, 2020 at Dr. B.P. Pal Auditorium of the Institute in which famous Kathak Dancer *Padmashri* Dr. Shovana Narayan performed the Kathak dance.

9.1.3 Special Lectures

Lal Bahadur Shastri Memorial Lecture: The Indian Agricultural Research Institute initiated the series of annual lectures in 1968 as a mark of respect to late Shri Lal Bahadur Shastri, the second Prime Minister of independent India. The 50th Lal Bahadur Shastri Memorial Lecture was delivered by Prof. Padmanabhan Balaram, Former Director, Indian Institute of Science, Bengaluru, on the topic "Chemistry, Biology and the Unity of Nature" on February 13, 2020. Professor R.B. Singh, Former Chancellor, CAU, Imphal presided over the function.

Dr. B.P. Pal Memorial Lecture: The 27th Dr. B.P. Pal Memorial Lecture was delivered by Dr. R.S. Paroda, Chairman, Trust for Advancement of Agricultural Sciences, New Delhi on the topic "Reforms for Secure and Sustainable Agriculture - a Road Map" on May 27, 2020 through virtual mode. Dr. Trilochan Mohapatra, Secretary (DARE) & Director General (ICAR), New Delhi presided over the function.

Lal Bahadur Shastri Memorial Lecture by P. Balaram

Teachers' Day Lecture: The Teachers' Day Lecture 2020 was organized jointly by the PG School, and the Genetics Club, IARI on September 5, 2020 through virtual mode. The dignitaries paid tributes to Dr. S. Radhakrishnan, the great philosopher, philanthropist and ex-President of India. On this occasion, Dr. Trilochan Mohapatra, Secretary, DARE and Director General, ICAR, New Delhi delivered a lecture on the topic "Future Perspectives in Agricultural Education". Prof. R.B. Singh, Former Chancellor, CAU, Imphal presided over the function.

Agricultural Education Day Lecture: The Agricultural Education Day Lecture was delivered by Dr. S.L. Mehta, Former Vice Chancellor, MPUAT, Udaipur and Former DDG (Edn.), ICAR, New Delhi on the topic "Quality of Agricultural Education holds the key to Agricultural Transformation" on December 3, 2020 through virtual mode. Dr. Ashok Kumar Singh, Director, IARI, New Delhi presided over the function.

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, the first two batches of MSc Agronomy of ANASTU have already graduated (in 2016 and 2018), and the 3rd Batch was to graduate in December 2020, but it is delayed due to the ongoing COVID pandemic related travel restrictions; the teaching of the 4th Batch was to start in April 2020, this too is delayed due to the pandemic. However, to maintain continuity the classes were arranged online from March 30, 2020 onwards. The guidance for thesis research of the students has been given online by their respective guides at the ICAR-IARI and ICAR-IVRI. An online Orientation and Teaching of the 4th Batch of ANASTU M.Sc. Agronomy Students at IARI, New Delhi was organized on November 16, 2020.

ACARE Programme: November 16, 2020 Under the ACARE programme, to strengthen the postgraduate education and human resource development, IARI in collaboration with YAU conducted two short term (two weeks) training programmes for the stakeholders of Myanmar Agriculture were conducted successfully. Dr. R.K. Pal, Former Director, ICAR-NRC on Pomegranate, Solapur joined ACARE as Resident Advisor on June 14, 2019.

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 Five lakh publications comprising scientific journals, research bulletins, monographs, post-graduate theses, scientific reports, reprints and other reference materials. It has more than 2144 members which include students, scientists and technical staff. More than 500 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 PCs with Wi-Fi connectivity, internet and e-mail facility for the convenience of the readers.

9.2.1 Acquisition Programme

9.2.1.1 Books

During the period of report the library received 2099 publications which includes 289 in Hindi books, 1360 English E- Books and 02 Advances & Annual Review. The library also acquired 126 gift publications, 147 IARI Thesis. Uploaded CDs of 175 Thesis (copy) in Krishikosh.

9.2.1.2 Serials

The Library received 1165 journals/serials through subscription, gifts and exchanges, subscribed to 42 foreign journals and 68 Indian journals, 30 Newsletters, gifts 61 titles. Total 107 publications accessioned. Received 89 annual scientific/technical reports of different institutions and 18 bulletins in the library during report period. Library also procured 12 online journals.

9.2.2 Document processing

Total number of document processed 571 consisting of 289 books, 175 post-graduate IARI thesis, Bulletins 18 and 89 Annual Reports were processed (classifying and cataloguing).

9.2.3 Resource Management

Apart from 2144 active registered members, the library served 50 to 100 users per day who comes from different agricultural universities/ICAR Institutes who consulted approximately 300 to 500 documents every day. Registered 90 new members (15 staff and 75 students). During the period under report 34 publications were issued and 189 publication returned. Under the Inter Library Loan System 8 documents were issued to various institutions. 190 No dues Certificate were issued.

9.2.4 Document Delivery Service

Resource management section of library is providing a Document Delivery Services to different users of agricultural field through CeRA. Total number of hits 19,639, total login session 612, searches 5,683, full text and abstract views 3,369. Total number of request received 6 through CeRA and uploaded requested articles in J-Gate

9.2.5 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. The objective of this course is to train the students to search the literature of their interest & literature search tools.

9.2.6 Krishikosh

Krishikosh provides ready software platform to implement all aspects of the open access policy, similar to 'Cloud Service' for individual institution's self-managed repository with central integration. These two products of E-Granth (i) Krishikosh and (ii) IDEAL are being used by all SAUs/DUs/CUs & ICAR Institutes. Up to March 2020 library uploaded 5469 thesis.

9.2.7 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, LIS Course, summer and Winter School Courses of different divisions and Directorate for the benefit of Scientists/Technical staff.

E-Language Lab

Reading Hall

Director's visit to the Library on January 20, 2020 for Library Art Gallery

9.3 AGRICULTURAL KNOWLEDGE MANAGEMENT UNIT (AKMU)

Currently, besides bioinformatics activities, the unit is entrusted with responsibility of design, development, hosting and maintenance of the e-resources,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) a dynamic database for the scientific staff of the institute including regional station scientists, (ii) ANN based prediction models for trap catch data for chickpea (bod bore) for ICRISAT, Hyderabadand (iii) Text Mining for Knowledge extraction through, similarity detection in two documnets and Keyword Extraction based on natural language processing (NLP).

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	551
b)	Symposia/conference papers	266
2. Books/Chapters in Books		
a)	Books	27
b)	Chapters in books	164
3. Popular Articles		**263**

10.2 IN-HOUSE PUBLICATIONS

10.2.1 Regular publications (English)

- IARI Annual Report 2019 (ISSN: 0972-6136)
- IARI News Quarterly (ISSN: 0972-6144) - four issues)
- IARI Current Events (Monthly)- 12 issues (Available only on IARI website)

10.2.2 Technical publication (English)

- Wings of Agri-Innovations (ISBN 978-93-83168-52-1)
- Fellow and Innovative Farmers 2020 (ISBN 978-93-83168-53-8)
- Catalogue of Fungal & Bacterial Cultures 1936-2019 (IX Edition) (ISBN 978-93-83168-54-5)
- Unnat Krishi Utpadan Takniki (Rashtriya Rajdhani Kshetra) (ISBN 978-93-83168-55-2)
- Plant Variety Protection, Seed Testing and Certification (TB-ICN: 237/2020)
- Integrated Approaches for Diagnostics and Management of Insect Pest, Vectors, Pollinators and Natural Enemies (TB-ICN: 238/2020)
- Virus Indexing and Genetic Fidelity of Tissue Culture Raised Plants (TB-ICN: 239/2020)
- Non-conventional Approaches for Genetic Improvement of Horticultural Crops (TB-ICN: 240/2020)
- Gene Editing and Phage Discovery (TB-ICN: 241/2020)
- DNA Barcoding for Insect Diagnosis (TB-ICN: 241/2020)
- Virus Diagnosis and Metagenomics for Virus Discovery (TB-ICN: 243/2020)
- Advances in Floriculture and Landscaping (TB-ICN: 244/2020)
- Genomics for Improvement of Horticultural Crops (TB-ICN: 245/2020)
- Crop Cultivars for Farmers' Prosperity (TB-ICN: 246/2020)

- Insecticides for Pest Management in Agricultural Crops (TB-ICN: 247/2020)
- Reading Manual on Introduction to Disaster Management (TB-ICN: 248/2020)
- Wheat Research over A Decade (2011-2020) at ICAR-IARI, RS Indore (TB-ICN: 249/2020)
- NutriTwist: Hallur Recipe Booklet (TB-ICN: 250/2020)

10.2.3 Niymit Prakashan (Hindi)

- Pusa Surbhi (Varshik) (ISSN : 2348-2656)
- Varshik Report 2019 (ISSN : 0972-7299)
- Pusa Samachar (Tremasik) (ISSN : 0972-7280)
- Prasar Doot (Tremasik)
- IARI Samyiki (Masik) (Available only on Institute's website)

10.2.4 Takniki Prakashan (Hindi)

- Fasal Utpadakta Badhaane hetu Krishi Bhoutiki ki Taknikein (ICN: H-175/2020)
- Khadyan Bhandaran ke Pramukh Keet evam unka Prabandhan (ICN: H-176/2020)
- Gunavatta Beej Utpadan se Kisano ki Aye Duguni Karna (ICN: H-177/2020)
- Sehat ke liye Poshan (ICN: H-178/2020)
- Sheetkaleen Faslon ka Beej Utpadan evam Bhandaran (ICN: H-179/2020)
- Dhanya evam Bagwani Faslon ke Parirakshan evam Mulyavardhan (Training Manual) (ICN: H-180/2020)
- Kisano ki Smradhi ke liye Faslon ki Unnat Kismein (ICN: H-181/2020)
- Aanuvanshik evam Padap Prajnan se Sambandhit Angreji-Hindi Shabdkosh (ICN: H-182/2020)
- Adhik Aye evem Surakshit Pryavaran hetu Samekit Keet Prabandhan evam Upyogi Keet Palan (ICN: H-183/2020)

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:

11.1 TECHNOLOGY COMMERCIALIZATION

During the year 2020, under '*Lab to Land*' Initiative, thirteen technologies of ICAR-IARI were transferred to Fifty two industry partners, resulting in total revenue generation of ₹ 28.50 lakh. The technologies transferred include Maize Hybrid Pusa Jawahar Hybrid Maize-1 (PJHM-1) and Wheat varieties HD 3226, HD 3086 and HD 2967, Rice varieties PB 1509 and 1718, Mustard varieties PM 27, PM 28, PM 30 and PM 31 and vegetable varieties: Okra- Pusa Bhindi-5, Brinjal- Pusa Vaibhav, Brinjal- Pusa Oishiki, Onion- Pusa Shobha, Garden pea-Pusa Prabal, Cow pea- Pusa Dharni.

11.2 INTELLECTUAL PROPERTY RIGHTS

Institutional

During the year 2020, seven patent applications and two copyright applications have been filed. Additionally, seven patents have been granted together with registrations of four trademarks, six PPVFRs and one copyright in the said time period.

IPRs	Application No./ Registration No./ Grant No.	Name of Innovation/ Technology/ Product/ Variety	Date of Filing/ Registration/ Grant	Application Filed/ Granted/ Registered**
Patent	338098 (518/DEL/2011)	Liquid bioinoculant of *Azotobacter chroococcum* and the process thereof	June 08, 2020	Granted
	202011024290	A microcontroller based real time data acquisition system integrated solar dryer	June 10, 2020	Filed
	202011026699	Powered Integral Equipment	June 24, 2020	Filed
	202011028155	UAN cum Seed Applicator	July 02, 2020	Filed
	341699 (2432/ DEL/2015)	Plant Transformation Vector for Suppressing Mips Gene Expression and Method for Culturing Low Phytate Soybean	July 15, 2020	Granted
	202011030310	Off-Grid Battery less Solar Refrigerated Evaporatively Cooled Mesh-Fabric Structure for Storage of Perishables	July 16, .2020	Filed
	343546 (3771/DEL/2012)	A Cross Flow Flexible Membrane Filtration Assembly for Small Processing Volume	August 08, 2020	Granted

	340541 (2361/DEL/2014)	Insecticidal Formulation of Novel Strain of Bacillus thuringensis AK 47	August 20, 2020	Granted
	202011035827	A Semi-Synthetic Diet For Mass Rearing of Lepidopteran Pests of Agricultural Importance	August 20, 2020	Filed
	202011035828	Efficient Methodology for Natural Vitamin E Extraction from Edible Vegetable Oils	August 20, 2020	Filed
	202011037363	Hydro, Hydro-Thermal and Thermal Near Infrared Rays Treatments To Reduce Rancidity In Pearl Millet Flour	August 31, 2020	Filed
	346124 (1802/DEL/2013)	Pusa Basmati Rice Thresher	September 04, 2020	Granted
	349105 (2964/DEL/2010)	Novel Naphthyridine Based Hydrazines As Potent Agrochemicals	October 13, 2020	Granted
	354498 (2093/DEL/2013)	Zinc in clay-mineral receptacles in nanoforms for their use as advanced materials including novel fertilizer	December 26, 2020	Granted
Trade Marks	4430609	UPJA	September 26, 2020	Registered
	4430611	UPJA	September 26, 2020	Registered
	4430610	UPJA	September 26, 2020	Registered
	4430607	SAMARTH	October 03, 2020	Registered
Copyrights	11672/2020-CO/SW	Draksha- Vitismod V1, A Grape Simulation Model	August 20, 2020	Filed
	21155/2020-CO/SW	Web InfoCrop - Wheat	-	Filed
	SW-13743/2020	Draksha- Vitismod V1, A Grape Simulation Model	-	Registered
PPV & FRA	REG/2019/141	Pusa Basmati 1637	October 23, 2020	Registered
	REG/2019/143	Pusa Samba 1850	October 23, 2020	Registered
	REG/2019/142	Pusa Basmati 1609	October 23, 2020	Registered
	-	HD 3117	October 26, 2020	Registered
	-	HD 3171	October 26, 2020	Registered
	REG/2022/389	Bread Wheat HD CSW16	October 26, 2020	Registered

IP Spectra

IP Spectra (Intellectual Property Facilitation Centre established at ZTM & BPD Unit, ICAR-IARI, New Delhi) has facilitated start-ups in various IP related services. IP Spectra has facilitated twenty patentability searches, eleven patent application filing, twenty seven trademark filings. About 200 participants have been benefited in fourty three intellectual property related sessions organised by IP Spectra.

IPRs	Application No./ Registration No./ Grant No.	Name of Beneficiary	Name of Innovation/ Technology/ Product/ Variety	Date of Filing/ Registration/ Grant	Application Filed/ Granted/ Registered**
Patent	appl. No.-202011021786	Baba Bidhi Chand Agro Pvt Ltd	Machine for burning waste material	May 24, 2020	Filed
	appl. No.-202011021552	Baba Bidhi Chand Agro Pvt Ltd	Machine for nursery bed preparation for rice seedlings	May 22, 2020	Filed
	appl. No.-202011024985	Baba Bidhi Chand Agro Pvt Ltd	An integrated machine for lifting, cleaning, packing and loading harvested grains	June 15, 2020	Filed
	201911049097	Bonformo (CT)Pvt. Ltd.	Smart Sugarcane Bud-Stalk Extractor	November 27, 2020	Filed
		DelvikNutritions	Whey Beverage With Fruit Content	September 15, 2020	Novelty Search Report
		Dr. SHREY CHAUDHARY	Mine detecting machine	October 4,2020	Patentability Search Report
Trademark	Class 35,4526058	IGKV RABI Raipur	IGKV RABI Raipur	June 10 2020	Filed
	Class 41,4526059	IGKV RABI Raipur	IGKV RABI Raipur	June 10 2020	Filed
	Class 41,4526060	IGKV RABI Raipur	ABHINAV	June 10 2020	Filed
	Class 41, 4526061	IGKV RABI Raipur	UDBHAV	June 10 2020	Filed
	4647583 In Class 30	Craftcomm Farms Private Limited	Mystiq Garden	September 09, 2020	Filed
	4647584 In Class 29	Craftcomm Farms Private Limited	Mystiq Garden	September 09, 2020	Filed
	4647585 In Class 31	Craftcomm Farms Private Limited	Mystiq Garden	September 09, 2020	Filed
	4647586 In Class 31	Craftcomm Farms Private Limited	Mystiq Garden	September 09, 2020	Filed
	4679280 In Class 7	Contrivantion labs	Calyxtract	September 29, 2020	Filed
	4679279 In Class 37	Contrivantion labs	Calyxtract	September 29, 2020	Filed
	Word Mark Money Plant In Class 31	Vaibhav Genetic Agri India	Money Plant		Trademark Application Forms Drafted
	Device Mark Money Plant In Class 31	Vaibhav Genetic Agri India	Money Plant		Filed

	Word Mark In-dogen In Class 31	Vaibhav Genetic Agri India	Indogen		Trademark Application Forms Drafted
	Device Mark In-dogenIn Class 31	Vaibhav Genetic Agri India	Indogen		Filed
	Word Mark Geno-maxx In Class 31	Vaibhav Genetic Agri India	Genomaxx		Trademark Application Forms Drafted
	Device Mark GenomaxxIn Class 31	Vaibhav Genetic Agri India	Genomaxx		Filed
	Device Mark For Balasore Agto Private Limited In Class 7,8,12	Balasore Agro Private Limited	Balasore Agro Private Limited		Trademark Application Forms Drafted
	4317357 In Class 25	Akanksha Creations	Neufaden	August 02,2020	Granted
	4317358 In Class 18	Akanksha Creations	Neufaden	August 02,2020	Granted
	4371405 In Class 9	Labfield Agro	Lafl	September 4, 2020	Granted
	4415413	Dr Sunny Malik	Device of two hands	September 14, 2020	Granted
Trademark	4647583 in class 30	Craftcomm Farms Private Limited	Mystiq garden	November 27, 2020	Response to office action
	4647584 in class 29	Craftcomm Farms Private Limited	Mystiq garden	October 15, 2020 and November 27, 2020	Response to office action
	4647586 in class 31	Craftcomm Farms Private Limited	Mystiq garden	November 27, 2020	Response to office action

11.3 AGRIBUSINESS INCUBATION

I. Incubation Activities

The year of 2020 brought new dynamics to the Pusa Krishi, ZTM & BPD Unit to amplify its capability and capacity as one of India's top agribusiness incubator. ZTM & BPD unit had gone completely gone online during unprecedented time and continuing incubation program along with various other new initiatives to create impact on India agri innovation ecosystem.

Programs: The unit has launched various programs for the development of the agribusiness incubation ecosystem.

1. Launch of Agri India Hackathon

Agri India Hackathon a program to create a multidimensional platform empowering Indian Agriculture Innovation organized by Pusa Krishi, ICAR - IARI, ICAR and Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare was launched on December 31, 2020 at Krishi Bhawan, New Delhi by Shri Narendra Singh Tomar Hon'ble Union Minister of Agriculture & Farmers Welfare along with Shri Kailash Choudhary, MOS (Agriculture & Farmers Welfare), Shri Parshottam Rupala, MOS (Agriculture & Farmers Welfare).

The Agri India Hackathon event is one of its kind national level effort to uplift the existing agriculture ecosystem and work towards the larger mission of boosting farmers' income and their overall welfare. This platform will give a chance to students and young start-ups to express their ideas and creativity. The event seeks to create an impact in five interconnected

Glimpse of agri india hackathon

areas to provide a roadmap for the future and the goal is to build an impact with new-age, fast & frugal innovations to navigate these focus areas. These focus areas are primarily: Mechanization of farming & allied activities, precision agriculture including applications of sensors, WSN, ICT, Artificial intelligence, IoT & drone, Supply Chain & Agriculture Logistics, Post-harvest, food technology & value addition, waste to wealth & green energy in agriculture. The event is partnered by many corporate members, agribusiness companies along with established Agri-business incubators across India. The backbone of event was hosted on by My Gov, which is an innovative platform to build a partnership between citizens and government with the help of technology for growth and development of India.

Weblink: https://innovateindia.mygov.in/agriindia-hackathon

Under agri India hackathon youth has chance to win a cash prize of ₹ 1,00,000 each at the end of event as per the focus area. The winning innovations will get an exclusive preference for incubation support, pre-seed & seed-stage funding of five lakhs & twenty five lakhs respectively, at any one of the Twenty nine RABIs, subject to assessment by the independent RABI. The winning innovations will also have the opportunity of field trial and also access technology validation from our network of institutions, if they opt for incubation support.

2. Launch of agri India meet

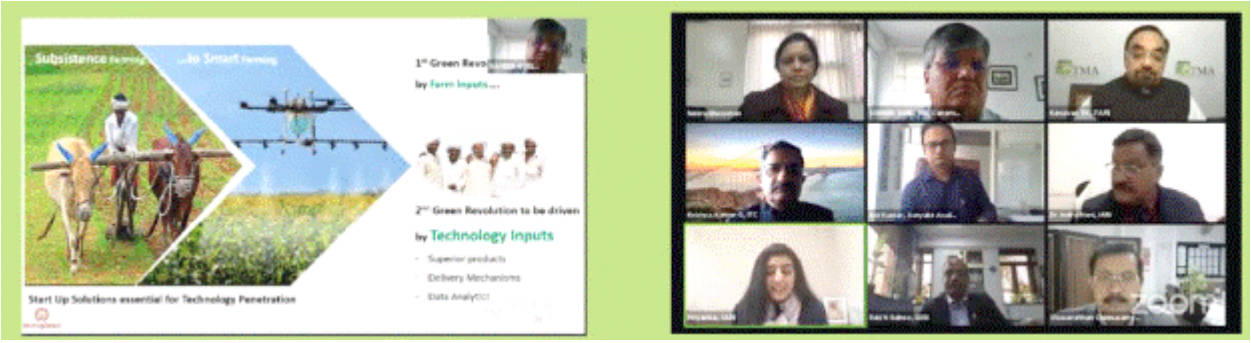
With more than forty speakers in seven sessions discussing the today & tomorrow of agriculture, agri India meets will create meaningful conversations & connections with the most important people in agriculture - from Businesses, Start-ups, Industry to Policy, Education, Media, and others. Each agri India meets are best known for its perfect blend of renowned representative from Agri-business Industry/ or Corporate coupled with dynamic Researcher/ or Academician along with Venture Capitalist in the sector and our startup whose journey keeps youth encouraging towards agripreneurship.

3. Launch of incubation program 2020

Conducted two-month incubation programme virtually combining the cohorts of ARISE 2020 and UPJA 2020 into one big cohort of thirty two startups in collaboration with social alpha as investment partner.

a. 'ARISE- Launchpad for agri startups' is an agripreneurship orientation program

ARISE was launched on March 1, 2020 to promote innovation and entrepreneurship of India's agri-startups ecosystem. This is a program to scale-up agri-



Agri India Meet 1: Future of Farm Mechanization & Precision Farming (December 30, 2020) had Keynote Speaker Mr. Sameer Goel, MD, Coromandel

startups that have passed the stage of ideation and have developed or have a ready prototype. Under this programme 331 applications were received online, and finally fifteen startups were selected after technical assessment & business viability by selection committee (RIC).

b. UPJA- launch pad for lab to market

UPJA was launched on April 22, 2020 to scale-up agri-startups that have passed the stage of prototype and have developed product with market traction. Under this programme, 219 applications were received, and finally seventeen startups were selected after technical assessment & business viability by selection committee (RIC) who had undergone two month online incubation program.

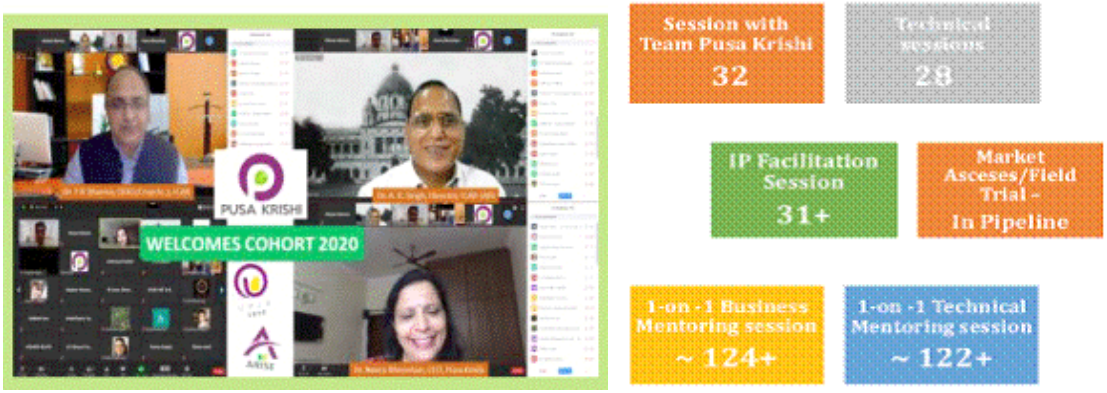
c. Two Months online incubation programme for ARISE & UPJA 2020:

Launched two month online incubation programme for Cohort of 32 startups from Arise and UPJA 2020 from July 6 – September 5, 2020. This two-month programme has witnessed a cross dimensional and seasoned speakers and experts from agribusiness domain who gave 360-degree perspective on various aspects from agriculture to design thinking, intellectual property and financial analysis. The main component was the 1-on-1 mentoring session for each startup by pool of technical scientific staff of IARI along with business and financial experts. This mentoring session helped the startups to scale with better incoming revenues, and providing them opportunity for pilot and technology validation.

d. RC (Fund Recommendation) Meeting of Cohort 2020

RC Meeting of Pusa Krishi for Cohort 2020 was held on October 6, 2020. The meeting was chaired by Ms. ChhaviJha, Joint Secretary, DAC & FW.

RKVY-RAFTAAR Selection & Monitoring Committee recommended eleven startups under Pre-Seed stage funding with a total funding support of ₹ 54,00,000 and seven start-ups are supported under



Meeting of Pusa Krishi for Cohort 2020

seed stage funding with a total funding support of ₹1,42,00,000.

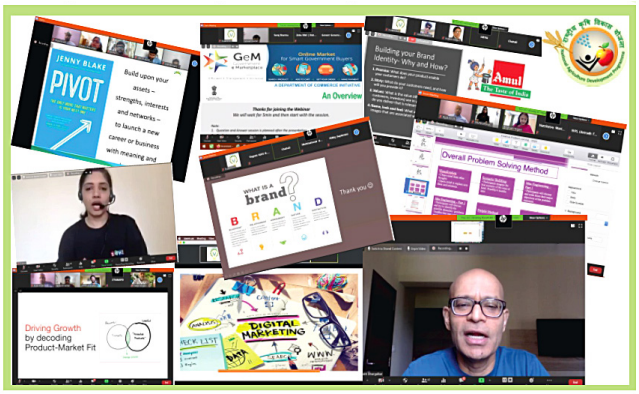
Meeting of Cohort 2020

4. Samarth: handholding the agri-business incubators under RKVY-RAFTAAR

a. Pusa Krishi, IARI-RABIs incubation series

Pusa Krishi launched its first and one of its kind virtual online incubation program and most probably the largest incubation program in the ecosystem judicially designed to help early stage to mid stage startups looking for a kick-start and networking connects.

As the knowledge partner under RKVY-RAFTAAR scheme of Ministry of Agriculture & Farmers' Welfare, Pusa Krishi conducted a full-fledged intense two months online incubation program for the start-ups from thriteen RKVY-RAFTAAR agribusiness incubators (RABIs). More than hundred start-ups across 13 incubators, which were selected for the funding support by Ministry attended this two-month intense online incubation program, after completing initial training at each respective RABIs. The series focussed on evidence-based entrepreneurship and trained the start-ups on the best practices of innovation and entrepreneurship management. The series adopted the design thinking process and included sessions that were focussed on business growth by industry experts. These sessions ranged from design thinking, creative problem solving, product market fit, hacking marketing and sales growth to financial management, regulatory aspects, IP and business.

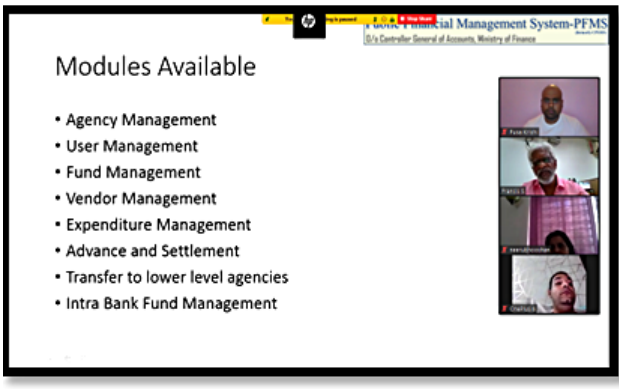


Pusa Krishi, IARI-RABIs Incubation Series

b. Workshop under samarth: innovation and incubation induction program:

It is a sector focused yearlong incubator professionals training program designed to train scientists, PIs, incubator managers and other professionals. During the year 2020, organized fifth and Sixth online workshops titled "Session on PFMS" and "Process Flow for Startup Funding under RKVY-RAFTAAR 2020" on April 13, 2020 and August 21, 2020 respectively. The workshop was attended by 120+ Incubator managers representing twenty agri-incubators pan India with all the PI/ Co-PI/ Business Manager.

Samarth: Innovation and incubation induction program



II. Handholding RABIs partner in their RIC and CIC meeting:

As a leading knowledge partner, Pusa Krishi extends its continuous support to nine RABIs through online virtual meeting and monitoring session. This quarter all RABIs have launched their incubation program in which one representative from Pusa Krishi team attended in the selection panel for selecting startups that would undergo two month of intense incubation program. Below are some pictures of online selection committee meeting organized by each RABI virtually. All startups who have been selected under RIC—II meeting will represent in front of Centre of Excellence Incubation Committee (CIC) under RKVY-RAFTAAR for final grant-in-aid approval. The amount approved to each incubate would be given milestone-based funding as defined in the guidelines of RKVY- RAFTAAR innovation and entrepreneurship component.

Other activities

a. ITMC Meeting: Two Institute Technology Management Committee (ITMC) meetings were organized *via.* online platform by the unit under the chairmanship of the Director, ICAR-IARI to evaluate research outcomes of fourty seven technologies, forage the inventions that need to be protected under IPR, management of IPR portfolios and to contrive the terms and conditions for commercialization of new varieties and technologies developed by IARI.

b. Techno-Commercial assessment and expert committee meeting: Two Techno-commercial assessment and expert committee online meeting with Agrinnovate India Limited were organized by ZTM&BPD unit for further fixation of the Terms and conditions for commercialization of eighty technologies developed by IARI and to decide whether the technology commercialization of particular technology/variety discussed in this meeting will be taken by AgIn or given to IARI.

III. 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, 143 corporate members have been enrolled so far in the FY 2020-21, generating a revenue of ₹ 6,53,500.

RIC and CIC meeting:

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 ten centres, improving quality in maize which has enabled several SAUs and ICAR institutes to upgrade and update themselves with new tools and techniques. Under the NAIP and NFBSFARA, IARI is the lead centre to develop state of art facilities and infrastructure on food science and phonemics led sciences. The NICRA programme of ICAR performed significantly by developing new genotypes for minimizing the negative impact of climate change in wheat by recombining QTL combinations for drought and heat tolerance apart from documenting the mitigation and adaptation phenomena to changing climate in rice and wheat.

In lieu with the consortia mode of project of ICAR, the Institute has been encouraging linkages and professional collaborations among national institutes to work on major research focus on 'Molecular breeding' for improvement of tolerance to biotic and abiotic stress, yield and quality traits in crops, and 'Hybrid technology' for higher productivity in selected field and horticultural crops. The Institute also identified some of the priority research areas through other ICAR Consortium Research Platforms as Mega seed platform, Genomics platform, Diagnostic and Vaccines, Energy platform, Water platform, Conservation agriculture platform, Farm mechanization and Precision farming, etc.

On public-private partnership mode, the role and participation of private sector in agricultural services is increasing in different forms and capacities. This underlines the need for ensuring effective public-private partnerships and linkages besides improving the structural and operational efficiency and governance of the institutions to make them farmer-friendly. Keeping this in view, the Institute has planned to forge collaboration with some of the private seed sector having strong R&D base and expertise in seed quality enhancement as well as with the advanced centres of research in other countries.

The Institute has extended liaison with private companies for commercialization of its technologies. Many IARI technologies with private and public enterprises have been commercialized.

The linkage system is being studied for strengthening extension under IARI-NGOs Partnership programme as well. Linkage with post offices as a new extension model was developed by IARI. The IARI has initiated an innovative extension programme for technology dissemination in partnership with selected NGOs for feasibility trials and promotion of agricultural technologies in their operational areas.

On Post Graduate Education, the Institute has recently approved a collaborative programme with University of Nebraska from USA for strengthening PG education. Efforts are being made to have such programmes with more universities on bilateral basis. The Institute is playing a very important role in institution building in other countries, namely, in the establishment of (i) Afghan National University of Agricultural Sciences and Technology, Afghanistan; and Advanced Centre for Agricultural Research and Education at Yezin Agricultural University, Myanmar. Further linkages extend towards establishment of IARI off-campus in selected ICAR Institutes. The classic examples are start of PhD programmes in IIHR, Bangalore and CIAE, Bhopal. The Institute is helping in the establishment of two IARI like Institution of excellence in Jharkhand and Assam. Students are being admitted to these institutions, namely, M.Sc. at IARI-Assam and IARI–Jharkhand in five disciplines *viz.*, Agronomy, Genetics, Soil Science & Agricultural Chemistry, Vegetable Science and Water Science & Technology from the academic year 2015-16.

In the arena of training, the centres of excellence at IARI have established linkages with different national institutions through their regular training programmes and also through other programmes offered through Centre of Advanced Faculty Training.

At the international level, the Institute has close linkages with some of the CGIAR's international agricultural research centres (IARCs), *viz.*, ICRISAT, CIMMYT, IRRI, and ICARDA. It also has linkages with other international organizations, *viz.*, FAO, IAEA, USAID, UNDP, WMO, UNIDO and UNEP. Several bilateral research linkages involving developed and developing countries also exist. These include linkages with USDA, selected universities in USA, Canada, Australia, World Bank, Rockefeller Foundation, Bill & Melinda Gates Foundation, European Commission, JAICA, JIRC, JSPS, ACIAR, AVRDC (Taiwan), etc.

The number of externally funded projects in operation during the period from January 1, 2020 to December 12, 2020 is given below:

Name of Funding Agency	**Number of Projects**
Within India Department of Biotechnology (DBT), Department of Science & Technology (DST), National Committee Plasticulture Application in Horticulture (NCPAH), Council of Scientific and Industrial Research (CSIR), Department of Agriculture and Cooperation (DAC), Indian Meteorological Department (IMD), Board of Research in Nuclear Sciences (BRNS), 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), NITI Aayog, Ministry of Environmental, Forest and Climate Change (MoEF&CC), UP Council of Agricultural Research (UPCAR), and Indian Council of Agricultural Research (ICAR)	189
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, Centre for Agriculture and Bioscience International (CABI), United Kingdom, HarvestPlus-International Food Policy Research Institute, USA, JIRCAS, Japan	14
Total	**203**

13. AWARDS AND RECOGNITIONS

- Dr. Rashmi Aggarwal, Dean (Additional Charge)/ Head, Division of Plant Pathology was awarded with Dr. Punjabrao Deshmukh Women Scientist Award, ICAR.
- Dr. P. K. Sahoo, Principal Scientist, Division of Agricultural Engineering was awarded (i) Dr. Rajendra Prasad Puraskar for Technical Books in Hindi in Agriculture and Allied Sciences, ICAR, New Delhi and (ii) Fellow Indian Society of Agricultural Engineers.
- Dr Manish Srivastav, Principal Scientist, Division of Fruits and Horticultural Technology awarded with Bharat Ratna Dr. C. Subramaniam Award for the Outstanding Teachers, ICAR, New Delhi.
- Dr. T.K. Das, Professor, Division of Agronomy awarded with Bharat Ratna Dr. C. Subramaniam Award for Outstanding Teachers, ICAR, New Delhi.
- Dr. M. Sivasamy, Principal Scientist & Head, IARI Regional Station Wellington was elected NAAS Fellow.
- Dr. Dharam Pal, Principal Scientist, IARI Regional Station Amartara Cottage, Shimla was elected NAAS Fellow.
- Dr. A.D. Munshi, Principal Scientist, Division of Vegetable Science was elected NAAS Fellow.
- Dr. S.S. Dey, Senior Scientist, Division of Vegetable Science was elected NAAS Associate.
- Dr. K. Annapurna, Head & Principal Scientist, Division of microbiology awarded with Eminent Scientist Award from DRASS.
- Dr. S.K. Singh, Principal Scientist & Head, Division of Fruits and Horticultural Technology was elected Fellow of the Society for Horticultural Research and Development.
- Dr. B.S. Tomar, Head & Principal Scientist, Division of Vegetable Science received Goutam Kalloo Award by Society for Horticultural Research and Development.
- Dr. C. Bharadwaj, Principal Scientist, Division of Genetics received CEGSB (ICRISAT) Outstanding Partnership Award.
- Dr. Neelu Jain, Principal Scientist, Division of Genetics awarded Woman Scientist- 2020 by Society for Advancement of Wheat and Barley Research.
- Dr. P. Jayaprakash, Principal Scientist, IARI Regional Station Wellington was elected SAWBAR Fellow.
- Dr. Gopala Krishnan S, Principal Scientist, Division of Genetics awarded with ARRW Fellowship.
- Dr. Shailesh Tripathi, Principal Scientist, Division of Genetics elected Fellow of Indian Society of Pulses Research and Development.
- Dr. Shruti Sethi, Principal Scientist, Division of Food Science and Post Harvest Technology was Elected Fellow, Indian Academy of Horticultural Sciences.
- Dr. Bikash Mandal, Principal Scientist, Division of plant pathology was awarded with Dr. B.P. Pal Memorial NABS-Best Scientist Award of National Academy of Biological Sciences.
- Dr. M.S. Saharan, Principal Scientist received Dr. K.C. Mehta and Dr. Manoranjan Mitra Award by Indian Phytopathological Society.

- Dr. G.P. Rao, Principal Scientist, Division of Plant Pathology was awarded with S.N. Dasgupta Memorial Award by Indian Phytopathological Society and (ii) elected fellow Royal Association for Science-led Socio-cultural Advancement, New Delhi
- Dr. Kajal K Biswas, Principal Scientist, Division of Plant Pathology was awarded with (i) J.F. Dastur Memorial Award (2020), Indian Phytopathological Society, and (ii) Elected Fellow Indian Society of Mycology and Plant Pathology.
- Dr. Anirban Roy, Principal Scientist, Division of Plant Pathology was elected Fellow of Indian Virological Society.
- Dr. A.K. Mishra, Principal Scientist, Water Technology Centre was elected Fellow of Indian Society of Tropical Agriculture.
- Dr. S. Naresh Kumar, Professor, CESCRA received Lifetime achievement Award by VDG Association.
- Dr. Suresh Kumar, Principal Scientist, Division of Biochemistry was awarded with Sushil Kumar Mukherjee Commemoration Lecture Award.
- Dr. Sunil Pabbi, Principal Scientist, Division of Microbiology awarded with Distinguished Scientist Award 2019 by Society for Plant Research.
- Dr. Renu Pandey, Principal Scientist, Division of Plant Physiology was awarded with G.S. Sirohi Award by Indian Society for Plant Physiology.
- Dr. A.K. Shukla, Principal Scientist, IARI Regional Station, Amartara Cottage, Shimla was awarded with Fellow Award from the Indian Society of arid Horticulture.
- Dr. V.B. Patel, Principal Scientist, Division of Fruits and Horticultural Technology was awarded with Sh. D.P. Ghosh Memorial Young Scientist Award.
- Dr. J.K. Ranjan, Principal Scientist, Division of Vegetable Science received Outstanding Horticultural Scientist Award by Society for Horticultural Research and Development.
- Dr. T.R. Das, Senior Scientist, Division of Genetics received National Eminent Researcher Award-2020.
- Dr. M.C. Meena, Senior Scientist, Division of Soil Science and Agricultural Chemistryawarded with Young Scientist Award-2019 by Mosaic Company Foundation.
- Dr. Deeba Kamil, Senior Scientist, Division of Plant Pathology was elected Fellow, Indian Phytopathological Society.
- Dr. Ranjeet R Kumar, Senior Scientist, Division of Biochemistry was elected Fellow of Indian Society of Plant Physiology.
- Dr. Partha Saha, Scientist, Division of Vegetable Science received Young Scientist award by Society for Horticultural Research and Development.
- Dr. G. Prakash, Scientist, Division of Plant Pathology awarded with M.K. Patel Young Scientist award.
- Dr. Vignesh Muthusamy, Scientist, Division of Genetics awarded with Pran Vohra Award by Indian Science Congress Association.
- Dr. Rajkumar Uttamrao Zunjare, Scientist, Division of Genetics awarded with Manihar Best Ph.D. Thesis award by MTAI.
- Mr. Aditya K. S., Scientist, Division of Agricultural Economics selected for Netaji Subhas ICAR-International Fellowship for pursuing Ph.D. abroad.
- Dr. Nithyashree M.L., Scientist, Division of Agricultural Economics awarded with Uma Lele Mentorship award 2020.
- Dr. Chavlesh Kumar, Scientist, Division of Fruits and Horticultural Technology was awarded with ICAR-Jawaharlal Nehru Award for Outstanding Doctoral Thesis Research.

- Dr. Girijesh Mahra, Scientist, Division of Agricultural Extension was awarded with सर्वश्रेष्ठ व्याख्यान विशिष्ठ हिन्दी पुरस्कार 2019-20.
- Dr. Veda Krishnan, Scientist, Division of Biochemistry recognised as Plantae Fellow, American Society for Plant Biologists.
- Dr. Pranjal Yadava, Scientist, Division of Plant Physiology was elected Fellow by Maize Technologists Association of India.
- Dr. Amit Kumar Goswami, Scientist, Division of Fruits and Horticultural Technology was awarded (i) Young Horticultural Scientist Award-2020 by Society for Horticultural Research and Development, and (ii) Young Scientist Award-2020 by Society for Community Mobilization for Sustainable Development.
- Dr. Sagar, Scientist, Division of Entomology was awarded with Young Scientist award by Dr. B. Vasantharaj David Foundation.
- Dr. Suresh M Nebapure, Scientist, Division of Entomology was awarded with Young Scientist award by Dr. B. Vasantharaj David Foundation.

In addition, a large number of our scientists received various awards instituted by the professional societies and also recognized by their peer groups by electing/nominating to the various positions in the societies and governmental and inter-governmental committees.

14. BUDGET ESTIMATES & UTILIZATION

Statement showing Budget Estimates (B.E.) & Revised Estimates (R.E) for the year 2019-20 under Unified Budget

(₹ in Lakhs)

		B.E. 2020-21					B.E. 2020-21 after 20% Cut				
S. 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	2550.00			120.00	**2670.00**					**0.00**
	ii. Residential building	632.00				**632.00**					**0.00**
	iii. Minor Works										
2	Equipments	1100.00		65.00	120.00	**1285.00**	100.00		20.34	20.00	**140.34**
3	Information Technology	0.00		3.00	0.00	**3.00**			0.94		**0.94**
4	Library Books and Journals	500.00				**500.00**	15.00				**15.00**
5	Vehicles & Vessels	145.00				**145.00**					**0.00**
6	Livestock	3.00				**3.00**					**0.00**
7	Furniture & fixtures	70.00		0.00	10.00	**80.00**	5.00			1.72	**6.72**
8	Others										
A	**Total – CAPITAL (Grants for creation of Capital Assets)**	**5000.00**	**0.00**	**68.00**	**250.00**	**5318.00**	**120.00**	**0.00**	**21.28**	**21.72**	**163.00**
	Grants in Aid - Salaries (REVENUE)										
1	Establishment Expenses										
	Salaries										
	i. Establishment Charges	23247.65				**23247.65**	23247.65				**23247.65**
	ii. Wages										
	iii. Overtime Allowance										
	Total – Establishment Expenses (Grant in Aid - Salaries)	23247.65	0.00	0.00	0.00	**23247.65**	**23247.65**	**0.00**	**0.00**	**0.00**	**23247.65**

											(₹ in Lakhs)
Grants in Aid - General (REVENUE)											
1	**Pension & Other Retirement Benefits**	20000.00				**20000.00**	20000.00				**20000.00**
2	**Traveling Allowance**										
	A. Domestic TA / Transfer TA	172.00				**172.00**	25.00				**25.00**
	B. Foreign TA	0.00				**0.00**					
	Total – Traveling Allowance	**172.00**	**0.00**	**0.00**	**0.00**	**172.00**	**25.00**	**0.00**	**0.00**	**0.00**	**25.00**
3	**Research & Operational Expenses**					**0.00**					**0.00**
	A. Research Expenses	1130.00		1.00	0.00	**1131.00**	500.00		0.30		**500.30**
	B. Operational Expenses	1570.00		40.00	0.00	**1610.00**	825.00		12.50		**837.50**
	Total - Research & Operational Expenses	**2700.00**	**0.00**	**41.00**	**0.00**	**2741.00**	**1325.00**	**0.00**	**12.80**	**0.00**	**1337.80**
4	**Administrative Expenses**					**0.00**					
	A. Infrastructure	3000.00				3000.00	1820.00				**1820.00**
	B. Communication	30.00				30.00	20.07				**20.07**
	C. Repairs & Maintenance										
	i. Equipments,Vehicles & Others	350.00				350.00	100.00				**100.00**
	ii. Office building	1200.00				1200.00	275.00				**275.00**
	iii.Residential building	900.00				900.00	75.00				**75.00**
	iv. Minor Works	200.00				200.00	25.00				**25.00**
	D. Others (excluding TA)	803.00				803.00	305.00				**305.00**
	Total - Administrative Expenses	**6483.00**	**0.00**	**0.00**	**590.00**	**6483.00**	**2620.07**	**0.00**	**0.00**	**0.00**	**2620.07**
5	Miscellaneous Expenses					**0.00**					
	A. HRD	50.00				**50.00**	10.00				**10.00**
	B. Other Items (Fellowships, Scholarships etc.)	1755.00				**1755.00**	950.00				**950.00**
	C. Publicity & Exhibitions	20.00		1.00		**21.00**	2.00		0.30		**2.30**
	D. Guest House – Maintenance	120.00				**120.00**	49.00				**49.00**
	E. Other Miscellaneous	300.00	190.00	8.00	600.00	**1098.00**	150.00	59.45	2.50	187.75	**399.70**
	Total - Miscellaneous Expenses	**2245.00**	**190.00**	**9.00**	**600.00**	**3044.00**	**1161.00**	**59.45**	**2.80**	**187.75**	**1411.00**
	Total Grant in Aid-General	**11600.00**	**190.00**	**50.00**	**600.00**	**12440.00**	**5131.07**	**59.45**	**15.60**	**187.75**	**5393.87**
	Total (Pension+General)	**31600.00**	**190.00**	**50.00**	**600.00**	**32440.00**	**25131.07**	**59.45**	**15.60**	**187.75**	**25393.87**
B	**Total Revenue (Grants in Aid - Salaries +Pension+ General)**	**54847.65**	**190.00**	**50.00**	**600.00**	**55687.65**	**48378.72**	**59.45**	**15.60**	**187.75**	**48641.52**
	Grand Total (Capital + Revenue)	**59847.65**	**190.00**	**118.00**	**850.00**	**61005.65**	**48498.72**	**59.45**	**36.88**	**209.47**	**48804.52**

15. STAFF POSITION

(As on 31.12.2020)

Sl. No.	Category	No. of posts	
		Sanctioned	Filled
A.	**SCIENTIFIC STAFF**		
1)	Research Management Personnel	06	02
2)	Principal Scientist	65	43
3)	Senior Scientist/Scientist (S.G.)	170	114
4)	Scientist	337	332
	Total	**578**	**491**
B.	**TECHNICAL STAFF**		
1)	Category III	11	08
2)	Category II	276	167
3)	Category I	281	224
	Total	**568**	**399**
C.	**ADMINISTRATIVE STAFF**		
1)	Group A	18	17
2)	Group B	243	199
3)	Group C	162	112
	Total	**423**	**328**
D.	**SKILLED SUPPORT STAFF**	**740**	**600**

16. POLICY DECISIONS AND ACTIVITIES UNDERTAKEN FOR THE BENEFIT OF DIFFERENTLY ABLED PERSONS

16.1 POLICY DECISIONS AND ACTIVITIES UNDERTAKEN FOR THE BENEFIT OF DIFFERENTLY ABLED PERSONS

The decisions and activities undertaken for the benefit of the differently abled persons are as follows:

- The benefits to the differently abled candidates in service matter as per instructions of ICAR/DOPT. Govt. of India as the case may be are followed.
- Five per cent of the total numbers 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 2021-21, twenty physically challenged students (ten M.Sc./M.Tech and 10 Ph.D.) were admitted against the reserved seats for differently abled candidates. However, in the event of there being no eligible suitable differently abled candidates in the earmarked discipline, to fill up the mentioned number of seats, such unfilled seats shall be transferred to other disciplines, where eligible suitable differently abled candidates are available for filling these seats.

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 December 12, 2020 are as follows:

Category	Total number of beneficiaries	Number of beneficiaries with disability	Percentage (%)
Technical	399	5	1.25
Administrative	328	9	2.74
Skilled Support Staff	600	7	1.17

17. OFFICIAL LANGUAGE (RAJBHASHA) IMPLEMENTATION

Article 343 of the Constitution, says that Hindi shall be the Official Language of the Union Government. To implement the objectives in letters and spirit, ICAR-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 program of the Department of Official Language, Ministry of Home Affairs, Govt. of India, an OL Inspection Committee was constituted under the chairmanship of Dr. Indramani, Head, and 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/Center, etc. and submitted inspection reports.

17.2 AWARDS AND HONOURS

The Institute was awarded first Prize Rajshri Tandon Rajbhasha Puraskar 2019-20 by ICAR, New Delhi in large member office category.

17.3 AWARD SCHEMES/COMPETITIONS

During the year 2019-20 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 implanted as per the directives of the Department four employees of the institute were given cash awards for doing their maximum official work in Hindi in the whole year.

17.3.2 Hindi vyavahar pratiyogita

Hindi Vyavahar Pratiyogita 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, Extension Division and Biochemistry Division amongst the divisions and Personnel-III Section, Directorate and Farm Service Operational Unit amongst the sections/units, Regional station Shimla,

Regional station Karnal, Regional Station, Kalimpong amongst the Regional stations were chosen to give the prizes.

17.3.3 Awards for Popular Science Writing in Different Journals

A competition for popular Science writing was organized for scientists/technical officers of the institute and winners were awarded first, second third and three consolation prizes of ₹ 7000/-, 5000/-, 3000/- & ₹ 2000 (each), respectively for their published articles in different journals.

17.3.4 Pusa Vishisht Hindi Pravakata Puraskar

Pusa Vishisht Pravakta Puraskar was given jointly to two scientists for their outstanding lectures in different training programs. Evaluation was done on the basis of recommendations of course coordinator and feedback of trainees. The puraskar carries a cash prize of ₹10,000/- and a certificate.

17.4 HINDI *CHETNA MAAS*

This year *Hindi Chetna Maas* was celebrated from September 14 to October 13, 2020. This month was inaugurated on September 14, 2020 through Zoom App and "Hindi Poem Recitation" competition was organized. In order to encourage the officials/ employees to do their official work in Hindi, various competitions were organized. This year due to COVID -19 some competitions were organized in online and offline mode. Hindi Poem Recitation, Extempore, Debate were organized through zoom app and Hindi noting and drafting, quiz, Hindi Typing and general knowledge competition only for the skilled supporting staff of the institute was organized in offline mode. A total of seven competitions were organized. Employees from all the categories of the institute participated in these competitions enthusiastically. Hindi Week/Hindi Day/Hindi Fortnight was 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". In addition, some special training/ workshops courses 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 Chemicals		
Winter School on "Harnessing new generation green technologies from plants, microbial and waste sources for sustainable crop, environmental and human health"	December 26, 2019-January 15, 2020	14
Division of Biochemistry		
Omics Tools and Techniques for Nutritional Evaluation and Enhancement	January 9-20, 2020	32
Division of Agricultural Economics		
Advances in Research Methodology for Social Sciences	August 31 - September 4, 2020	50
Division of Agricultural Engineering		
Training programme of progressive famers of Uttar Pradesh on crop residue management and advancements in small scale farm mechanization to increase farm productivity	March 6-8, 2020	12
Division of Agricultural Extension		
NAHEP-CAAST sponsored online training on life skills and personality development	September 21-25, 2020	40
Division of Entomology		
Training on Integrated approach for diagnostics and management of Insect pests, Vectors, Pollinators and Natural enemies	January 20-24, 2020	10
DST-SERB sponsored Training programme on DNA Barcoding for Insect Diagnosis	February 19-21 2020	27
Division of Floriculture and Landscape Architecture		
Model training course (MTC) on Advances in Floriculture and Landscaping	February 20-27, 2020	20
Division of Food Science and Post Harvest Technology		
Online training programme on धान्य एवं बागवानी फसलों के परिरक्षण एवं मूल्यवर्धन	September 7- 11, 2020	20
Division of Fruit and Horticultural Technology		
ICAR sponsored Winter School on Non-conventional Approaches for Genetic Improvement of Perennial Horticultural Crops	January 17 - February 6, 2020	24
Division of Microbiology		
Pusa Decomposer Technology	August 27, 2020	50
Uses of Biofertilizer for Organic Farming	September 9, 2020	50
Biocomposting and biofertilizer technology	September 21, 2020	67

Rhizosphere Engineering: Genomes to Metagenomes	February 7, 2020	50
Transnational Research Needs and Applications of Plant Microbiomes	February 25-27, 2020	50
Bioinformatic Analysis on Soil Microbial Community Sequence Data	August 12-13, 2020	100
Division of Plant Pathology		
NAHEP sponsored training on Pathophenotyping and genome guided characterization of rust fungi infecting wheat and other cereals	January 22-February 1, 2020	25
National Certification System of Tissue Culture Raised Plants	February 03-07, 2020	4
Division of Plant Physiology		
NAHEP-CAAST sponsored training program on Next-Generation Sequencing and Computational Biology of Agriculture.	March 4-6, 2020	30
Division of Vegetable Science		
NAHEP and CAAST sponsored training on Genomics for Improvement of Horticultural Crops	February 24 – March 5, 2020	25
Seed Production Unit		
सब्जी बीज उत्पादन एक सफल व्यवसाय	February 12, 2020	50
रबी फसलों का बीजोत्पादन	February 17, 2020	55
Regional Station, Indore		
Wheat & wheat seed production technology	January 13, 14, 17, 24-27, 2020	830
Seed Production & Certification	January 24, 2020	20
Wheat & wheat seed production technology	February 05, 10, 19, 2020	208
Wheat & wheat seed production technology	March 1-3, 2020	4,800 Visitors
Kharif crops diversification with Urd and Maize in Tribal Areas	June 16, 2020	65
Monitoring and On-Farm training in *kharif* Urd and Maize	July 22, 2020	45
On -farm training and Field Day Urd & Maize	September 10, 2020	72
Field preparation and Wheat Production Technology in Tribal Areas	October 08, 2020	25
Gehun ke bharpoor utpadan ke liye nayi kisme aur unnat takneek	October 09, 2020	40
Wheat Production Technology in Tribal Areas	October 21, 2020	46
Wheat Production Technology	October 22, 2020	24
On-farm training of Tribal Wheat farmers and sowing for Wheat Demonstrations	October 27, 28, 31, 2020	80
On-farm training of Tribal Wheat farmers and sowing for Wheat Demonstrations	November 04, 07, 2020	65
On-farm training of Tribal Wheat farmers for Weed Control	December 04, 2020	52
Regional Centre, Karnal		
Farmers training on seed production and storage of winter crops	February 25-27, 2020	20
Regional Station, Kalimpong		
Agronomic practices for enhanced yield of mustard	February 3, 2020	45
Vermi-composting	February 15, 2020	38
Organic cultivation of high value vegetable crops	December 12, 2020	50
Regional Centre, Katrain		
Farmer's training organized on production technologies of temperate vegetables and ornamental crops	January 28-30, 2020	20
Farmer's training on organized temperate vegetable production under the Schedules Caste Sub-Plan (SCSP)	March 05, 2020	20

Regional Station, Shimla		
Training under MGMG on apple, pear, kiwi, pomegranate, stone fruits and strawberry cultivation and wheat-barley cultivation	January 26, and February 04, 2020	120
Training-pruning of temperate fruit crops and propagation techniques	February 05, 2020	30
Training on cultivation of Fruit Crops and nursery techniques	March 03-07, 2020	60
Training program on seb me nursery aur bagicha prabandhan ke liye aadhunik taknik	December 03-05, 2020	65
AKMU Unit		
ICT Applications in Agricultural Research for technical staff sponsored by HRD, ICAR	March 16-20, 2020	25

18.1.1 Training Programmes Organized by the Institute's Centre for Agricultural Technology Assessment and Transfer (CATAT)

In all, five on-campus training programmes were organised for agriculture officials and Progressive farmers of different States. These programmes were attended by 135 participants from Rajasthan, Tripura and NCR Delhi.

CATAT		
Name of the training programme	**Dates/Month**	**No. of trainees**
Improved Agricultural Technologies for Higher Income for farmers of North Tripura District, Tripura	January 19-23, 2020	13
Improved Agricultural Technologies' for Farmers of Dausa District (Rajasthan)	February 21-25, 2020	32
Training on Grading, Packing and Post-Harvest Management	January 24, 2020	30
Protected Cultivation	February 4, 2020	30
Bio-fertilizers and Waste Management from Crop Residue and Compost Preparation	March 12, 2020	30

19. MISCELLANY

I. Ongoing Projects at IARI as on December 31, 2020

(A) In-house Research Projects	:	**199**
School of Crop Improvement	:	53
School of Horticultural Sciences	:	21
School of Crop Protection	:	44
School of Natural Resource Management	:	54
School of Basic Sciences	:	16
School of Social Sciences	:	11
(B) Flagship Programmes	:	**14**

II. Scientific Meetings Organized

a) Workshops	15
b) Seminars	25
c) Summer institutes/Winter school	06
d) Farmers' day (s)	26
e) Others	242
Total	**314**

III. Participation of Personnel in Scientific Meetings

India

a) Seminars	197
b) Scientific meetings	324
c) Workshops	135
d) Symposia	88
e) Others	176
Total	**920**

Abroad

a) Seminars	03
b) Scientific meetings	03
c) Workshops	05
d) Symposia	03
e) Others	13
Total	**27**

IV. Suggestions Given / Decisions Taken at the Meetings of Senior Management Personnel

Academic Council (January 1, 2020 to December 31, 2020)

- Online Academic activities implemented during Covid -19 pandemic: (i) Online registration and fee payment; (ii) Webinar series on topical interest; (iii) Upgradation of PGS Online management system; (iv) Open book examination for comprehensive exam and III-Trimester examination (2019-20 session); (v) During II-Trimester (2019-20 session), awarding of grades based on midterm exam marks/assignments; (vi) Online mode of - Thesis submission & evaluation, pre-qualifying & Qualifying exam, Final (vii) Viva Voce Exam, Credit seminar, ORW presentation and thesis seminar; (viii) Online meeting of Standing Committees, Academic Council, Professors meeting, Advisory Committee, and Board of Studies; (ix) In some special cases, considered changes in approved ORWs without affecting Merit Medal nomination guidelines.
- Switching over from Trimester to Semester System from academic session 2020-21and accordingly the revision of Course Curricula
- The approval on the nomination of two distinguished IARI alumni and world Food Prize winners *viz.*, Dr. Sanjaya Rajaram and Dr. Rattan Lal for the Conformation of the degree of Doctorate of Science (Honoris causa).

Research Advisory Committee

School of Crop Improvement

- Quality issues like low glycemic index in rice, biofortified wheat for bread and biscuit making, high malt barley, varieties for fast food purposes in different food crops should be developed.

- In wheat, focus should be given on molecular breeding for biotic/abiotic stress tolerance and higher hectoliter weight. Surface seeding of wheat should be explored in case of rice-wheat cropping system.
- In all released varieties of wheat, hectoliters weight should be included in varietal description.
- Crops where sufficient information on genomic and genetic resources are available, haplotype-based breeding approach should be used for development of multiple stress tolerant varieties with higher productivity to overcome effects of the climatic change.
- Emphasis should be given to breed short duration varieties of field crops for growing an additional crop between the two seasons to increase the cropping intensity, soil health, productivity and profitability.
- Pre-breeding should be given top priority in all crops for broadening the genetic base, breaking genetic ceiling to yield and enhancing resistance to biotic/ abiotic stress tolerance through utilization of novel genetic resources.
- Emphasis should be given on development of varieties amenable to mechanical harvesting in case of oilseeds and pulses.
- Policy guidelines for incentivizing cultivation/ promotion of biofortified crops for strengthening nutritional security should be developed and submitted to the concerned departments for needful.

School of Horticulture

- Improved vegetable and flower varieties with early maturity suitable for filling the gap between rice-wheat cropping systems should be developed.
- Vegetables are key to nutritional security. Research needs to be intensified for development of biofortified vegetable varieties, processing types of tomato and leafy greens.
- Medicinal and therapeutic potential of under-utilized vegetables like chow-chow, ash gourd; *Coccinia* (kundru, Ivygourd) etc. and flowers like rose, jasmine etc. should be explored.
- Affordable technologies mainly of *vertical farming*, *aeroponics* and *hydroponics* are very much needed in the present scenario of reduced space, water and energy. Such technologies need to be to standardized with regard to structure, crops and fertigation scheduling along with their prototypes.
- Horticulture-based economy should be promoted to overcome poverty and hidden hunger, enhancing farmer's income through value addition, product development and export promotion.
- Utilization of farmers' varieties, landraces, and wild forms as donors agreed for traits related to better agronomy, quality and resistance to biotic/ abiotic stresses should receive focus. Farmers should be appropriately incentivized through benefit sharing mechanism if PPV&FRA protected varieties are used as donors.
- Seed and planting material production in case of horticultural crops should be strengthened for early commercialization of new varieties. Germplasm, including wild species and genetic stocks, should be evaluated for providing unique rootstocks.

School of Natural Resource Management

- Research on formulating the minimum maintenance dose of K, threshold values of soil organic carbon in relation to soil health and crop productivity, safe limits of metals and metalloids in soil should be intensified.
- Recommendations of Pusa STFR meter should be validated under field conditions and efforts should be made to alleviate the iron deficiency under direct seeded rice.
- Agricultural water footprint should be studied on watershed to basin level. Irrigation performance/ management at basin/regional level should be

studied using remote sensing approach.

- Technologies, including crop and farming systems diversification, should be developed to arrest groundwater depletion through efficient and climate smart water management.
- Preparedness plan should be developed to address the challenges due to 2°C rise in temperature owing to climate change specifically for resultant water stress.
- Guidelines for use of waste water should be developed with the data generated from the last five year plan, while adhering and incorporating the FAO guidelines.
- Emphasis should be given on development of DSS (based on modelling) to manage biotic and abiotic stresses.
- Integrated farming system needs to be evaluated in terms of energy flow, water budgeting and nutrient dynamics and detailed economic analysis of farming system needs to be done with the help of economists.
- Experiments may be conducted on integration of existing crop residue management (CRM) machines with Pusa Decomposer cost and impact of Pusa Decomposer should be worked out. Also, development of integrated machine system for paddy straw management may be undertaken in context of air pollution and carbon economy.
- Efforts should be made for upscaling solar fridge for prevention of postharvest losses of perishables.
- Macro level approach should be considered for Natural Resource Management projects leading to policy papers for decision makers.

School of Crop Protection

- There is need to exercise careful choice of plants for bio pesticides discovery rather than using/ plants which have potential for alternative high value uses.
- Strategies for identification of new molecules (agro-chemicals) and scaling up their production should be worked out and the basic work carried out in the Division of Agricultural Chemicals should lead to products of applied value.
- Epidemiological studies on emerging plant diseases should be done.
- Actual pest/pathogen management work should be undertaken using integrated approaches.
- Work to be initiated on termite management, which is still a major problem.
- More emphasis to be given on diseases like Karnal bunt of wheat, particularly with respect to identification of resistance sources.
- Shelf life of EPN formulations should be studied at varied temperature conditions and data on reaction kinetics of controlled release formulations to be generated.
- Division of agricultural chemicals should bring out a bulletin for public awareness based on safety data generated on pesticide residue research, also highlighting the impact on export.

School of Basic Sciences

- In addition to rice and wheat, other field and horticultural crops, need to be included in basic sciences studies.
- Fine mapping of QTLs, and validation of genes and promoters in the QTLs regions need to be intensified.
- For gene function studies, protein-protein interaction, cellular localization of proteins, and heterologous systems such as yeast and Arabidopsis need to be explored.
- Pathways and mechanisms need to be studied/ engineered to enhance the partitioning of micronutrient into endosperm.
- Germplasm diversity may be mined for

identification of new genes and mechanisms to combat climate change. For example, rice cv. Nagina 22 needs to be deeply analysed to mine novel genes for stress tolerance.

- In Soybean, cultivars with novel traits such as herbicide tolerance (HT), higher productivity and adaptation to major soybean ecologies including north India should be developed.
- Apomictic F1 seed production should be explored in crops where hybrid development is in progress.

School of Social Sciences

- Science communication for public awareness should be emphasized. Use of ICT and Artificial Intelligence based initiatives like Decision Support System tools and apps should be promoted for development of quality database as well as advisories and policy making.
- Value-chain based development model, internalizing the status and prospect of value addition along the value chain, for income enhancement should be analyzed and promoted.
- Interdisciplinary research should be taken to address the issues of socioeconomic- ecological considerations related to development of innovation and policies.
- Policy briefs of significant results should be published towards transforming agri-food systems.
- Systematic studies on economic impact of various technologies developed by the Institute on socio-economic wellbeing of farmers and other stakeholders should be carried out to seek more investment in research and technology development and transfer.

Post Graduate School

- All efforts to be made to make IARI a Global University and get a ranking among top world Universities, and a short, medium, and long-term action and implementation plan should be prepared towards this end.
- More international collaborations for degree programmes and faculty exchange should be explored.

Administrative and Financial Issues

- Filling of vacant posts of scientist, technical, administrative and supporting staff should be taken on priority.
- Mechanism should be developed for resource generation for the Institute from commercialization of IARI technologies/varieties which bring impressive economic value to the nation through domestic/ export market.
- Most of the allocated budgetary amount is utilized for meeting committed expenses (salary, pension, security, annual maintenance) and little is left for research work. To maintain the research and teaching standards and to meet the expectations from IARI, the RAC recommended allocation of necessary funds to the institute.

General Recommendations

- Under new education policy of the Government, ICAR-IARI must emerge as the first and the foremost Multi-disciplinary Educational and Research University (MERU) and should become a model for the universities within and in other countries. The kind of academic freedom required, must be provided to IARI to develop as a world class university.
- The progress made in making IARI truly multi and interdisciplinary institution is highly appreciated. It must show the way forward to surround Agriculture with Basic and Social Sciences.
- Monitoring, evaluation, and impact assessment should be institutionalized, emphasizing differentiated responsibility and accountability with provisions for mid-course corrections.
- A very strong group in socio economics and human

science is required to synergize social, economic and ecological gains and sustainability, and to suggest policy options and actions.

- Research in agriculture must be farmer friendly and reach them for welfare enhancement. Scientists must strive with this theme.
- There is a need to strengthen information and communication system. Science of communication must assume greater importance for increasing awareness among various stakeholders and to facilitate technology transfer and adoption.
- IARI should regularly bring out policy briefs based on critical scientific analysis and develop a good database for decision support system.
- IARI should strengthen information-knowledge-innovation continuum, keeping smaller holder farmers at the center of the stage, and promoting public-private-partnership.
- The institute may form a committee to ascertain/ identify technologies for data generation and validation through organized testing of the developed technologies other than varieties.
- Facilities should be strengthened to adopt marker aided selection and haploids development to speed up crop improvement.
- For quality check of truthfully labelled seeds produced by private seed producers under MOU's, institute level monitoring system should be established.
- India slipped in meeting the Millennium Development Goals. We are off track in meeting the SDG 1 and 2, which are most influenced by agriculture. Therefore, the role of IARI is of paramount importance in transforming Indian Agriculture to meet the SDGs – Agenda 2030.

V. Resource Generation

1) Consultancy & other services

Consultancy services: ₹ 1,77,000/-
Contract research: ₹ 14,99,387/-
Contract service: ₹ 33,240/-
Training: ₹ 1,73,000/-
Total (A): ₹ 18,82,627/-

2) Revolving fund

Sale Proceeds Revenue Generated

(a) Seed: ₹ 4,62,86,172/-
(b) Commercialization: ₹ 6,60,263/-
(c) Prototype manufacturing: ₹ 1,02,26,651/-
Total (B): ₹ 5, 71,73,086/-

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 : ₹ 1,46,448
(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. : ₹ 0.00
(d) Cash transferred from Syndicate Bank to Directors 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): ₹ 7,13,000
Total (C) : ₹ **8,59,448**
Grand Total (A+B+C): ₹ **18, 82,627+ ₹ 5, 71, 73,086+ ₹ 8, 59,448= ₹ 5, 99, 15,161/-**

VI. All India Coordinated Research Projects in Operation during the year January 1, 2020 to December 31, 2020

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
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. All India Coordinated Research Project on Vegetable Crops
18. Adhoc Cooperating Center of AICRP on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants, Indian Institute of Soil Science, Bhopal
19. All India Coordinated Research Project on Ergonomics & Safety in Agriculture (ESA)
20. All India Coordinated Research Project on Pearl Millet
21. All India Coordinated Research Project on Rapeseed-Mustard
22. All India Network Research Program on Onion & Garlic (AINRPOG)

VII. Foreign visitors during January 1 to December 31, 2020

List of foreign visitors from January 1 to December 31, 2020		
S.No.	**Details of Visit**	**Date of Visit**
1.	A delegation from Bhutan was led by Dasho Karma Tshiteen former Chairman of Civil Service Commission, Bhutan	January 23, 2020

Delegation from Bhutan

Appendix 1
Members of Board of Management of IARI
(As on 31.12.2020)

Chairman
Dr. A.K. Singh
Director, IARI

Members
Dr. Rashmi Aggarwal
Dean & Joint Director (Education)
(Acting), IARI

Dr. Prakash Shastri
Professor (Plant Pathology)
College of Agriculture, Rajmata
Vijiyaraje Scindia krishi
Vishwavidyalaya (RVSKVV)
Khandwa, M.P.

Shri Akhilesh Kumar
Shyama Bhavan, Mathiya Zirat
Motihari, East Champaran (Bihar)

Dr. Rajendra Prasad S
Vice-Chancellor
University of Agricultural
Sciences, Bengaluru, Karnataka

Dr. S.K. Malhotra
Agriculture Commissioner
Deptt. of Agril. and Cooperation
Ministry of Agriculture,
Krishi Bhawan, New Delhi

Prof. Pratap Bhanu Singh Bhadoria
Agri. & Food Engg., IIT Kharagpur

Dr. V.P. Singh, Padamshree,
Ex-principal Scientist
Division of Genetics

Shri Ramkumar Saharawat
Garhi, Sakhawatpur, Budhana
Muzaffanagar

Dr. T.V.R.S. Sharma
Former Emeritus Scientist &
Principal Scientist
Central Island Agricultural
Research Institute, Garacharma
Port Blair

Dr. V.K. Singh
Joint Director (Extension) and
Head, Agronomy
IARI, New Delhi

Dr. Rajbir Yadav
Head, Division of Genetics
IARI, New Delhi

Dr. Alka Singh
Head, Division of Agricultural
Economics
IARI, New Delhi

Dr. K. Annapurna
Head, Division of Microbiology
IARI, New Delhi

Dr. Pramila Krishanan
Head, Division of Agricultural
Physics
IARI, New Delhi

Dr. Anupama Singh
Head, Division of Agricultural
Chemicals
IARI, New Delhi

Dr. Shailly Praveen
Head, Division of Biochemistry
IARI, New Delhi

Dr. S.S. Sindhu
Head, Division of Floriculture &
Landscaping
IARI, New Delhi

Smt. Sanjeevan Prakash
Comptroller, IARI, Jharkhand

Sh. Madhu Vyas
Secretary-cum-Commissioner
(Development)
Govt. of NCT of Delhi

Member - Secretary
Sh. Pushpendra Kumar
Joint Director (Adm.), IARI

Appendix 2
Members of Research Advisory Committee of IARI
(As on 31.12.2020)

Chairman
Dr. R.B. Singh
Former President NAAS and Member Planning Commission

Members
Dr. J.P. Tandon
Former Director, IIWBR, Karnal

Dr. K.V. Peter
Former VC, KAU, Kerala

Dr. A.K. Sikka
Former DDG (NRM), ICAR

Dr. B.S. Parmar
Former Joint Director (Research), IARI, New Delhi

Dr. J.P. Khurana
Professor of Plant Molecular Biology, University of Delhi, South Campus

Dr. R.S. Deshpande
Ex-Director, Institute of Social & Economic Change, Bangalore

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

Appendix 3

Members of Academic Council of IARI

(As on 31.12.2020)

Chairperson
Dr. A.K. Singh
Director

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. (Ms.) Sarvjeet Kaur
Director (Acting) (NIPB)

Dr. Rajender Parsad
Director, (IASRI)

Dr. M.R. Dinesh
Director, IIHR, Bengaluru

Dr. C.R. Mehta
Director, CIAE, Bhopal

Dr. A.K.Singh
Joint Director (Res.) (Additional charge)

Dr. V.K. Singh
Joint Director (Extn.) (Additional charge)

Dr. H.S. Gupta
Former DG, BISA & Director, IARI
New Delhi

Dr. S.N. Puri
Former VC, CAU
Imphal

Dr. A.K. Sikka
Former DDG (NRM), ICAR
IWMI Representative-India &
Principal Researcher
International Water Management
Institute New Delhi

Dr. P. Das
Former DDG (Agril. Extn.)
ICAR, New Delhi

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. Anil Rai
Professor, Bioinformatics

Dr. Sudeep Marwaha
Professor, Computer Application

Dr. (Ms.) Debjani Dey
Professor, Entomology

Dr. Soora Naresh Kumar
Professor, Environmental Sciences

Dr. K.P. Singh
Professor, Floriculture and Landscaping

Dr. S.K. Jha
Professor, Post Harvest Technology

Dr. O.P. Awasthi
Professor, Fruits and Horticultural Technology

Dr. Vinod
Professor, Genetics

Dr. (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. Chakrabarty
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

Shri. V.R. Srinivasan
Comptroller

Dr. A Nagaraja
Elected Faculty Representatives (2)
Principal Scientist, Fruit Science

Dr. (Ms.) Renu Pandey
Principal Scientist, Plant Physiology

Shri Deep Chand
Incharge, IARI Library
Mr. Rahul Kumar
President, PGSSU

Mr. Manu S.M.
Students' Representative to the Academic Council

Member Secretary
Shri Pushpendra Kumar
Registrar

Appendix 4

Members of Extension Council of IARI

(As on 31.12.2020)

Chairperson

Dr. A.K. Singh
Director
IARI, New Delhi

Members

Dr. D.K. Yadav
Head, SST, School Coordinator, Crop Improvement

Dr. V.K. Singh
Jt. Director (Extn.), IARI, New Delhi,

Jt. Director (Res.), 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, NRM

Dr. Indra Mani
Head, Agril. Engg, IARI
Dr. R.N. Pandey, Head, SSAC, IARI

Dr. Gyanendra Singh
I/C. Seed Production, Unit, IARI

Dr. J.P.S. Dabas
I/c CATAT, IARI

Dr. Man Singh
Project Director, WTC, IARI
Dr. V.K. Pandita, Head, IARI Regional Station Karnal

Dr. S.K. Malhotra
Agril. Commissioner, MOA & FW

Sh. A.P. Saini
Jt. Director (Agri.) Delhi Development Department.

Dr. Garima Gupta
Director, Delhi Agricultural Marketing Board, 9, Institutional Area, Pankha Road, Janakpuri, 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

The Dy. Director General (Agril. Extn.), ICAR

Sh. Ratnesh Kumar, Jt. Director (Admn.), IARI, New Delhi

Dr. Rakesh Nanda
Professor, SKUAST, Jammu

Mr. Anil P. Joshi
Chairman, Hesco (V.O. Representative) Village : Shuklapur, P.O. : Ambiwala Via: Prem Nagar, Dehradun Uttrakhand

Mr. Allwyn Glatdston World Vision (V.O. Representative), Pant Marg, New Delhi-110001
Mr. Rajesh Aggarwal, Managing Director, (Agro Industry Representative) Insecticide India Limited, 401-402, Lusa Tower, Azadpur Commercial Complex Delhi)

Shri Anil Kumar Srivastava (DD Representative)
The Additional Director General DD Kisan CPC, 175, Asian Games Village Complex Siri Fort, New Delhi- 110049

Dr. Ritu Rajput
CC: Shiv Nandan Lal) All India Radio, Akashwani Bhawan, New Delhi - 110001

Sh. V.R. Srinivasan
Comptroller, IARI, New Delhi

Member-Secretary

Dr. Premlata Singh, Head, Agril. Extn, & School Coordinator, Social Sciences, IARI, New Delhi

Farmers:

Mr. Sandeep Goel, B-1, Industrial Estate, Bazpur Road, Kashipur, Uttarakhand

Ms. Pooja Sharma, w/o Sh Manoj Kumar, Vill –Chander Post Budhera Dist. Gurugram

Appendix 5
Members of Institute Research Council (IRC)
(As on 31.12.2020)

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 31.12.2020)

Chairman
Dr. A.K. Singh
Director, IARI, New Delhi

Members (Official Side)
Dr. V.K. Singh
Joint Director (Extension)
(Additional Charge)
IARI, New Delhi

Dr. A.K. Singh
Joint Director (Research) (Acting)

Head, IARI, Regional Station, Karnal

Head, Regional station, Shimla
Comptroller, IARI, New Delhi

Secretary (Official Side)
Joint Director (Adm.),
IARI, New Delhi

Members of the Staff Side (Elected)
Sh. Raj Kumar
UDC, Directorate, Secretary (Staff side), IARI, New Delhi

Sh. Ganesh Rai
T-3, Division of Entomology

Sh. Atiq Ahmed
T-5, Agricultural Physics

Sh. Veer Pal Singh
T-5, CPCT

Sh. Bhavesh Kumar
T-2, ME Unit, Directorate

Smt. Sonia Rawat
Assistant, Directorate

Sh. Pankaj
UDC, Directorate

Sh. Satyendra Kumar
AAO, Directorate

Sh. Bijender Singh
SSS, CATAT

Sh. Raj Pal
SSS, Directorate

Sh. Shashi Kant Kamat
SSS, Seed Production Unit

Sh. Umesh Thakur
SSS, Audit, Directorate

Appendix 7

Members of Grievance Committee of IARI

(As on 31.12.2020)

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 31.12.2020)

Directorate

Director
Dr. Ashok Kumar Singh

Joint Director (Research) (Add. Charge)
Dr. A.K. Singh

Dean & Joint Director (Education) (Add. Charge)
Dr. Rashmi Aggarwal

Joint Director (Extension) (Add. Charge)
Dr. V.K. Singh

Joint Director (Admn.) & Registrar
Mr. Pushpendra Kumar

Principal Scientist (PME)
Dr. M. Jayanthi

Incharge, Publication Unit
Dr. G.P. Rao

Comptroller
Mr. V.R. Srinivasan

Chief Administrative Officers
Mr. Sanjeev Kumar Sinha

Agricultural Chemicals
Head
Dr. Anupama

Professor
Dr. (Ms.) Neera Singh

Network Project Coordinator
Dr. K.K. Sharma

Agricultural Economics

Head (Acting)
Dr. Alka Singh

Professor
Dr. Alka Singh

Agricultural Engineering

Head (Acting)
Dr. Indra Mani

Professor
Dr. D.K. Singh

Agricultural Extension

Head (Acting)
Dr. Prem Lata Singh

Professor
Dr. R.N. Padaria

Agricultural Physics

Head (Acting)
Dr. P. Krishnan

Professor
Dr. V.K. Sehgal

Agronomy

Head (Acting)
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 Land-scaping

Head (Acting)
Dr. S.S. Sindhu

Professor
Dr. K.P. Singh

Fruits and Horticultural Technology

Head
Dr. S.K. Singh

Professor
Dr. O.P. Awasthi

Genetics

Head (Acting)
Dr. Rajbir Yadav

Professor
Dr. Vinod

Microbiology & CCUBGA

Head (Acting)
Dr. Annapurna K.

Professor
Dr. Radha Prasanna

Nematology

Head (Acting)
Dr. Uma Rao

Professor
Dr. M.R. Khan

Project Coordinator Honey Bee (Acting)
Dr. Balraj Singh

Plant Pathology

Head (Acting)
Dr. Rashmi Aggarwal

Professor
Dr. V.K. Baranwal

Plant Physiology

Head (Acting)
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 (Acting)
Dr. D.K. Yadava

Professor
Dr. S.K. Chakraborty

Soil Science and Agricultural Chemistry

Head (Acting)
Dr. R.N. Pandey

Professor
Dr. S.P. Datta

Vegetable Science

Head
Dr. B.S. Tomar

Professor
Dr. T.K. Behera

Centre for Environment Science and Climate Resilient Agriculture (CESCRA)*

Head (Acting)
Dr. Bhupinder Singh

Professor
Dr. Naresh Kumar

Water Technology Centre

Project Director (Incharge)
Dr. Man Singh

Professor
Dr. Man Singh

Centre for Agricultural Technology Assessment and Transfer

Incharge
Dr. J.P.S. Dabaas

Centre for Protected Cultivation Technology

Incharge
Dr. Indra Mani

Agricultural Knowledge Management Unit (AKMU)

Incharge
Dr. A.K. Mishra

Agricultural Technology Information Centre (ATIC)

Incharge
Dr. N.V. Kumbhare

Farm Operation Service Unit

Incharge
Dr. Manoj Khanna

National Phytotron Facility

Incharge
Dr. Akshay Talukdar

Seed Production Unit

Incharge
Dr. Gyanendra Singh

Zonal Technology Management & Business Planning and Development (ZTM & BPD) Unit

Incharge
Dr. Neeru Bhooshan

IARI Library

Incharge (Library Services)
Dr. Madan Pal

IARI Regional Station, Amartara Cottage, Shimla

Head (Acting)
Dr. K.K. Pramanick

IARI Regional Station, Indore

Head (Acting)
Dr. S.V. Sai Prasad

IARI Regional Station Kalimpong

Incharge
Dr. Dwijendra Barman

IARI Regional Station, Karnal

Head
Dr. V.K. Pandita

IARI Regional Station, Katrain

Head (Acting)
Dr. Chandar Prakash

IARI Regional Station, Pune

Head
Dr. G.K. Mahapatro

IARI Regional Station, Pusa

Head (Acting)
Dr. K.K. Singh

IARI Regional Station Wellington (The Nilgiris)

Head (Acting)
Dr. M. Sivaswamy

IARI Rice Breeding & Genetics Research Centre, Aduthurai

Incharge
Dr. M. Nagarajan

IARI Centre for Improvement of Pulses in South, Dharwad

Incharge
Dr. B.S. Patil

IARI Krishi Vigyan Kendra Shikohpur, Gurgaon

Incharge
Dr. Anamika Sharma

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*Formerly Division of Environmental Sciences and including Nuclear Research

Mandate

Basic, strategic and anticipatory research in field and horticultural crops for enhanced productivity and quality.

Research in frontier areas to develop resource use efficient integrated crop management technologies for sustainable agricultural production system.

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