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INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

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National Symposium on

Hybrid Technology for Enhancing Crop Productivity (NSHT)

8-10 January, 2025

Proceedings and Recommendations






FSII Federation of Seed Industry of India — Science for Farmers' Prosperity

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RASI SEEDS

RASI Vijay 50

BAYER

nsa National Seed Association of India

ACSEN Agriscience

SEEDWORKS

Trust for Advancement of Agricultural Sciences (TAAS)

GOAL

Harnessing the potential of agricultural sciences for the welfare of the people.

MISSION

Promoting growth and advancement of agriculture through scientific partnerships, policy advocacy and public awareness.

OBJECTIVES

- To act as a 'Think Tank' to deliberate on key issues relating to agricultural research and innovation for development (ARI4D) and influence policy decisions
- To organize workshops, conferences, brainstorming sessions, policy dialogues seminars and special lectures on emerging issues and new developments in agricultural sciences
- To disseminate knowledge among stakeholders through publication of proceedings, strategy papers and policy papers
- To confer awards to the scientists and farmers for their outstanding contributions having impact on Indian agriculture
- To facilitate scientific interactions and partnership building of non-resident Indian agricultural scientists with Indian scientists

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National Symposium on

Hybrid Technology for Enhancing Crop Productivity (NSHT)

8-10 January, 2025

Venue: **AP Shinde Symposium Hall, NASC, New Delhi-110012**

Proceedings and Recommendations

Organizers

Trust for Advancement of Agricultural Sciences (TAAS), New Delhi
Indian Council of Agricultural Research (ICAR), New Delhi
International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad
International Maize and Wheat Improvement Centre (CIMMYT), Mexico
International Rice Research Institute (IRRI), Philippines
Indian Society of Plant Genetic Resources (ISPGR), New Delhi

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Foreword

The National Symposium on Hybrid Technology for Enhancing Crop Productivity (NSHT) was organized to address the current challenges of food security in the face of global uncertainties. As we navigate through economic disparities, climate change, and geopolitical conflicts, the urgency to enhance agricultural productivity becomes more pronounced. The COVID-19 pandemic and ongoing geopolitical tensions have severely disrupted global food supply chains, threatening the ability to meet the Sustainable Development Goals (SDGs) of reducing poverty and eradicating hunger. With the global population projected to reach approximately 8.55 billion by 2030, the demand for diversified food with improved nutritional quality will further escalate.

In the above context, the hybrid technology presents a formidable solution to enhance yield, nutritional quality, and resilience to biotic and abiotic stresses. Further, through harnessing advanced techniques — such as marker-assisted selection, genetic engineering, genome/gene editing, and doubled haploid breeding — we can accelerate on-going breeding efforts to produce new hybrids with required traits. The Symposium provided a platform for the experts to share the current status and propose strategies for maximizing the yield potential of crops. The deliberations also focussed on making hybrid seeds more easily accessible and affordable to the smallholder farmers.

Public-private partnerships emerged as key element in scaling innovation relating to hybrid technology. Also, the need for an enabling regulatory environment which supports intellectual property rights (IPRs) was underscored to attract more investment in agricultural research. Additionally, the adoption of genetically modified (GM) crops was considered important for enhancing productivity and farmer income.

Finally, it became evident that a collaborative effort among researchers, policymakers, industry partners, and farmers is vital for realizing the full potential of hybrid technology. The recommendations, thus, provide a clear Road Map for future towards greater use of hybrid technology in a Mission Mode to increase both production and productivity, thus, ensuring both sustainability and higher income of farmers. I take this opportunity to congratulate the Editors for their meticulous efforts in bringing out this publication in a record time.

RS Paroda
Chairman, TAAS, and
Former Secretary, DARE & DG, ICAR

Abbreviations and Acronyms

ABS	Access and Benefit-Sharing
ADG	Assistant Director General
AgriSure	Agri Fund for Startups & Rural Enterprises
AI	Artificial Intelligence
AICRP	All India Coordinated Research Project
AMGA	Apomixis Mediated Genome Addition
BBM1	Baby Boom 1
BMR	Brown Midrib
CAGR	Compound Annual Growth Rate
CAZRI	Central Arid Zone Research Institute
CGIAR	Consultative Group on International Agricultural Research
CGMS	Created Using a Cytoplasmic Male Sterility
CIMMYT	International Maize and Wheat Improvement Centre
CMS	Cytoplasmic Male Sterility
COVID	Coronavirus Disease
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRISPR-Cas	CRISPR Associated Protein
CRP	Consortia Research Platform
DAC	Department of Agriculture and Cooperation
DARE	Department of Agricultural Research and Education
DBT	Department of Biotechnology
DDG	Deputy Director General
DFR	Directorate of Floricultural Research
DH	Doubled Haploidy
DKMA	Directorate of Knowledge Management in Agriculture

DMH-11	Dhara Mustard Hybrid-11
DMR	Directorate of Maize Research
DSIR	Department of Scientific and Industrial Research
DSR	Direct-Seeded Rice
DSSST	Department of Seed Science and Seed Technology
FAAS	Function as a Service
FAO	Food and Agriculture Organization of the United Nations
FLDs	Field Level Demonstrations
FPOs	Farmer Producer Organizations
FSII	Federation of Seed Industry of India
G×E×M×S	Genotype-by-Environment-by-Management-by-Season
GA3	Gibberellic Acid
GBS	Genotyping by Sequencing
GDP	Gross Domestic Production
GE	Gene Editing
GEBV	Genomic-based Estimates of Breeding Values
GI	Glycemic Index
GM	Genetically Modified
GMS	Genetic Male Sterility
GS	Genomic Selection
GST	Goods and Services Tax
GTR	Glucosinolate Transporter
GWAS	Genome-Wise Association Studies
HAPA	Hybridization-supplemented Apomixis-components Partitioning Approach
HDPS	High-Density Planting Systems
HI-Edit	Hybrid Breeding in Polyploids, One Pot Genome Editing to Produce Transgene Free Hybrids
HPRC	Hybrid Parents Research Consortia
HRDC	Hybrid Rice Development Consortium

HRTSI	Hybrid Rice Technologies for Seed Industry
HYV	High Yielding Variety
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIHR	Indian Institute of Horticultural Research
IIMR	Indian Institute of Maize Research
IIOR	Indian Institute of Oilseeds Research
IIPR	Indian Institute of Pulses Research
IISER	Indian Institute of Science Education and Research
IISS	Indian Institute of Seed Science
IIVR	Indian Institute of Vegetable Research
IoT	Internet of Things
IP	Intellectual Property
IPRs	Intellectual Property Rights
IPTT	International Progeny Testing Trials
IRRI	International Rice Research Institute
ISPGR	Indian Society of Plant Genetic Resources
MAHYCO	Maharashtra Hybrid Seed Company
MARB	Marker-Assisted Reverse Breeding
MAS	Marker-Assisted Selection
MLN	Maize Lethal Necrosis
MoEFCC	Ministry of Environment, Forest, and Climate Change
MoU	Memorandum of Understanding
MQTL	Meta-QTL
MVPs	Minimum Viable Products
NAAS	National Academy of Agricultural Science
NASC	National Agriculture Science Complex
NBA	National Biodiversity Authority

NBPGR	National Bureau of Plant Genetic Resources
NGS	Next-Generation Sequencing
NIPB	National Institute for Plant Biotechnology
NSAI	National Seed Association of India
ORBS	One Rice Breeding Strategy
PAU	Punjab Agricultural University
PEBV	Pedigree-based Estimates of Breeding Values
PPPs	Public-Private Partnerships
PPV&FRA	Protection of Plant Varieties and Farmers Rights Act
PPV&FRA	Protection of Plant Varieties and Farmers Rights Authority
PTGMS	Photoperiod/Thermo-Sensitive Genic Male Sterility
QPM	Quality Protein Maize
QTL	Quantitative Trait Loci
R&D	Research and Development
RFS	Rice False Smut
RGA	Rapid Generation Advancement
RPCAU	Dr Rajendra Prasad Central Agriculture University
SAUs	State Agricultural Universities
SDG	Sustainable Development Goal
SI	Self-Incompatibility
SMEs	Small and Medium Enterprises
SOPs	Standard Operating Procedures
TAAS	Trust for Advancement of Agricultural Sciences
TGMS	Temperature-sensitive Genic Male Sterility
USD	United States Dollar
VCU	Value for Cultivation and Use
VPKAS	Vivekananda Parvatiya Krishi Anusandhan Sansthan

National Symposium on
Hybrid Technology for Enhancing Crop Productivity (NSHT)

BACKGROUND

Context and Rationale

Global food insecurity concerns have lately been rising on account of economic inequality, poverty, climate change, economic slowdown and political conflicts. The shocks of COVID 19 epidemic in 2019-20, and Russia-Ukraine and Israel-Palestine wars going on since early 2022 and 2023, respectively, have greatly intensified these concerns by severely disrupting the global food supply chain. These developments are threatening food security having implications on achieving sustainable development goals (SDG), especially to reduce poverty and ending hunger and malnutrition by 2030. According to the Food and Agriculture Organization of the United Nations (FAO), the global population is increasing. Further, the food and nutritional needs globally are increasing due to increasing population, economic development and changing food habits. This would require greater emphasis on improving productivity and production of diversified foods with better nutritional quality.

Among various possible options, hybrid technology has substantial potential for genetic enhancement of yield, nutritional quality, resistance/tolerance to biotic/abiotic stresses, adaptation to climate change, etc. Hybrid technology aided by doubled haploidy (DH), marker-assisted selection (MAS), genetic engineering, genome/gene editing, and precise phenotyping. In India, the first systematic hybrid breeding program was started in maize in 1957 with the initiation of an All-India Coordinated Maize Improvement Project under the auspices of the Indian Council of Agricultural Research (ICAR). As a result, large numbers of double cross and double top cross hybrids were released for general cultivation. Later, realizing that single cross hybrids have greater yield potential, the maize breeding program was reoriented in 1980s under a special hybrid breeding program for nine crops, including maize. As a result, the first single cross maize hybrid was released in 1995, followed by many others. These hybrids, beside those introduced by multinational seed companies, helped increase area (now 10 mha), productivity (from 1.0 to now 3.5 t/ha) and production (37.5 mt) of maize in the last two decades.

India is known to have bred the world's first commercial hybrids of sorghum (1964), grain pearl millet (1965), castor (1968), cotton (1970), pigeon pea (1991) and safflower (1997). The country has also made great strides in breeding of commercial hybrids in rice, safflower, tomato, cauliflower, cabbage, muskmelon, watermelon, brinjal, chilly, etc.

With the implementation of the New Seed Policy in 1988, and subsequent enactment of Protection of Plant Varieties and Farmers Rights Act (PPV&FRA) in 2001, bulk import of quality hybrid seeds and the adoption of hybrids of different crops got real impetus leading to faster growth of both public and private seed sectors.

CHALLENGES AND OPPORTUNITIES

Maize is not only the first but also the most successful example of utilization of heterosis in crops to enhance the agricultural production. The introduction of single-cross hybrid cultivars resulted in the expansion of area from 6.61 mha in 2000-01 to 10.04 mha in 2022-23 and increase in production from 12.04 mt to 34.61 mt, and productivity from 1.82 t/ha to 3.44 t/ha during the same period. In spite of adopting single-cross hybrid cultivars, there is still not only wide variation in maize productivity in the country but also substantial gap between average productivity at the global level (5.75 t/ha) *versus* that in India (3.44 t/ha).

Hybrid rice technology is an extremely promising option for boosting productivity approximately by 15-20 per cent over that of rice varieties. In fact, through hybrid rice technology, covering almost 50 per cent area (about 15.0 mha), China has been harvesting 15 million tons of extra rice per year since last four decades. On the contrary, India initiated systematic hybrid rice research in 1989 and thus, became the second country to cultivate hybrid rice commercially. Yet, the area covered in the last three decades has not yet exceeded 2.0 mha. The encouraging fact, however, is that area so far covered is mostly the rainfed upland rice in eastern India, reflecting again superiority of hybrid technology under water stress environment. Like in China, hybrid rice technology in India, has not yet made significant impact in irrigated ecosystems. It would require extensive investment and full-time commitment of researchers to develop appropriate rice hybrids and economically viable hybrid seed production technology involving public and private seed agencies. The latter would also require a close collaboration between the two sectors. A mutually acceptable model of collaboration needs to be developed in India.

It is by now well established that hybrid technology can increase productivity significantly and the farmers are happy to embrace hybrid crops, However, maximum potential of hybrid technology is yet to be realized as area under hybrid varieties

in different crops varies considerably. It is almost 12 mha (94%) in cotton, 0.46 mha (78%) in sunflower, 5.6 mha (60%) in maize, 2.84 mha (40%) in pearl millet, and 1.5 mha (28%) in sorghum. This obviously reflects that there is still vast scope to further harness the potential of hybrid technology by adopting a well-planned research and development (R&D) strategy at the national level.

ABOUT THE SYMPOSIUM

Hybrid technology in crops offers an opportunity to increase productivity by 15-20 per cent over that of true breeding varieties. To expand the adoption of hybrid cultivars, a 3-day **National Symposium on Hybrid Technology for Enhanced Crop Productivity** was organized by the Trust for Advancement of Agricultural Sciences (TAAS) in collaboration with Indian Council of Agricultural Research (ICAR) and Consultative Group on International Agricultural Research (CGIAR) Institutes, namely, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Maize, Wheat Improvement Centre (CIMMYT), International Rice Research Institute (IRRI), and Indian Society of Plant Genetic Resources (ISPGR), at the National Agriculture Science Complex (NASC), Pusa Campus, New Delhi, on 8-10 January 2025 and supported by Federation of Seed Industry of India (FSII), Maharashtra Hybrid Seed Company (MAHYCO), Rasi Seeds (P) Ltd., Bayer CropScience Limited, National Seed Association of India (NSAI), ACSEN Agriscience (P) Ltd. and SeedWorks International. A total of 274 participants (175 in-person and 99 virtually) including researchers, policymakers, representative of CG centres and private sector participated in the symposium.

OBJECTIVES

- To understand the current status of hybrid research in various crops
- To discuss current scientific and policy constraints in scaling hybrid breeding and seed production for increased productivity
- To foster closer public-private partnership for promoting hybrid breeding and seed production
- To develop strategies and 'Way Forward' for accelerating adoption of hybrid technology on a large scale in the national interest

EXPECTED OUTCOMES

- The constraints for scaling hybrid breeding technology identified
- Application of molecular and other tools for accelerating hybrid breeding technology in major crops assessed

- The expected economic and social benefits of adopting hybrid technology in crops well understood
- Strategy for strengthening public-private partnership for hybrid breeding and seed production developed
- Enabling policies for strengthening hybrid R&D for improving crop productivity and production suggested

INAUGURAL SESSION

The Chief Guest **Dr PK Mishra**, Principal Secretary to the Prime Minister, in his inaugural address emphasized that the agricultural transformation must balance the twin goals of ensuring food security and improving farmer profitability with hybrid technology serving as a key enabler. He stressed on multi-pronged approaches involving increased adoption of hybrid technology in profitable crops along with diversification into horticulture, livestock, and fisheries, and enhanced technology adoption by small-holder farmers. To increase farmers' income, research needs to be directed to developing technologies that make hybrids affordable to small-holder farmers, including by saving hybrid seeds from one season to another season without losing hybrid vigour. Dr Mishra further emphasized that since public-private partnership is very important, a consortium approach need to be adopted to bring public and private sector together at one platform for the common cause to benefit the farmers. Enforcement of intellectual property (IP) is equally important to increase the investments and impact of agricultural research including hybrid variety development.

Dr Mishra's complete address can be accessed through following link: https://youtu.be/sViFLvFDgNY

Padma Bhushan Awardee, **Dr RS Paroda**, Chairman, TAAS, chaired the Inaugural Session. He underlined the importance and potential of hybrid technology to increase the production and productivity in the crops. He recalled the development of hybrid program in mission mode in India and deliberated on some success stories pertaining to increasing the production and productivity by using hybrid varieties of maize and cotton. However, we need to go a long way to match the

rice production and acreage realized in China using hybrid rice. Dr Paroda mentioned that there is a need to have clarity about the adoption of GM technology as it has a great potential to enhance the productivity and income of the small-holder farmers. Government needs to consider reducing taxes on seed

and encourage the adoption of hybrid seed varieties. The potential for India to become a major player in the global seed industry was also highlighted.

Dr Paroda's complete address can be accessed through following link: https://youtu.be/wDBW3l80aus

In his speech, **Dr T Mohapatra**, Chairperson, PPV&FRA and Vice Chairman of TAAS, welcomed the Chief Guest, dignitaries, distinguished invitees and participants, set the context of the Symposium and highlighted the potential of hybrid technology to increase the production and productivity.

Mr Ajai Rana, Chairman, FSII, emphasized the importance of hybrid technology in increasing productivity and income for farmers. He also highlighted the need for more investment in agricultural research and seed development, as well as the need for a policy framework for intellectual property protection and science-based decision-making.

Dr Stanford Blade, Interim-Director General, ICRISAT, highlighted the organization's work in developing resilient and robust systems, including the use of germplasm and developing material. He also emphasized the need for South-South collaboration in agriculture, particularly with African countries.

Dr Bram Govaerts, Director General, CIMMYT participated virtually and emphasized on hybrid technology and its potential for transforming agriculture. He also mentioned the importance of public-private partnerships in promoting hybrid technology.

The Abstract Book — a Compilation of Extended Summaries of Keynote and Invited Lectures and Abstracts of Posters — was released by the Chief Guest.

The Inaugural Session was concluded with formal vote of thanks by **Dr Bhag Mal**, Secretary, TAAS to the Chief Guest, dignitaries and distinguished invitees and delegates.

TECHNICAL SESSION I: HYBRID CROPS RESEARCH AND DEVELOPMENT – AN OVERVIEW

Co-Chairs: **Dr RB Singh**, Former President, NAAS, New Delhi
Dr Renu Swarup, Former Secretary, DBT, New Delhi

Convener: **Dr GP Mishra**, Head, DSSST, IARI, New Delhi

Rapporteurs: **Dr Shailendra K Jha**, Senior Scientist, ICAR-IARI, New Delhi
Dr Chandan Kapoor, Senior Scientist, ICAR-IARI, New Delhi

During the Technical Session I: Hybrid Crops Research and Development — An overview, two keynote lectures and one invited lecture were presented.

Keynote and Invited Lectures

Dr BM Prasanna, Distinguished Scientist & Regional Director for Asia, CIMMYT, New Delhi, delivered a keynote lecture on *Accelerating hybrid crop breeding: CIMMYT's experience and general perspective*. He highlighted the importance of advanced technologies, including doubled haploid (DH) technology, molecular markers, genomic selection, and advanced phenotyping, for developing climate-resilient hybrids. He stressed the use of DH technology to accelerate breeding cycles and improve genetic gain, advocating for the incorporation of genotype-by-environment-by-management-by-season (G×E×M×S) interactions through on-farm trials and the leveraging of social heterogeneity across diverse farming systems. He explained CIMMYT's innovative licensing model's role in expanding the reach of new hybrids, and described the application of gene editing to develop male sterility and resistance to maize lethal necrosis (MLN) virus. Dr Prasanna, further highlighted the use of a robust marker-trait pipeline and molecular tools for MAS and genomic selection/prediction, emphasizing cost-effective hybrid seed production, the necessity of strong public-private partnerships, and the importance of predictive breeding for broader impact. He underscored the need for equitable access to these technologies, considering intellectual property rights (IPRs), and advocated for the use of breeding platforms and Big Data analytics to optimize breeding programs, thereby reducing costs and improving efficiency of development of hybrid varieties.

Dr Ephrem Habyarimana, Sorghum Breeding Lead, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad, made a keynote

presentation on behalf of Dr Stanford Blade, Director General – Interim, ICRISAT, on *Hybrid research in dryland crops: Progress and future prospects*. While describing the Breeding Schemes at ICRISAT, he advocated for the adoption of speed breeding, improved heterotic grouping, and genomic selection to enhance heterosis and develop climate-resilient hybrids for dryland crops. He emphasized the importance of diversifying the base (B) and recurrent (R) lines used in hybrid development to maximize yield potential. To accelerate the breeding process, he recommended utilizing doubled haploid (DH) technology, rapid generation advancement (RGA), and genomic selection (GS). Dr Habyarimana highlighted the available resources and platforms at ICRISAT, suggesting their utilization for improved hybrid development. Finally, he emphasized the use of effective dissemination strategies, including active seed distribution and supportive government policies, to rapidly deploy newly developed varieties to farmers' fields.

Dr Venkatram Vasantwada, Managing Director and Chief Executive Officer, SeedWorks International Ltd, Hyderabad**,** delivered an invited lecture on *Hybrid crops research by private sector: Recent advances*. He advocated for the development and implementation of advanced technologies, rapid cultivar improvement, and market-driven innovation in hybrid technology. He highlighted the potential of hybrid technology in direct-seeded rice (DSR) for efficient weed control, and emphasized the integration of artificial intelligence (AI) and remote sensing in plant breeding. Based on the lessons learned from *Bt* cotton cultivation and production in India, he called for increased access to genetically modified (GM) technology and stronger public-private partnerships (PPPs) to address key challenges, urging an intensified and accelerated pace of PPP collaboration, and the development of business-friendly policies.

Dr Renu Swarup, Co-Chair of the Session and Former Secretary, Department of Biotechnology (DBT), suggested for increased research efforts to accelerate technological development and ensure broader access to new technologies. She advocated for – democratizing agricultural research and collaboration through PPPs, and the inclusion of start-ups to foster innovation.

Dr RB Singh, Co-Chair of the Session and Former President, National Academy of Agricultural Sciences (NAAS) while concluding the Session emphasized the importance of a collaborative, consortium-based approach to national-level hybrid breeding programs. He called for incentives to promote hybrid breeding and the integration of quantitative genetics with molecular techniques for faster product development. He further suggested a synergistic approach combining scientific social responsibility and corporate social responsibility for improved societal outcomes.

The salient points/recommendations that emerged from the above discussion are summarized here.

- Integrate doubled haploid (DH) technology, molecular markers, genomic selection, and advanced phenotyping platforms to accelerate breeding cycles and enhance genetic gains, particularly for climate resilience.
- Establish and strengthen PPPs to scale-up hybrid breeding efforts and ensure equitable access to technological advancements.
- Employ gene editing technologies to develop male sterile lines and optimize hybrid seed production methods.
- Implement speed breeding and DH technology to shorten breeding cycles and rapidly deploy climate-resilient hybrids.
- Use artificial intelligence (AI) and remote sensing technologies to enhance the efficiency and precision of hybrid breeding programs.
- Provide incentives for hybrid breeding research, integrate quantitative and molecular genetics approaches, and promote synergies between corporate social responsibility and scientific social responsibility for improved societal impact.

TECHNICAL SESSION II: GERMPLASM MANAGEMENT FOR HYBRID CROP BREEDING

Co-Chairs: **Dr SK Vasal**, Former Distinguished Scientist, CIMMYT, Mexico
Dr PL Gautam, Chancellor, RPCAU, Pusa, Samastipur

Convener: **Dr Kuldeep Singh**, Head, Genebank, ICRISAT, Patancheru, Hyderabad

Rapporteurs: **Dr Dharminder Pathak**, Senior Cotton Breeder, PAU, Ludhiana
Dr Rama Prashat G, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi

The agenda of Technical Session II included one keynote lecture, two invited lectures and four rapid oral presentations.

Keynote and Invited Lectures

Dr HD Upadhyaya, Plant Genome Mapping Laboratory, University of Georgia, Athens, Geogia, USA, made a keynote presentation on *Genetic resources for hybrid development*. He highlighted the crucial role of plant genetic resources in achieving multiple United Nations' Sustainable Development Goals (SDGs), particularly in ensuring food, feed, nutritional, and environmental security. He noted the underutilization of germplasm collections—attributing this primarily to the sheer size of collections and a lack of reliable data on economically important traits. In his presentation, Dr Upadhyaya addressed all following questions related to usage of genetic resources for hybrid breeding e.g. — (i) what have we done so far with the germplasm as the Global Public Good ?; (ii) are our germplasm collections complete in terms of geographical areas?; (iii) are germplasm collections used adequately in crop improvement?; (iv) what are core germplasm collections?; (v) do core collections help in enhancing use of germplasm in crop improvement programs?; (vi) are core/mini core collections developed using molecular markers better than those developed by using qualitative and/or quantitative phenotypic traits?; (viii) are mini core collections useful in meeting needs of breeders and other researchers in providing appropriate germplasm?; (x) are mini core collections useful to NARS partners for trait-specific genetically diverse germplasm for crop improvement?; (x) do mini core collections help in enhanced use of germplasm in crop improvement?; and (xi) do sources identified from mini core result into trait enhancement and drive

faster genetic gains in breeding programs? While presenting the details of pigeon pea, groundnut and sorghum mini core as a source of multiple traits germplasm, he advocated for the development of mini-core collections, drawn from existing germplasm, to make available to plant breeders the genetic diversity across multiple traits. Systematic evaluation of these mini-core collections would facilitate the identification of germplasm lines possessing useful agronomic, nutritional, and stress-resistance traits, ultimately accelerating the crop improvement efforts.

Dr Gopala Krishnan, Head, Division of Genetics, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, delivered invited lecture on *Hybrid-oriented source germplasm for improvement of hybrids*. He stressed on the need for hybrid-oriented source germplasm, sources of male sterile cytoplasm in crops, development of hybrid-oriented germplasm and genes/QTL, donors in various crops. He emphasized the importance of germplasm improvement for effective hybrid development. He highlighted the diverse genetic resources available in existing crop landraces, including valuable traits related to plant architecture, stress tolerance, and grain quality. Given the significance of identifying genotypes with unique and desirable alleles, he underscored the need for germplasm prospecting to enhance parental lines. He reviewed the progress and future potential of developing hybrid-oriented germplasm in rice, maize, pearl millet, pigeonpea, Indian mustard, and wheat.

Dr Ephrem Habyarimana, Sorghum Breeding Lead, ICRISAT, Patancheru, Hyderabad, made a presentation on *Consortia approach for germplasm improvement and hybrid development*. He described the engaging consortia approach to germplasm enhancement and hybrid development engaging both public and private sector. He highlighted the Hybrid Parents Research Consortia (HPRC) as a model for public-private sector collaboration. ICRISAT's strategy of developing and sharing semi-finished products with the private sector for further processing into finished hybrid products was presented as a mechanism for streamlining product development and facilitating a cyclical improvement process. Following this approach, ICRISAT develops breeding materials (hybrid parents) and shares semi-finished products to the private sector to develop finished products; mostly hybrids and the private sector has a good seed production chain and marketing network, and helps disseminate high-quality seed. This synergy of developing

parental lines and making hybrid seed available to farmers had a greater and quicker impact of hybrid breeding in farmers' fields.

Rapid Oral Presentations

Presenter	**Dr Vinay Rojaria**, ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi
Title	Development and characterization of lpa1 and lpa2-based low phytate double mutants for kernel quality, yield, and agro-morphological traits for utilization in low phytate maize hybrid breeding
Key findings	• Novel low-phytate maize double mutants (lpa1/lpa2) achieved a 41 per cent phytic acid reduction (1.73 mg/g vs 2.92 mg/g) without negatively impacting grain yield or other agronomic traits. • This enhanced micronutrient bioavailability (iron and zinc) offers a sustainable approach to combat micronutrient malnutrition. • These double mutants provide a valuable resource for breeding low-phytate maize hybrids, improving nutritional quality in both food and feed.

Presenter	**Dr Abhishek Bohra**, ICAR-Indian Institute of Pulses Research (IIPR), Kanpur, Uttar Pradesh
Title	Expanding the arsenal of male sterile germplasm for accelerating hybrid pigeon pea research and breeding
Key findings	• Two new short-duration pigeonpea hybrids were developed using cytoplasmic male sterility (CMS) technology, demonstrating the potential of hybrid vigour to overcome yield plateaus. • Fourteen new CMS lines were developed by backcrossing, retaining the pollen sterility phenotype while incorporating the nuclear genome of elite pigeonpea varieties, expanding the genetic diversity of CMS lines available for hybrid breeding. • Potential restorer lines (R-lines) for these new CMS lines were identified, enabling immediate application in pigeonpea hybrid research and breeding programs.

Presenter	**Dr RK Khulbe**, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand
Title	Development of popcorn DH lines for augmenting popcorn germplasm base and development of high yielding popcorn hybrids
Key findings	• India's popcorn breeding programs are hampered by a limited germplasm base, predominantly relying on foreign varieties, highlighting the need to expand indigenous resources. • Utilizing doubled haploid (DH) technology, 87 new popcorn DH lines were developed from two existing hybrids, showcasing significant variation in key agronomic and quality traits (maturity, plant height, cob size, popping, expansion). • These DH lines offer a valuable resource for broadening the germplasm pool, serving as potential parents for superior popcorn hybrids and enhancing future breeding programs.

Presenter	**Dr P Shashikumara**, ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh
Title	Mapping BMR trait and introgression into different genetic backgrounds for developing low lignin and high biomass pearl millet genotypes
Key findings	• A novel SSR marker (Xpsmp2077) linked to the brown midrib (bmr) gene in pearl millet was identified using a bulk segregant analysis approach. • This marker facilitates MAS for improved forage quality (reduced lignin, enhanced digestibility) by enabling efficient selection of bmr lines within segregating populations. • MAS using this marker accelerated the development of high-biomass, low-lignin pearl millet cultivars, ultimately improving forage quality and animal feed.

The following salient points/recommendations emerged from the discussion:

- A germplasm management strategy should be developed for proper flow of materials from genebank to different groups for efficient utilization in breeding programs.
- A consortium of research partners need to be developed having simple standard operating procedures (SOPs) for sharing of quality breeding materials and data withstanding bureaucratic pulls and pressures.
- Long-term vision and commitment is essential while using wild relatives; short term approach leads to wastage of resources, efforts and negative results views.
- Greater use and prospecting sources for desirable traits from landraces and wild relatives is needed for sustainable conservation of germplasm.
- PPP is essential for efficient utilization of hybrid-oriented source germplasm and finished products.

TECHNICAL SESSION-III: BIOTECHNOLOGY FOR ACCELERATING HYBRID CROP BREEDING

Co-Chairs: **Dr Deepak Pental**, ANRF-National Science Chair, Centre for Genetic Manipulation of Crop Plants, and Former Vice Chancellor, University of Delhi, Delhi
Dr RC Bhattacharya, Director, ICAR-NIPB, New Delhi

Convener: **Dr BM Prasanna**, Distinguished Scientist and Regional Director for Asia, CIMMYT, New Delhi

Rapporteurs: **Dr Firoz Hossain**, Principal Scientist, ICAR-IARI, New Delhi
Dr BS Vivek, Maize Breeder, CIMMYT, Hyderabad

The agenda of Technical Session III included one keynote lecture, three invited lectures and two rapid oral presentations.

Keynote and Invited Lectures

Dr Venkatesan Sundaresan, Professor, University of California, Davis, California, USA, made a pre-recorded video presentation as keynote lecture on *Technologies for clonal propagation of hybrid crops through seeds*. Given the self-pollinating nature of the rice crop, he highlighted the difficulty in using the three-line system (A, B, R) in rice and proposed one-line hybrids by fixing heterosis through

apomixis. He demonstrated how coupling *Baby Boom 1* (*BBM1*) gene (responsible for bypassing fertilization) with MiMe mutation led to the development of synthetic apomictic rice hybrids. Further, *WOX9A* gene along with the *BBM1* gene increased parthenogenesis by 4-15-fold over *BBM1* alone. Apomictic inter sub-specific cross of *indica* x *japonica* showed up to 97 per cent fertility compared to the non-apomictic versions. He elaborated the wider use of such apomictic systems in fixing hybrid vigour in crosses that have segregation problems, for example, in: (i) wild x domesticated rice; (ii) sugarcane hybrids; (iii) wheat x rye (triticale) crosses. Variation in parthenogenesis and fertility across genotypes, need for intensive field testing of newly developed apomictic plants, and development of transgene-free plants are the current concerns.

Dr Ravi Maruthachalam, Senior Scientist, Indian Institute of Science Education and Research (IISER), Thiruvananthapuram, Kerala, delivered an invited lecture on *Disruptive innovations in hybrid breeding*. His presentation covered the following topics: rapid transfer of CMS, production of cybrids, analytical breeding – simplify hybrid breeding in polyploids, one pot genome editing to produce transgene free hybrids (HI-Edit), engineered minichromosomes for introducing combined traits, and reverse breeding. He also outlined the following disruptive innovations in hybrid technology, *viz.*, (a) precision breeding with gene editing; (b) predictive breeding through machine learning; (c) digital phenotyping; (d) synthetic biology with new traits and genetic circuits; and (e) *in planta* haploid production. He detailed the use of *in vivo* haploid production technology through CENH3 system, which can produce both maternal and paternal haploids, and cybrids. He suggested that CENH3-based system could simplify the breeding in polyploids through analytical breeding. He emphasized the importance of CENH3 in HI-Edit system, mini-chromosomes and reverse breeding. He also discussed the challenges such as regulatory issues, ownership of genetic resources, high-cost of infrastructure, and public concerns to use the disruptive innovations in hybrid breeding.

Dr Raman Babu, Distinguished Laureate and Seed Product Development Lead for South-Asia at Corteva Agriscience, Hyderabad, delivered the invited lecture on *Data-driven predictive breeding in hybrid crops – progress and prospects*. He presented five paradigm shifts during the last 25 years in relation to enhancement of hybrid breeding: (i) revolutionary change in the maize line development through doubled haploid (DH) technology where millions of lines are being generated annually by

the private sector; nearly 95 per cent of the lines used in the maize breeding programs of big MNCs are DH. DH lines in mustard are being derived using pollen (androgenesis); this could potentially happen in other crops; (ii) selection of lines based more on genotyping than phenotyping due to the sheer volume of DH lines being generated in maize. Various marker based applications (breeder-ready markers for simple traits, genomic selection for complex traits, prediction based on genomic relationships, sparse testcrossing, sparse phenotyping) coupled with data analytics impacted the size-and-shape of the breeding funnel where a wider diversity is assayed in a shorter time span; (iii) precision-based phenotyping system coupled with digitization, machines engineered for stress simulation and high throughput assays, powerful statistical models, cloud storage and computing, thus enabling smaller seed companies to access such technologies; (iv) successful hybridization in self-pollinated crops (e.g. non-CMS based, non-wheat hybrids are on the horizon for release in 2027); and (v) disruptive technologies like gene-editing could be mainstreamed to enable, for instance, a combination of traits such as yield with multiple disease resistance to be moved as a single locus. He emphasized on the imminent need for enhancing the *per se* performance of the female lines to enhance seed producibility for making hybrid technology more profitable. Technologies such as pollen preservation and dusting should be considered. Dr Babu also advocated that public-private partnerships are particularly needed for improving seed producibility, which in turn will increase the returns on investment for seed producers and decrease the cost of goods sold.

Dr Pankaj Kaushal, Director, ICAR-Indian Grassland and Fodder Research Institute, Jhansi, made a presentation on *Learnings from apomictic grasses towards fixation of hybrid vigour*. He presented the work being done in India on the use of apomixis in grasses. Apomixis, asexual seed production, creates genetically identical offspring, preserving hybrid vigour across generations. While common in some plant families, it is absent in major cereals. Research focuses on understanding apomixis mechanisms in natural apomicts (e.g., *Panicum*, *Pennisetum*), and transferring these traits to crops

was discussed. This involves a complex process of apomeiosis, parthenogenesis, and functional endosperm development, sometimes uncoupled, leading to ploidy manipulation hybridization-supplemented apomixis-components partitioning approach (HAPA). A novel approach, apomixis mediated genome addition (AMGA), leverages apomixis to introduce desirable traits from wild relatives, as demonstrated in pearl millet, resulting in a new commercial cultivar, first in the world, released for rangeland conditions. Ultimately, combining knowledge of natural apomixis with sexual reproduction holds the key to fixing hybrid vigour through apomixis technology. He mentioned that in Guinea grass, they could achieve 3x, 4x, 5x, 6x, 7x, 8x, 9x and 11x polyploidization, which was documented in the Limca Book of Records. He also presented some of the candidate genes such as *BBM1* that can be used in apomixis. AMGA was achieved in *Pennisetum*. He also mentioned that bajra × napier grass hybrid, which is otherwise sterile, could be converted to fertile version using novel breeding technologies.

Rapid Oral Presentations

Presenter	**Dr Hriipulou Duo**, ICAR-Indian Agricultural Research Institute, New Delhi
Title	Revisiting floury2 gene after 50 years: Development of subtropically adapted maize hybrids with enhanced methionine in maize kernels using genomics-assisted breeding
Key findings	• A PCR-based marker was developed to efficiently select for the fl2 mutation, increasing methionine content in maize. • Genomics-assisted breeding successfully incorporated the fl2 mutation into a high-yielding QPM hybrid, resulting in significantly higher methionine content (>0.320% in flour) without compromising other nutritional traits (lysine, tryptophan, provitamin A). • This improved hybrid offers a cost-effective alternative to synthetic methionine supplementation in animal feed, with significant implications for addressing malnutrition in developing countries

Presenter	**Dr Rashmi Chhabra,** ICAR-Indian Agricultural Research Institute, New Delhi
Title	Making sweetcorn hybrids healthier with vitamins, amino acids and antioxidants through genomics-assisted breeding

Key findings	• Four elite sweet corn lines were biofortified through genomics-assisted breeding, incorporating genes for enhanced levels of vitamins A and E, lysine, tryptophan, and anthocyanins. • Marker-assisted selection ensured the efficient introgression of desired genes while maintaining the high kernel sweetness of the original lines (>18% brix). • These novel, multi-nutrient-rich sweet corn genotypes represent a significant advancement in improving the nutritional value of sweet corn, offering a potential solution to malnutrition.

The following salient points/recommendations emerged from the discussion:

- Adopt synthetic apomixis for hybrid seed production that allows for the production of seeds without fertilization and to achieve greater genetic stability and uniformity in hybrid varieties and to significantly shorten the breeding cycle.
- Undertake research for improved recombination techniques, particularly in recombination-lean genomic regions, to accelerate hybrid breeding. Explore the potential of genes like *BBM1*, *WOX9A*, and *CENH3* for heterosis fixation and haploid induction in rice and other crops.
- Enhance predictability in hybrid seed production by implementing advanced forecasting tools and technologies to better predict weather patterns impacting seed production.
- Strengthen data management from All-India crop research networks, leveraging AI for enhancing the breeding efficiency.
- Public-private partnerships are needed to effectively utilize disruptive genetic innovations. Enhancing the *per se* performance of the female lines in hybrid seed production and significantly improving seed reproducibility is important to make hybrid technology more profitable.
- There is need for policy support to incentivize investment in hybrid seed research and development and support for smallholder farmers to access hybrid seeds through subsidies or financial assistance programs and strengthen IPRs to handle IP violations efficiently by legal frameworks to protect the rights of breeders.

EVENING LECTURE-I

Chair: **Dr T Mohapatra**, Chairperson, PPV&FRA, New Delhi

Convener: **Dr S Gopala Krishnan**, Head, Division of Genetics, ICAR-IARI, New Delhi

Rapporteur: **Dr H Prashanth Babu**, Senior Scientist, ICAR-IARI, New Delhi

Dr SK Vasal, World Food Laureate and Distinguished Scientist, CIMMYT, Mexico, delivered an Evening Lecture on *Hybrid breeding for unstoppable genetic gains*. He presented the breeding model adopted in CIMMYT in which, two-tier system (back-up unit and advanced unit) had germplasm flow from bank to pools and from pools to advanced unit. Germplasm was also shared for International Progeny Testing Trials (IPTT's) globally for improved cycles and development of site-specific and across the sites experimental varieties. Dr Vasal also discussed the breeding model of Canada which is 3-tier system. The Hierarchical Open-ended Corn Breeding System, designed for production of single cross hybrids in corn. He emphasized on the importance of effectively utilizing crop germplasm, including landraces and gene pools, which are critical for addressing future agricultural challenges. He opined that despite the large genetic variability available, only 5 per cent of the maize germplasm has been used in hybrid breeding in USA, highlighting the need for enhancing utilization of diverse germplasm. Maize, with its high recombination potential, would prove pivotal for future breeding programs. To prevent genetic bottlenecks, reducing excessive reliance on limited germplasm sources is also crucial. He advocated the need for global collaboration to create an international germplasm pool by integrating resources from diverse regions. He opined that improving populations require understanding heterotic patterns, which are vital for creating new and diverse heterotic groups and subgroups within the individual heterotic groups. The transition in maize breeding from multi-parent hybrids underscores the need for robust inbred line development through early-generation inter-crossing and recurrent selection for developing valuable single-cross hybrids.

In addition, strong inbred germplasm can be built by selecting traits as well as testing with diverse testers and targeting biotic and abiotic traits for better adaptation. Maximizing heterosis through enhanced progenitor and crossbred performance are the key to achieving higher yields and improved adaptation. Evaluating trait diversity and targeting key breeding traits are essential steps to developing hybrids with greater adaptability and resilience. Sustaining long-term

genetic gains necessitates diverse germplasm, identifying high-GCA and high-SCA lines, and ensuring effective seed production of parental lines. Tools such as doubled haploids and recurrent selection, coupled with private-public partnerships, provide significant opportunities for innovation.

Following key recommendations emerged from the above lecture:

- Efforts need to be intensified in specific domains of hybrid improvement including prospecting germplasm for emerging stresses, developing heterotic pool, creating a robust germplasm management system, and enhanced use of novel tools such as haploid inducers, doubled haploids and genomic selection for ensuring long-term genetic gains.
- There is a need to strengthen hybrid research through developing frameworks for effective partnership, augmenting resources for research, human resource development and capacity building.

TECHNICAL SESSION IV: CURRENT STATUS AND FUTURE PROSPECTS IN HYBRID CROP BREEDING I (FOOD AND FIBRE CROPS)

Co-Chairs: **Dr BS Dhillon**, Former Vice Chancellor, Punjab Agricultural University (PAU), Ludhiana
Dr T Ramasami, Chairman, Rasi Seeds (P) Ltd., Coimbatore

Convener: **Dr C Tara Satyavathi**, Director, ICAR-IIMR, Hyderabad

Rapporteurs: **Dr SP Singh**, Principal Scientist, Division of Genetics, ICAR-IARI, New Delhi
Dr Rajkumar Zunjare, Scientist, Division of Genetics, ICAR-IARI, New Delhi

The agenda of Technical Session IV included one keynote lecture, 11 invited lectures and three rapid oral presentations.

Keynote and Invited Lectures

Dr Jauhar Ali, Principal Scientist, Hybrid Rice Breeding Lead, Leader, Hybrid Rice Technologies for Seed Industry (HRTSI) Unit, Head, Hybrid Rice Development Consortium (HRDC), Rice Breeding Innovation Department, International Rice Research Institute (IRRI), Philippines, delivered a keynote lecture on *Advances in hybrid rice breeding*. He presented the details of climate-resilient rice inbred varietal releases in Asia and East and

South Africa. Thirty-six varieties directly developed at IRRI, tested, adapted and released in target countries in a record time of 7-9 years were deployed in 33 mha of cumulative area. Also, 104 climate-resilient varieties from IRRI are in the pipeline for release in over six countries. Dr Ali also presented a detailed account on biofortified rice cultivars (iron >15 ppm; >30 ppm) and multiple stress tolerant low glycemic index (GI) rice cultivars developed at IRRI. He stated that hybrid rice offers a significant solution to increasing rice production, particularly amidst climate change, promising yield increases exceeding 25 per cent. However, widespread adoption faces challenges including inconsistent yield stability, susceptibility to stresses, and limited market acceptance. At IRRI, these issues were addressed through genomic selection, developing climate-resilient parental lines, and creating market-driven two-line hybrids with improved grain quality. Cost reduction is tackled by utilizing temperature-sensitive genic male sterility (TGMS) lines, achieving higher seed yields (>3 t/ha) with improved heterosis (>30%). The Super Stigma-TGMS line dramatically enhances seed production. The work at IRRI also combats diseases like Rice False Smut (RFS) through resistant lines, and incorporates its One Rice Breeding Strategy (ORBS) into hybrid rice development. He also presented advancements in herbicide-resistant materials and prioritized the two-line hybrid rice technology. Dr Ali advocated that future research needs to be focussed on developing apomictic hybrids for greater genetic stability, targeting specific market demands. These advancements aim to expand global hybrid rice adoption and ensure sustainable food security.

Dr HS Jat, Director, ICAR-IIMR, Ludhiana, made an invited presentation on *India's maize improvement program: Challenges, progress, and roadmap*. He highlighted India's remarkable progress in maize production, increasing from 1.73 mt in 1950-51 to nearly 38 mt in 2022-23, driven by a shift from composites to single-cross hybrids and improved agricultural practices. Challenges included abiotic and biotic stresses, seed access, and post-harvest losses, but organized research since 1957, including the development of hybrids and marker-assisted selection, has significantly improved productivity. Dr Jat discussed about the widespread adoption of single-cross hybrids (~65 % coverage), the key to this success, resulting in per-day productivity nearing US levels in some regions. He highlighted improved agronomic practices, mechanization, and seed production hubs, with notable success in expanding maize cultivation in Assam and West Bengal through linkage and capacity-building

efforts. He mentioned that future needs are — developing high-yielding, climate-resilient hybrids suitable for bioethanol production; improving by-product quality; enhancing ethanol extraction efficiency; and accelerating genetic gain through innovative tools like gene editing and genomic selection. Dr Jat further advocated that expanding maize cultivation ecology, upscaling best practices, and improving infrastructure for handling the harvest are also crucial for meeting the projected 65 mt demand by 2030.

Dr Venkatesh Hubli, Director-Research**,** Savannah Seeds Private limited, Hyderabad, made a presentation on *Development and scaling of hybrid rice by private sector in India*. He highlighted the significant role of hybrid rice in enhancing food security, particularly for the projected population growth and increased rice demand. While hybrid rice offers a 20-30 per cent yield advantage over traditional varieties, its adoption in India has lagged behind China. He highlighted the historical context, noting that while research began in the 1980s, serious commitment started later, with significant contributions from both the public and private sectors, especially Mahyco, Pioneer, and Cargill. Currently, 80 private companies are involved in hybrid rice development, responsible for 89 of the 127 released hybrids in India. Despite the success, challenges remain, including the high cost of hybrid seeds compared to inbred varieties, the need for intensive irrigation and inputs, and insufficient access to information and finance for farmers. Dr Hubli mentioned that public-private partnerships are crucial to successful commercialization, but continued research and development are vital to overcome challenges like unpredictable weather and inconsistent heterosis, ensuring broader hybrid rice adoption. He concluded the presentation by emphasizing that private sector engagement was and is essential for making hybrid rice a profitable venture for Indian farmers, boosting agricultural productivity and promoting sustainability.

Dr Firoz Hossain, Principal Scientist, ICAR-Indian Agricultural Research Institute, New Delhi, delivered an invited lecture on *Breeding for nutritional quality traits in maize: Status and prospects*. He addressed the global challenge of malnutrition and presented crop biofortification, specifically in maize, as a sustainable and cost-effective solution. He highlighted the deficiencies in traditional maize — low lysine, tryptophan, methionine, provitamin A, vitamin E, anthocyanins, iron, and zinc and how MAS accelerates the development of biofortified hybrids. Several examples of MAS-derived QPM (quality protein maize) hybrids with improved protein

quality, provitamin A, vitamin E, and anthocyanins were presented. He expressed his concerns that despite the success in developing biofortified maize, adoption remains limited globally, due to concerns about lower yields, a narrow germplasm base, and a lack of consumer informed awareness. He discussed that field and sweet corn hybrids enriched with multiple nutrient traits were developed without any yield penalties and biofortified maize hybrids licensed to 19 companies under 45 MoUs, and ₹ 1.27 crore revenue was generated, revealing their growing demand and popularity. Dr Hossain emphasized the need for stronger research collaborations, effective marketing and branding to highlight health benefits, industry partnerships with buy-back policies, robust extension services targeting farmers and communities, and supportive government policies, including increased MSP for biofortified maize, to increase adoption and contribute to nutritional security, particularly in underserved regions.

Dr Nimesh Lad, Head Breeding (Row Crops), Mahyco (P) Ltd., Jalna, made a presentation entitled *Hybrid wheat breeding: Current status, challenges and way forward strategies*, emphasizing on the urgent need for increased wheat production to meet future food demands for which hybrid wheat is a promising solution. While hybrid wheat is commercially successful in some regions, its global adoption remains limited (<1%). Dr Lad discussed key factors influencing hybrid wheat success: heterosis levels (yield advantages of 10-20 per cent were reported, but higher levels needed for commercial viability), efficient hybrid seed production systems (including cytoplasmic genetic male sterility, chemical hybridization agents, or genetic male sterility), the development of heterotic pools, optimizing floral traits (plant height and flowering time) for pollination efficiency, maximizing seed set, and standardizing seeding rates. He mentioned that addressal of these challenges requires a multi-pronged approach: (i) establishing public-private partnerships for hybrid parent development, (ii) creating diverse heterotic pools with desirable traits and adaptability, (iii) employing marker-assisted selection and genomic prediction to improve hybrid performance, and (iv) using gene editing and speed breeding to accelerate the breeding process. He concluded that there

is a significant scientific progress and that integrating these strategies into commercially viable and sustainable Hybrid-Parent Research and Development Consortium in PPP mode is the next crucial step.

Dr C Tara Satyavathi, Director, ICAR-Indian Institute of Millets Research, Hyderabad, delivered an invited lecture on *Hybrid millets and sorghum breeding*. She highlighted the significant role of hybrid millet breeding in India's agricultural success, specifically focusing on sorghum and pearl millet. She mentioned that the development of hybrids in these crops significantly increased productivity and area under cultivation compared to traditional varieties. Pearl millet hybrid breeding, capitalizing on its outcrossing nature, achieved impressive annual yield gains. Dr Satyavathi mentioned that currently, hybrids dominate pearl millet cultivation in favourable conditions, while varieties are restricted to less suitable areas. She emphasized that the consistent yield superiority of hybrids (approximately 25%) over traditional varieties, even in drought-prone regions. While downy mildew initially hampered early hybrid development, strong public and private sector breeding programs have generated significant genetic diversity in parental lines, mitigating disease pressure. India's substantial pearl millet production (7.0 mha) showcases the success of this approach. She pointed out that, for the first time, benchmark levels of Fe (42 ppm) and Zn (32 ppm) were achieved in hybrids in All India Coordinated Research Project (AICRP) trials. Sorghum hybrid breeding, leveraging stable CMS mechanisms, similarly resulted in high-yielding grain and forage hybrids. However, *rabi* sorghum hybrid adoption remains limited due to consumer preferences. She advocated for the use of genomic prediction and genomic selection to accelerate the development of superior hybrid millets with traits like high yield, disease resistance, and improved nutritional value, and adaptation to diverse agro-ecological conditions.

Dr Abhishek Bohra, Principal Scientist, ICAR-Indian Institute of Pulses Research, Kanpur, made a presentation on behalf of Dr GP Dixit, Director, ICAR-IIPR, on *Hybrid pigeonpea breeding in India: Retrospect, status and prospects*. In his presentation, Dr Bohra highlighted the potential of hybrid breeding to enhance pigeonpea production.

He mentioned that while pigeonpea yields remain relatively low, the exploitation of heterosis offers a promising avenue for improvement. Initially, genetic male sterility (GMS) was used, but the economic challenges of maintaining male-sterile lines led to a shift towards CMS. He mentioned that several CMS-based hybrids were released, notably IPH 15-03 and IPH 09-5, which offer high yields, disease resistance, and early maturity, particularly advantageous for intercropping systems, which were licensed to private seed companies to facilitate wider adoption. He emphasized the ongoing development of new CMS lines in diverse genetic backgrounds, and the exploration of temperature-sensitive genetic male sterility (TGMS) as a more efficient seed production system. The use of molecular markers for hybrid purity testing and for identifying restorer lines was highlighted by him as a significant advancement in accelerating hybrid breeding and improving efficiency. The presentation was concluded by advocating for the integration of genomic prediction to further optimize hybrid breeding programs in pigeonpea, achieving long-term yield gains.

Dr KV Subbarao, Partner — Agvaya LLP, Hyderabad, delivered an invited lecture entitled *The hybrid mustard breakthrough: Bridging innovation and farmer profitability*. He mentioned about India's rapeseed-mustard production which falls short of domestic demand, necessitating substantial imports. Dr Subbarao advocated that hybrid technology, initially hampered by unreliable seed production, has experienced rapid farmer adoption since 2010, which is driven by private sector initiatives. This success stems from higher yields, improved oil content and quality, better disease resistance, and effective market strategies. The improvement is aimed at enhancing biotic stress resistance (*Sclerotinia, Striga, Alternaria*), oil content (3-4%), and reducing glucosinolates. Further genetic enhancements will target yield-related traits (seed size, test weight, siliqua number), abiotic stress tolerance (frost, drought), and pest resistance (aphids). He emphasized that the sustained growth requires accelerated breeding programs utilizing diverse germplasm, MAS, gene editing for key traits, and optimized production strategies including expansion into underserved markets and delayed-season cultivation as hybrid mustard pave a viable path towards reducing edible oil imports and enhancing income for Indian farmers.

Dr RK Mathur, Director, ICAR-Indian Institute of Oilseeds Research, Hyderabad, made a presentation on *Heterosis breeding in oilseeds crops*. He mentioned that India's oilseed sector is crucial to its agricultural economy, contributing significantly

to gross domestic production (GDP) and employing millions of farmers. The country is a leading producer of several oilseeds, yet imports remain substantial. Hybrid technology, particularly in sunflower, castor, and safflower, increased productivity. The presentation detailed out the development and release of numerous sunflower, castor, and safflower hybrids, highlighting the use of CMS and genic male sterility (GMS) systems. Challenges in hybrid seed production were discussed, emphasizing the need for specialized knowledge and resources. He mentioned about the future research priorities that include developing disease-resistant hybrids, enhancing oil content and quality, improving yield-related traits, and increasing abiotic stress tolerance. He also stressed the need for developing more stable male-sterile lines, improving genetic purity maintenance, and diversifying CMS sources to broaden genetic diversity and heterosis. Ultimately, the goal is to create superior hybrids adapted to various cropping systems, promoting domestic oilseed production and reducing reliance on imports.

Dr N Kannan, Principal Breeder – Cotton, Rasi Seeds Private Limited, Attur, Salem, Tamil Nadu, made a presentation on *GM cotton hybrid breeding*. While presenting trends in cotton production in India, he mentioned that India's cotton sector, a major contributor to economy, faces the challenge of doubling lint production by 2030 to meet the growing demand. He expressed his concerns that although the introduction of *Bt* cotton significantly boosted yields, the productivity has recently plateaued due to pest resistance, climate change, and other factors. The presentation highlighted the historical shift from traditional varieties to high-yielding hybrids, emphasizing the significant increase in productivity achieved through hybrid technology. However, challenges persist, including pink bollworm resistance, erratic weather, and limited germplasm.

Dr Kannan advocated for the integration of advanced breeding technologies such as MAS, gene editing, and genomic selection to accelerate the development of climate-resilient, pest-resistant hybrids with improved fibre quality. The adoption of high-density planting systems (HDPS) and mechanization were presented as crucial for improving profitability and addressing labour shortages. He advocated that government support through collaborative initiatives with public institutions,

promoting HDPS infrastructure, fostering public-private partnerships, simplifying germplasm sharing, and establishing clear guidelines for gene editing are essential for enhancing India's global competitiveness in the cotton industry.

Dr P Senguttuvel, Senior Scientist, ICAR-Indian Institute of Rice Research, Hyderabad, made a presentation on *Hybrid rice in India: Public sector perspectives*. He informed that India's hybrid rice program has yielded 162 commercially released hybrids. In *Kharif* 2023, 3.5 mha were planted with hybrid varieties (8% of total rice area), boosting production by 5-6 million tons. However, the adoption lags behind due to factors like marginal heterosis, a narrow genetic base, and high seed costs. Ongoing research addresses these limitations by improving female parental lines (stigma exertions, outcrossing), incorporating disease resistance (bacterial blight, blast), and enhancing grain quality. He mentioned that the challenges persist in yield heterosis, genetic base limitations, consumer preferences, and pest/disease susceptibility. Additionally, the economic constraints (high seed costs, low market prices) and policy limitations also hinder widespread adoption of hybrid varieties in rice. He discussed about national research consortium (funded by ICAR since 2015, involving nine centers), which focuses on developing new hybrids for diverse ecologies, diversifying CMS sources, and improving two-line breeding systems; making significant progress in developing aerobic and saline-tolerant hybrids, improving restorer lines, and exploring heterotic gene pools. Dr Senguttuvel also discussed the strategies for promoting hybrid rice — expanded research networks, refined seed production technologies, enhanced technology transfer, and supportive government policies. These policies would focus on increased funding, contract farming models, and stronger public-private sector collaboration. He also advocated for conducting large number of minikit trials and field level demonstrations (FLDs) in different states to identify the most promising hybrids for promotion.

Dr Lakshmi Kant, Director, ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, delivered a lecture on *Hybrid breeding for quality protein maize (QPM) and other traits for biofortification*. He mentioned that QPM hybrids, enhanced with the *opaque2* gene and modifiers, significantly improve the lysine and tryptophan content of maize, combating malnutrition in maize-dependent regions. QPM benefits both human nutrition (improved growth, immunity, cognitive development) and poultry (reduced reliance on synthetic lysine, improved feed efficiency). He advocated that for breeding QPM hybrids, conventional (backcrossing, recurrent

selection) and modern techniques (doubled haploid technology, marker-assisted selection) should be utilized effectively. He also discussed the challenges that include yield gaps compared to conventional hybrids and environmental instability of modifiers. However, genomic tools (GWAS, genomic selection) and CRISPR-Cas 9 gene editing are accelerating the progress. He mentioned that ICAR-VPKAS, Almora, played a pioneering role in developing several high-yielding QPM hybrids, including one with provitamin A and low phytate. These hybrids have improved nutritional quality and farmer livelihoods, particularly in the Himalayan region. Future QPM development aims to enhance drought tolerance, pest resistance, and incorporate additional micronutrients (provitamin A, low phytate, vitamin E). He emphasized that widespread adoption of QPM maize requires robust seed systems, farmer participation, and strong collaboration between research, policymakers, and extension services.

Rapid Oral Presentations

Presenter	**Dr Vinay Bhatt,** ICAR-Indian Agricultural Research Institute, New Delhi
Title	Utilizing genomics-assisted breeding to develop provitamin A-rich low phytate quality protein maize (QPM) hybrids
Key findings	• Genomics-assisted breeding successfully stacked genes (lpa1-1, crtRB1, opaque2) into elite maize inbreds, resulting in significantly reduced phytic acid levels (by ~36%), increased provitamin A, lysine, and tryptophan content, while maintaining acceptable agronomic performance. • Four new biofortified maize hybrids were developed using these improved inbreds, demonstrating enhanced nutritional value (lower phytic acid, higher provitamin A, lysine, and tryptophan) across multiple locations with comparable grain yields to the original inbreds. • The developed biofortified maize hybrids offer a promising strategy to combat malnutrition by improving the bioavailability of essential micronutrients (iron and zinc) and improving the protein quality of maize.

Presenter	**Dr Satheesh Naik SJ,** ICAR-Indian Institute of Pulses Research, Kanpur
Title	Transforming agriculture with hybrid pigeonpea: A success story
Key findings	• ICAR-IIPR, Kanpur developed two high-yielding hybrid pigeonpea varieties (IPH 15-3 and IPH 09-5), resistant to wilt and *Phytophthora* blight, achieving yields of 2,426 kg/ha and 2,293 kg/ha, respectively, significantly higher than traditional varieties. • Successful demonstration trials across 11 Indian states showed a 28-30 per cent increase in average pigeonpea yields and a substantial boost in farmer net incomes (₹ 95,997/ha), showcasing the economic viability and impact on food security. • The program included farmer training and seed production programs, demonstrating the potential for widespread adoption of hybrid pigeonpea to revolutionize pigeonpea production and enhance food security on a larger scale.

Presenter	**Dr Shrikant Yankanchi,** ICAR-Indian Institute of Maize Research, Ludhiana, Punjab
Title	A comprehensive meta-QTL analysis for selected nutritional traits in maize
Key findings	• Meta-QTL (MQTL) analysis identified 34 stable QTLs associated with key nutritional traits in maize (grain zinc, grain iron, kernel oil, protein content), significantly reducing the confidence intervals of previously identified QTLs compared to individual studies (4.86-fold decrease). • 591 candidate genes within the MQTL regions were identified, including 8 with known functions related to zinc and iron homeostasis, kernel oil biosynthesis, and protein content/quality. This provides valuable opportunity for future genetic improvement efforts. • The study demonstrates the power of MQTL analysis in maize breeding, providing stable genomic regions for marker-assisted selection and accelerating the development of superior maize genotypes with enhanced nutritional value.

Following recommendations emerged from the deliberations in the above session:

- Prioritize two-line hybrid rice technology to reduce seed costs and initiate a Hybrid Mission 2.0 focusing on early-maturing pigeonpea hybrids for the North-western plains.
- Enhance hybrid breeding through pre-breeding programs improving parental lines, genomic prediction for multiple desirable traits, and accelerated breeding techniques.
- Develop efficient seed production and technology transfer systems, including alternative locations and honeybee-mediated pollination for mustard, while ensuring protection of parental lines and hybrids under PPV&FRA.
- Promote biofortified maize and fully exploit the potential of castor and safflower hybrids, including developing a cost-effective HDPS ecosystem with cost effective planter, harvester, pre-cleaners and standardizing of canopy management and defoliation protocol for effective implementation of HDPS and mechanical harvesting.

TECHNICAL SESSION V: CURRENT STATUS AND FUTURE PROSPECTS IN HYBRID CROP BREEDING II (HORTICULTURAL CROPS)

Chair: **Dr HP Singh**, Former DDG (Hort.), ICAR, New Delhi

Conveners: **Dr TK Behera**, Director, ICAR-IIHR, Bengaluru
Dr KV Prasad, Director, ICAR-DFR, Pune

Rapporteurs: **Dr P Naveen Kumar**, Head, Division of Flower and Medicinal Crops, ICAR-IIHR, Bengaluru
Dr SS Dey, Principal Scientist, Division of Vegetable Crops, ICAR-IARI, New Delhi

The agenda of Technical Session V included one keynote lecture, three invited lectures and four rapid oral presentations.

Keynote and Invited Lectures

Dr TK Behera, Director, ICAR-Indian Institute of Horticultural Research (IIHR), Bengaluru, presented a keynote lecture on *Hybrid research in horticultural crops*. He provided a detailed historical account on hybrid research on fruit, vegetable and flower crops. He mentioned that hybrid technology in Indian

horticulture has significantly advanced since the 1980s, particularly in vegetables where F_1 hybrids are common, mirroring field crop adoption. Successes include tomato, chili, okra, and others, with hybrids exhibiting uniformity, vigor, yield improvements, and disease resistance. Public and private sectors are actively involved, focusing on developing superior inbred lines, market segmentation, diverse hybridization mechanisms (male sterility, gynoecy), double haploid production, and genome editing. He also mentioned that fruit crop hybridization has also yielded positive results in shelf life, quality, and disease resistance across various species (apple, mango, guava, etc.), including low-chill varieties. Notable examples include Arka Sahan custard apple and Kaveri passion fruit. Flower crop hybridization varies depending on propagation method. Vegetatively propagated crops (rose, gerbera) rely on selection from hybrid populations. Seed-propagated crops (petunia, marigold) utilize F_1 hybrids for uniformity. He opined that while private companies heavily rely on imports, ICAR-IIHR is leading public sector efforts, particularly in marigold, releasing male-sterile lines and F_1 hybrids to meet both flower production and carotenoid extraction demands. Dr Behera emphasized on using recent advancements in double haploids, male sterility exploitation, applications including marker-assisted reverse breeding (MARB) which reverts hybrid into inbred lines, and genome editing for development of hybrids across horticultural sectors.

Dr Prakash Patil, Project Coordinator (Fruits), ICAR-Indian Institute of Horticultural Research, Bengaluru, made a presentation on *Hybrid breeding in fruit crops: Current status and future prospects*. He highlighted that hybrid breeding in fruit crops significantly enhances yield, quality, pest resistance, and climate adaptability using both traditional and modern methods. While traditional clonal selection yielded improved varieties in diverse fruits (*aonla, bael,* banana, grapes, guava, *sapota*, litchi, citrus, *ber,* tamarind, jackfruit), hybridization further accelerated progress, resulting in high-yielding, high-quality hybrids like Arka Udaya mango, Arka Kiran guava, and Arka Prabhat papaya, showcasing improved traits such as regular bearing, enhanced nutrient content, and extended shelf life. Modern technologies like next-generation sequencing (NGS), quantitative trait loci (QTL) identification, MAS, tissue culture, and genomic tools are accelerating hybrid development, while mutation breeding expanded genetic diversity (e.g., dwarf papaya). Dr Patil described the challenges for hybridization in fruit crops that include long breeding cycles and complex

inheritance patterns. He suggested that future directions need to involve CRISPR/ Cas 9, gene pyramiding, leverage AI, machine learning, big data, and bioinformatics for digital integration, and speed breeding for faster development of climate-resilient and consumer-preferred varieties. Success requires continued investment, collaborative research, supportive policies, and strong public-private partnerships to ensure widespread adoption and enhanced food security.

Dr Girish Patil, Vice President, ACSEN Agri-science Pvt. Ltd, Bengaluru, delivered an invited lecture on *Breeding tomorrow's vegetables: Integrating technology, nutrition, and sustainability*. He presented an account of current status and future growth of global and Indian vegetable seed market. During 2022, the global vegetable seed market was worth USD 7.64 billion and expected to reach USD 12.48 billion by 2031 (CAGR of 5.6%). Similarly, Indian vegetable seed market is USD 700.9 million, and expected to grow USD 970 million by 2030 (CAGR 5.56%). He mentioned that breeding faces challenges from climate change (abiotic stresses), evolving pests and diseases (biotic stresses), and shifting consumer preferences (calorie-consciousness, plant-based diet, nutrition, sustainability, traceability). He opined that advanced technologies are crucial for overcoming these hurdles and emphasized the use of AI-driven phenotyping and predictive modeling to accelerate variety development, optimizing yield, disease resistance, and nutrient density. Biotechnology (CRISPR, MAS) enables precise gene editing and faster selection of desirable traits and speed breeding drastically shortens generation times. Consumer-centric breeding prioritizes high-nutrient varieties, reduced bitterness, and sustainable production practices. Rootstock breeding enhances resilience to biotic and abiotic stresses. He mentioned that innovations in urban agriculture (vertical farming, aeroponics) address the growing demand for fresh produce in cities, promoting sustainability and efficient resource use for vegetables. Dr Patil opined that genomic tools (genome sequencing, mapping) provide deeper insights into plant genetics, facilitating informed breeding decisions and germplasm conservation. The integration of these advanced technologies is transforming the vegetable seed industry, creating nutrient-dense, resilient, and sustainable vegetable varieties. This contributes to global nutritional security and supports farmer livelihoods through higher yields and market appeal, shaping a future of accessible, nutritious vegetables for all.

Dr KV Prasad, Director**,** ICAR-Directorate of Floricultural Research, Pune, made a presentation on *Breeding for new hybrids in flower crops*. He presented historical

account of hybrid breeding and current status of hybrid varieties in flower crops. He mentioned that India's floriculture industry, a significant contributor to the national economy (₹25,700 crore domestically, ₹ 700 crore in exports), relies heavily on seed production, with a substantial import component (~USD 88 million). India exports flower seeds worth USD 123 million, primarily from private players in Punjab, Haryana, Karnataka, West Bengal, and Maharashtra. About the progress on flower crops, he mentioned that early hybrid flower research began at ICAR-IARI and ICAR-IIHR, later expanding to ICAR-DFR and other institutions, developing hybrids in various species (rose, marigold, etc.). Indo-American Hybrid Seeds pioneered private sector hybrid seed production, initially focusing on export. Other companies like Beauscape Farms and others significantly contribute to the export market (Holland, UK, USA, etc.). An ICAR network project (2000) boosted F_1 hybrid development in several flower crops (aster, marigold, pansy, etc.), though challenges remain. These include self-incompatibility, male sterility, inbred development, and prolonged dormancy. Understanding the interplay of plant, pollinator, and environmental factors is the key to improving hybrid seed production, he advocated that harnessing heterosis can improve crop yields and develop climate-resilient varieties whereas seed/ planting material standards and seed chain have yet to evolve for meeting the global standards for flower crop production.

Rapid Oral Presentations

Presenter	**Dr NK Hedau,** ICAR-Vivekanand Krishi Parvatiya Anusandhan Sansthan (VPKAS), Almora
Title	Exploitation of CMS line in hybrid development in long-day onion (*Allium cepa* L.) at ICAR-VPKAS, Almora
Key findings	• A novel cytoplasmic male sterility (CMS) onion line (INGR 22084) suitable for intermediate/long-day conditions was developed and registered, addressing a major constraint in Indian onion production.

Key findings	• This CMS line is well-suited for developing F_1 hybrids for *rabi* season cultivation in plains, mid-hills, and high-hills, regions currently lacking recommended F_1 hybrids. • The new CMS line is being utilized in a breeding program, resulted in one F_1 hybrid (VLP-68) currently undergoing final testing, potentially leading to significantly higher yields compared to open-pollinated cultivars.

Presenter	**Dr Shrawan Singh,** Division of Vegetable Science, ICAR-Indian Agricultural Research Institute (IARI), New Delhi
Title	Current status and future prospects of hybrid breeding in Indian cauliflower for higher yield, nutraceuticals and disease resistance
Key findings	• India is the second-largest cauliflower producer globally, surpassing the world average productivity (19.4 t/ha vs 18.8 t/ha), largely due to the development and adoption of high-yielding hybrids. These hybrids exhibit significant heterosis in earliness, curd weight, yield, disease tolerance, and heat stress tolerance. • IARI developed several high-yielding cauliflower hybrids utilizing both CMS and self-incompatibility (SI) systems, showing yield increases of 30-45 per cent compared to open-pollinated varieties. New disease resistance sources (black rot, downy mildew) were also incorporated. • Future cauliflower hybrid breeding aims to diversify CMS systems, develop multi-disease resistant hybrids, enhance curding plasticity, reduce pesticide retention, and increase nutritional value (ß-carotene, anthocyanin, glucosinolates), benefiting farmers and consumers alike.

Presenter	**Dr BK Singh,** ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi
Title	Development of CMS lines and hybrids of early cauliflower for better curd quality, shorter duration and higher yield

Key findings	• ICAR-IIVR, Varanasi developed 35 F_1 cauliflower hybrids for the early maturity group (mid-September to mid-November) prevalent in North India, focusing on traits crucial for this hot, humid environment (uniform establishment, curd quality, yield). • Utilizing the Ogura CMS system, three promising hybrids (VRCFH-407, VRCFH-408, VRCFH-410) were identified, exhibiting superior curd compactness, marketable yield, and shorter maturity compared to the leading commercial hybrid (Syn-1522). • These new hybrids offer farmers increased choices with improved traits such as shorter duration and higher marketable curd weight, potentially increasing productivity and profitability.

Following salient points/recommendations emerged from the deliberation during the session:

- Utilize advanced technologies (NGS, RNAi, genome editing, DHs, MARB, speed breeding) to accelerate germplasm characterization, trait identification, and improvement in fruit, vegetable and flower crops. Greater focus is needed on developing hybrids and improved varieties for both seed-propagated and vegetatively propagated horticultural species.
- Prioritize the development of hybrids in seed-propagated flower crops (marigold, aster, etc.) for both domestic and export markets, emphasizing nutritional enhancement and climate resilience.
- Foster global and public-private partnerships to facilitate the exchange of genetic resources, collaborative research, and the development of superior fruit and flower crop varieties/hybrids.
- Enhance funding to use the latest biotechnological tools/approaches and for engaging skilled human resources for development of improved varieties in fruits and flowers, which are as good as that of hybrids (as these are vegetatively propagated) without much impediments of maintaining parental lines (A/B/R lines).

EVENING LECTURE-II

Chair: **Dr RS Paroda**, Chairman, TAAS, New Delhi

Convener: **Dr Anuradha Agrawal**, Project Director, DKMA, ICAR, New Delhi

Rapporteur: **Dr Vartika Srivastav**, Senior Scientist, ICAR-NBPGR, New Delhi

Dr Deepak Pental, ANRF-National Science Chair, Centre for Genetic Manipulation of Crop Plants, University of Delhi South Campus, New Delhi, delivered an evening lecture on *Technological advances for hybrid crop breeding to ensure food and nutrition security*. The lecture centred around his extensive research on *Brassica* breeding in India, with a focus on the role of heterosis breeding in improving mustard crop. Dr Pental highlighted the transformative impact of genetic tools on mustard breeding, opening new possibilities to enhance its agronomic traits and quality attributes.

In view of the self-pollinating nature of mustard, he emphasized the need for a reliable pollination control mechanism to maximize the benefits of heterosis breeding. He discussed various systems such as CMS, photoperiod/thermo-sensitive genic male sterility (PTGMS), the Barnase-Barstar system, and third generation genic male sterility (GMS). Among these, he identified the Barnase-Barstar system as particularly promising for its potential in biotechnological advancements in mustard improvement. He also presented a detailed timeline of research leading to the development of the transgenic mustard hybrid, DMH-11 (Dhara Mustard Hybrid-11), which utilizes barnase, barstar, and bar genes. Although, DMH-11 was ready as early as 2002, but regulatory approval for its environmental release by the Ministry of Environment, Forest, and Climate Change (MoEFCC) was granted after two decades, on 25 October 2022, marking a significant milestone in Indian agriculture.

Mustard holds a crucial position among oilseed crops in India, and recent advances in genome editing technologies, such as CRISPR, further enhanced its breeding potential. Dr Pental highlighted the use of CRISPR to develop double-zero mustard lines with low-seed and high-leaf glucosinolates by editing glucosinolate transporter (GTR) genes. This innovation improved oil quality, offering consumers a flavourful and nutritious option. He concluded by underscoring how genetic tools have revolutionized mustard improvement, providing precision, efficiency, and novel solutions to agronomic challenges. These advancements are essential for building sustainable agriculture and achieving food security. He noted that

with robust governmental support, these technologies have the potential to create a resilient, productive, and equitable agricultural system capable of addressing future challenges

In his concluding remarks, Dr RS Paroda reflected on the mustard research journey shared by Dr Pental, emphasizing that research demands not only knowledge but also patience and perseverance. He expressed optimism that with focused discussions and increased awareness among policymakers, GM mustard and other GM crops could become a reality in India. Dr Anuradha Agrawal, Convener, extended the formal vote of thanks at the end of the session.

Following major recommendations emerged out of the presentation made by Dr Pental:

- Advance transgenic mustard by continued efforts are essentially needed in developing transgenic mustard and other oilseed crops to address the food security challenges.
- Leverage genetic tools to utilize advanced genetic technologies such as CRISPR and genome editing for precise trait improvements.
- Robust and enabling policy support is needed to promote and facilitate advancements in agricultural biotechnology.

TECHNICAL SESSION VI: STRATEGIES FOR HYBRID SEED PRODUCTION AND MANAGEMENT

Co-Chairs: **Dr HS Gupta**, Chairman, Farmers Commission, Assam
Dr Paresh Verma, Executive Director, Shriram Bioseed Genetics Pvt. Ltd, Hyderabad

Convener: **Dr DK Yadava**, ADG (Seed), ICAR, New Delhi

Rapporteurs: **Dr Vignesh M**, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi
Dr Prolay K Bhowmick, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi

The agenda of Technical Session VI included one keynote lecture, four invited lectures and four rapid oral presentations.

Keynote and Invited Lectures

Dr DK Yadava, ADG (Seed), ICAR, New Delhi, delivered keynote lecture on *National policies and strengthening public-private partnership for hybrid crop development*. He gave an overview of the research priorities and achievements of National Agricultural Research System in the development of hybrids in

different crops. He discussed about the share of the public sector in the development of hybrids and the increasing commercialization of public-sector-bred hybrids in major crops during the past 10 years. He also presented different types of models being adopted in ICAR for licensing of the public-bred hybrids. Besides, the licensing of the finished products like hybrids, guidelines are being developed to license trait-specific germplasm, which can be further used by the private sector in product development. Dr Yadava outlined several areas for public-private collaboration, e.g. licensing of released cultivars; collaborative and contract research; value for cultivation and use (VCU) platform of AICRP network; germplasm exchange; sharing trait specific novel germplasm/transgenic events/ genome-edited events/pre-breeding/advanced breeding lines/parental lines of hybrids; development of crop specific consortia-platform; development and sharing of diagnostic kits for detection of specific native gene and transgene; student exchange programme; training and capacity building; and partnership with farmer producer organizations (FPOs) and cooperatives. To further strengthen the seed system and making the quality seed available to farmers, Dr Yadava emphasized the need to revise the extant on regulations and policies. He also suggested an active public-private partnership in R&D for the use of cutting-edge technologies, seed production, and upscaling of hybrids and emphasized for regular interaction with the private sector to facilitate optimum regulation of seed pricing towards make hybrid seeds affordable. He highlighted the significant achievements of Consortia Research Platform (CRP) on Hybrid Technology launched during 2014-15, which has contributed in development of 28 hybrids in rice, pigeon pea, mustard, tomato and cauliflower. It was further suggested that the ongoing CRP on Hybrid Technology needs to be expanded with the inclusion of more crops and traits.

Dr Sanjay Kumar, Director, ICAR-Indian Institute of Seed Science, Mau, made a presentation on *National initiatives in hybrid seed production*. He highlighted the hybrid seed production and market scenario in India, and the transformative potential of hybrid seed production in Indian agriculture. Despite India's vast arable land and agricultural workforce, challenges include low mechanization, fragmented landholdings, and yield stagnation.

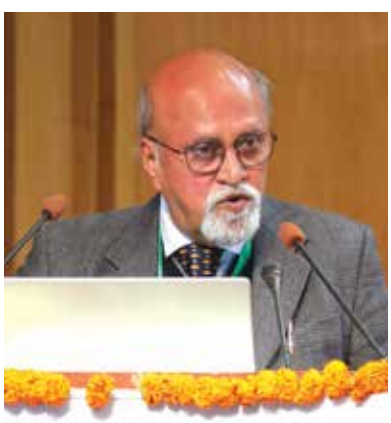
While hybrid seeds dominate in some crops (cotton, castor), adoption in staples remains low, presenting a significant untapped market (USD 1.44 billion). Dr Kumar discussed the challenges in hybrid seed production like high production costs, climate change impacts, consumer preferences, and market fragmentation which hinder wider adoption of hybrid varieties by the farmers. He mentioned that opportunities lie in developing climate-resilient and nutritionally rich hybrids, leveraging technological innovations (like CRISPR), and fostering public-private partnerships. He discussed about the strategies for accelerated adoption that include boosting R&D, optimizing seed production systems, utilizing digital platforms, educating farmers, and implementing supportive policies. The benefits of hybrid seed production include higher yields (20-30% increase), rural employment, and export potential were also discussed. He advocated for addressing the challenges through strategic interventions and collaborations are crucial for ensuring quality seed production and its marketing with increased R&D, policy support, and farmer-centric initiatives to unlock the full potential of hybrid seed technology.

Dr RS Mahala, President – Research (Field Crops), SeedWorks International Pvt. Ltd, Hyderabad, presented an account on *Hybrid breeding and maintenance of parental lines*. His presentation centered around evolution of hybrid breeding; hybrid breeding objectives; drivers of genetic gain; tools and technologies to accelerate genetic gain; CMS-based breeding model for hybrid development; maintenance of parental lines; and components of seed quality. He emphasized on prioritizing stakeholder needs (organization, farmers, consumers) for efficient hybrid breeding programs. He advocated that inbred development can be accelerated using high-throughput speed breeding and molecular tools like single seed descent and DH. Although, breeding methods have advanced from phenotypic selection to incorporate genomic selection (GS) and CRISPR technology, yet maintaining germplasm diversity is crucial. He discussed that hybrid development uses techniques like hand emasculation, CMS, GMS, and TGMS. Inbred value is assessed through hybrid performance, using data like genomic-based estimates of breeding values (GEBV), pedigree-based estimates of breeding values (PEBV), and genetic distance in cross design. He mentioned that a structured breeding and testing matrix guide efficient hybrid development, typically involving 3-4 years of testing and 1-2 years of agronomic evaluation. Discussing the importance of maintenance breeding, he mentioned that maintenance breeding ensures parental line and hybrid purity for robust seed production,

adhering to quality standards and multi-generation seed multiplication systems. He mooted that during multiplication process of parental lines and hybrid seed production, seed should meet the recommended quality standards in terms of physical, physiological, genetic purity and seed health.

Dr SK Chakrabarty, Principal Scientist, Division of Seed Science and Seed Technology, ICAR-Indian Agricultural Research Institute, New Delhi, delivered a lecture on *Development of hybrid seed production technology and management of male sterile line*. He discussed the importance of high-quality seeds, especially hybrids, which significantly increase crop productivity (up to 20%). Therefore, for efficient seed production technology is crucial for ensuring sufficient, affordable supplies of hybrid seeds. While discussion about the genetic principles in hybrid seed production, he mentioned that successful hybrid seed production depends on understanding plant, pollinator, and environmental interactions. Commercial hybrid seed production requires either unisexual flowers or easily emasculated flowers (female parent) and synchronized flowering and abundant pollen (male parent). Agronomic management is essential. Innovations in plant reproductive systems address limitations in sex expression. He concluded that modern breeding techniques (MAS, genomic prediction, genetic engineering, etc.) are necessary to streamline seed production and enhance crop performance.

Dr AR Sadananda, Managing Director, Agreeva Agrigenetics Pvt. Ltd, Bengaluru, made a presentation on *Agribiotech start-up ecosystem — present status vis-a-vis hybrid development*. He discussed that India's Startup initiative that has spurred significant growth in agritech, with over 5,000 startups, largely focused on big data, supply chains, Function as a Service (FAAS), and Internet of Things (IoT). Government support through various programs has fueled this expansion, and the agritech market is projected to explode. However, challenges persist, including low farm yields compared to developed nations and a need for affordable, accessible technologies. Biotechnology offers crucial solutions, but faces challenges. Agri-biotech start-ups encounter difficulties in accessing funding, facing investor hesitancy due to the long gestation periods and high risks inherent in agriculture. Regulatory burdens (costly and



time consuming), particularly regarding germplasm access and product testing, add significant costs and time delays. Government funding is insufficient and short-term, hindering the development of minimum viable products (MVPs) and regulatory compliance. Dr Sadananda advocated for special status for agri-biotech startups, easing regulatory hurdles, streamlining germplasm access and testing, and establishing a dedicated long-term funding mechanism to foster growth and innovation in this crucial sector.

Dr Paresh Verma, Executive Director, Bioseed Genetics India Ltd, Hyderabad, made a presentation on *Regulating seed pricing and its implications*. He discussed that seeds are a crucial agricultural input, contributing significantly to productivity (70-80% of gains) despite representing a small portion (<10%) of cultivation costs. He mentioned that seed is not a commodity; different varieties offer varying value across conditions. Although, hybrid and HYV seed adoption is widespread among farmers of all sizes but successful adoption hinges on demonstrable economic benefits. He advocated that significant R&D investment is essential (globally 15%, in India 5-15% of turnover), encompassing multiple crops, breeding stations, testing, and market-driven product development, leveraging technologies like DH, MAS, and GS. Dr Verma expressed his concerns that India's regulatory framework (Seeds Act, Essential Commodities Act) includes price control, the government's price control mechanism, particularly impacting Bt cotton, arbitrarily sets prices without considering the varying value of different hybrids. Such controls, however, treat diverse hybrids as a single commodity, suppressing seed prices below production costs resulting in shrinking company margins, reduced R&D, business failures, and a rise in low-quality seed suppliers, ultimately hindering innovation.

Rapid Oral Presentations

Presenter	**Dr Sudipta Basu,** Division of Seed Science and Technology, ICAR-IARI, New Delhi
Title	Standardisation of seed production technology of parthenocarpic gynoecious cucumber; Pusa gynoecious parthenocarpic cucumber hybrid–1 under nethouse conditions

Key findings	• For Pusa Gynoecious Parthenocarpic Cucumber Hybrid-1, planting the male parent 10 days earlier than the female parent maximized hybrid seed production due to better flowering synchronization. Pollination between 6-10 am on the day of anthesis yielded the highest fruit and seed set. • Spring-summer season proved superior to the *kharif* for hybrid seed production in North India. A 3:1 female-to-male planting ratio and a fruit load of 3 fruits per vine were optimal for high-quality seed yield. Silver thiosulphate application induced male flowers for parental line maintenance. • Standardized the seed production technology for Pusa Gynoecious Parthenocarpic Cucumber Hybrid-1 under protected (net house) conditions, achieved a yield of 1-1.2 kg/100 m^2 in the spring-summer season.

Presenter	**Dr SL Jat,** ICAR-Indian Institute of Maize Research, Ludhiana
Title	Breaking barriers in maize seed production: The success story of DMRH 1308 and DMRH 1301 hybrids
Key findings	• Efficient maize hybrid seed production requires careful experimentation to determine optimal site, season, planting time, and ratios, along with standardized flowering synchronization and best practices. Essential resources include skilled labor, isolation facilities, irrigation, and high-performing parental lines. • Public sector maize hybrids, like DMRH 1308 and DMRH 1301, demonstrated success through significant breeder seed production and distribution via DAC and collaborations with private seed companies. High yields, adaptability, and responsiveness to inputs of these hybrids have driven their widespread adoption. • To achieve nationwide hybrid maize coverage (10.7 mha), significantly more breeder seed (approximately 180 q) is needed. While participatory seed production involving FPOs and SMEs shows promise, scaling up requires strategic planning and collaboration to meet growing demand.

Presenter	**Dr J Jawahar Lal,** ICAR-Indian Institute of Oilseeds Research, Hyderabad
Title	High yielding CGMS-based safflower hybrid: ISH-402
Key findings	• ICAR-IIOR developed the safflower hybrid ISH-402, demonstrating significantly higher seed yield (+21% over the best variety, +46% over the best hybrid) and oil yield (+35% and +52% respectively) at the national level. The hybrid also showed a higher oil content (30.8%) compared to checks. • ISH-402 was created using a cytoplasmic male sterility (CGMS) system, a crucial step in efficient hybrid safflower seed production. This system, developed independently in India, enables controlled cross-pollination for hybrid seed production. • The standardized seed production technology for ISH-402 has been perfected, paving the way for increased safflower cultivation in India. The superior yield and oil content of the hybrid offer unprecedented opportunities to revitalize safflower production.

Presenter	**Dr Anamika Chandel,** Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi
Title	Impact of exogenous GA3 application on morphological traits and flowering synchronization in or gene introgressed in Indian cauliflower
Key findings	• Application of gibberellic acid (GA3) significantly improved morphological traits in both orange (CFOr) and white (CFWT) cauliflower genotypes. A 500 ppm concentration at the vegetative and curd initiation stages yielded the best results. • The study demonstrated that GA3 application, specifically 250-500 ppm at the vegetative and curd initiation stages, effectively synchronized flowering time between the orange and white cauliflower genotypes, crucial for hybrid seed production. • The findings suggest that GA3 application can mitigate the growth and developmental penalties associated with the *Or* gene in orange cauliflower, thus improving seed production and enabling the development of orange cauliflower hybrids.

Following major recommendations emerged from the above session:

- Revise the Seed Act, Rules, and Policies to align with current and future food security needs, facilitating innovation and streamlining the processes for agri-biotech startups.
- Establish robust PPP mechanisms for upscaling hybrid seed production of publicly bred varieties, leveraging private sector expertise in marketing and distribution. This includes flexible pricing models to ensure affordability and competitiveness.
- Launch a mega national program dedicated to hybrid seed technology, expanding research on crops and traits. Create 'Centers of Excellence' focused on seed production, capacity building, and value addition.
- Develop and utilize digital platforms for marketing and supply chain optimization, employing AI and Big Data for demand forecasting and efficient resource allocation. Improve access to germplasm for start-ups and identify new seed production sites.
- ICAR/DBT to establish funding scheme like AgriSure (Agri Fund for Startups & Rural Enterprises), for long term funding for generation and validation of MVPs.
- Implement Flexible Pricing Mechanisms for hybrid seeds to incentivize industry and farmers to adopt hybrid varieties by ensuring that seed prices are competitive and aligned with the benefits of increased yields
- Department of Agriculture and Farmers Welfare, ICAR and the Seed Associations should have regular stakeholder meetings to address industry challenges.

PANEL DISCUSSION ON WAY FORWARD

Co-Chairs: **Dr RS Paroda**, Chairman, TAAS, New Delhi
Dr RB Singh, Former President, NAAS, New Delhi

Convener: **Dr RK Tyagi**, Senior Consultant, TAAS, New Delhi

Rapporteurs: **Dr Akshay K Talukdar**, Principal Scientist, ICAR-IARI, New Delhi
Dr KK Vinod, Principal Scientist, ICAR-IARI, New Delhi

Seven esteemed panelists participated in the discussion, addressing various points and concerns; the highlights of their interventions are given below:

Dr PL Gautam, Chancellor, RPCAU, Pusa, Samastipur, provided an insightful overview of the coordinated hybrid research efforts that began in 1957, focusing on maize within the ICAR and State Agricultural Universities (SAUs). He noted that while SAUs were tasked with developing hybrid varieties, there was a significant

gap in strategies for effectively delivering these hybrid seeds to farmers. To address this issue, the National Seed Corporation and State Seed Corporations were established to ensure seed availability; however, these entities now require revitalization to enhance their effectiveness. To bridge the existing gaps, Dr Gautam emphasized on the potential of PPPs, suggesting that there is considerable scope for creating consortia that span from research to evaluation of hybrid products. He also pointed out the need for alternative approaches, such as fostering start-ups in the agricultural sector. However, these start-ups often face challenges related to recognition, germplasm sharing, and navigating regulatory processes; thus, it is essential to address these issues to enable their functionality. He also highlighted the importance of linking agricultural graduates with hybrid varietal development programs, which is crucial for fostering innovation and expertise in this field. He concluded by stating that ICAR must develop mechanisms and guidelines for effective public-private partnerships, complete with clear standard operating procedures (SOPs) to facilitate collaboration and progress in hybrid research and development.

Dr AK Singh, Former Director, ICAR-IARI, New Delhi, highlighted several critical issues regarding hybrid crop breeding and seed production. He recalled that the Indian Foundation Seed Service Association was initially established to ensure an adequate supply of foundation seeds for hybrid crops to industry partners. Although, the Indian Agricultural Research Institute (IARI) signed 20 memoranda of understanding (MoUs) for the RH-10 rice variety with private sector partners, this initiative was eventually discontinued. He suggested that organizations like the FSII and the NSAI could develop a similar proposal to enhance the foundation seed multiplication system. Also, the ICAR should establish a comparable framework to this effect. Dr Singh pointed out that seed production research in the public sector is currently weak and emphasized the need for mandatory data generation and submission regarding seed production research and productivity alongside variety release proposals. If producibility of a variety falls below a minimum benchmark, it should be rejected. In the private sector, varietal development is closely monitored by developers, marketers, and producers; Dr

Singh argued that a similar oversight mechanism should be implemented within ICAR. He also mentioned that when private companies seek MoUs for licensing a variety, they often require multi-location testing; however, the public sector lacks sufficient capacity to produce F_1 seeds for adequate testing. He raised concerns about the National Biodiversity Authority's restrictions on sharing materials with private companies that have foreign partnerships, noting that these regulations can delay germplasm sharing. There is an urgent need for streamlining these processes. Furthermore, he pointed out that hybrid wheat breeding in the public sector is currently lagging behind private sector efforts, which are yielding promising results. Therefore, he recommended that ICAR should revive its wheat hybrid breeding program. Timely availability of quality hybrid seeds is crucial for farmers. Dr Singh stressed that when hybrid varieties are released, quality assurance and milling recovery data (e.g. for rice) should be included in the release proposals to instil the confidence in farmers and avoid confusion similar to recent issues faced by Punjab farmers regarding rice hybrid seeds. He noted that while the public sector developed 28 hybrids of biofortified maize without any yield penalty, no private seed companies came forward for licensing these varieties. To promote biofortified crops for food and nutritional security, he called for policy changes and incentives for farmers, suggesting that new maize varieties should mandatorily include at least one biofortification trait to qualify for its release and notification like it was done for pearl millet. Dr Singh also highlighted the need for significant investment in disruptive innovation research to encourage private sector participation. A strong intellectual property rights (IPR) protection system is essential to safeguard private sector interests, and FSII and NSAI should establish a framework for IPR protection. Finally, he proposed establishing a National Mission on the Development and Promotion of Hybrid Technology to focus on researchable issues related to disruptive innovations, recommending an allocation of ₹ 1,000 crore over five years to facilitate revolutionary changes in hybrid technology adoption. He concluded by stating that GST on seeds should be removed and that DSIR registration should not be mandatory for start-ups for at least three to four years until they get established and become effectively functional.

Dr Raju Barwale, Chairman, Mahyco, Jalna, virtually participated in the panel discussion and focussed on the critical need for a supportive environment for private sector engagement in agricultural technology including hybrid technology. He stressed the importance of establishing science-based regulatory policies that foster confidence and encourage investment within the industry. Streamlining governmental processes was another key point, advocating for harmonized activities across different agencies to ensure efficiency and ultimately benefiting farmers.

Commercialization of existing technologies and a significant increase in R&D funding were also highlighted as crucial elements for progress. Finally, Dr Barwale emphasized on the need for a robust and effective re-enforcement of PPV&FRA to safeguard the interests and innovations of the private sector.

Dr Ram Kaundinya, Senior Advisor, FSII, New Delhi, participated virtually in the panel discussion. He emphasized several important points regarding the hybrid seed sector. He noted that the cost of seeds constitutes only 4-8 per cent of the total inputs in crop production, which suggests that the seed price control mechanism should be evaluated in a way that balances the interests of both the industry and farmers, especially considering that labour costs account for 40-50 per cent of total production expenses. He advocated for enhanced investment by public and private sectors; the private sector should invest at least 6-10 per cent of their resources in research and development focused on market-driven research in crop breeding. Dr Kaundinya highlighted the significance of hybrids in edible oil, pulses, and vegetables, urging to prioritize the research and development efforts in these crops utilizing disruptive innovations for hybrid crop breeding. He pointed out that high-quality seed production is currently limited to specific areas, which necessitates a broader approach to ensure availability of hybrid seeds in different crops and focused research on seed production technologies. Furthermore, he stressed that government should promote GM and gene-edited technologies for enhancing production and productivity. Therefore, there is a need for enabling policies to be in place to protect IPRs related to disruptive technologies.

Dr OP Yadav, Director, ICAR-CAZRI, Jodhpur, highlighted several key points regarding hybrid crop development. He noted that there is significant progress in hybrid development for both cross-pollinated and self-pollinated crops such as rice, with reports indicating a 10 per cent heterosis observed in wheat. Despite substantial investments in wheat and rice research, the compound annual growth rate (CAGR) for these crops remains low at 1-1.5 per cent, compared to 4-5 per cent for maize and pearl millet, primarily due to the effective commercialization of heterosis. Dr Yadav acknowledged the constraints presented by ICAR in exploiting heterosis across

different crops but expressed optimism about the increasing openness of ICAR to collaborate with the private sector through PPPs in the coming years. He pointed out that private sector expectations include exclusive products or technologies, given their substantial investments in production and marketing. However, public sector leaders and breeders are often hesitant to share exclusive rights owing to rule and regulations in public research system, indicating a need for protective measures for the interest of these individuals from vigilance enquiries, etc. He raised the challenge of enhancing heterosis across various crops, noting that the science behind it is complex. Drawing from his experience, Dr Yadav advocated for heterotic grouping, a practice already showing positive results in maize and pearl millet, emphasizing the need for an action plan to develop more heterotic groups through coordinated hybridization programs. Additionally, he mentioned that approximately 26,000 DH lines were generated at CIMMYT's facility in Bengaluru in the last three years. While generating DH lines is feasible, he cautioned that the hybrid development process is lengthy and often results in high material discard rates based on GBS as experienced by Corteva. He suggested focusing on fewer crosses with parents that exhibit significant genetic variation to maximize heterosis exploitation. Dr Yadav also pointed out that while the public sector has unrestricted access to global germplasm, its weakness lies in product development and marketing. In contrast, the private sector excels in these areas. He urged for collaboration between public and private sectors to complement each other's strengths rather than compete, which could lead to enhanced genetic gains and extended heterosis benefits over the next five to six years for crops like maize and rice.

Dr Deepak Prem, Regulatory Affairs Lead, Seeds and Traits, Bayer CropScience India Ltd, New Delhi, raised several important points regarding the future of hybrid breeding. He acknowledged the significance of traditional breeding methods while questioning how heterosis can be predicted using sequencing markers in conjunction with quantum computing. He wondered whether this task would become the responsibility of plant breeders or be facilitated by AI tools and expressed uncertainty about our readiness to tackle these complex questions. He recognized

that the private sector is largely driven by breeders trained in public institutions and emphasized the need to realize the value of heterosis in staple crops like rice, wheat, and maize and also in vegetables. The private sector has made significant contributions by bringing valuable germplasm from global partners. He stressed on the necessity for a conducive policy environment to foster scientific progress, particularly for GM and GE crops. He also noted challenges in sharing materials due to complicated regulations under the National Biodiversity Authority (NBA) and Access and Benefit-Sharing (ABS) frameworks. He called for reforms in ABS regulations, as current guidelines do not provide sufficient exceptions for private sector breeders, creating hurdles for multinational companies and impeding scientific advancement. He pointed out that Bayer produces seeds in India for other companies abroad, suggesting that India can become a seed hub by implementing new phytosanitary guidelines. To facilitate this, there needs to be an easier system for importing and exporting seeds. He highlighted that hybrids developed in India are not exclusively for domestic use; however, the lengthy NBA process poses challenges for Indian companies looking to market their products internationally. Finally, he suggested to incentivizing R&D in hybrid technology through increased funding and a review of tax policies by the Department of Scientific and Industrial Research (DSIR).

Dr Sain Dass, Former Director, DMR, New Delhi, emphasized several critical points regarding the future of hybrid crop breeding. He asserted that market-driven research should be the primary focus for the public sector in hybrid crop development. According to him, it is essential that products have a clear market presence prior to the notification of hybrid varieties, ensuring that they meet the needs and demands of farmers and consumers. Furthermore, he highlighted the necessity for the public sector to take the lead in research areas where the private sector may not be actively involved. This is crucial for ensuring comprehensive advancements in hybrid technology that benefit all stakeholders including farmers. He also stressed that hybrid varieties must be adaptable and suitable for various cropping systems, thereby, maximizing their utility and effectiveness across different agricultural contexts.

Based on the discussion by the panellists and interaction with the participants, following recommendations emanated during this session:

- Establish consortia-based public-private partnerships to promote hybrid systems across the country, facilitating collaboration and resource sharing. Market-driven

research to develop a hybrid suitable to any cropping system should be taken-up by public sector also.

- Focus on human resource development by integrating hybrid science into educational curricula and encouraging youth participation in hybrid seed production.
- Develop a cohesive regulatory system between state and central authorities to streamline the adoption of hybrid technologies across regional boundaries.
- Revisit the Acts and Rules governing the seed industry and plant variety protection to align with modern scientific requirements and advancements to instill the confidence in all stakeholders.
- Launch a National Mission on Hybrid Breeding for exploitation of heterosis to support the development and popularization of hybrid, utilizing disruptive and innovative technologies to ensure food and nutritional security.
- Initiate discussions on the implications of GST and other taxes for the seed industry to ensure that tax policies facilitate rather than delay hybrid seed research and adoption of technologies.
- Ensure that hybrid research is market-oriented, with adequate investment from both public and private sectors to meet the demands of farmers.
- Prioritize research areas such as enhancing the mechanism of heterosis with adequate support to exploit apomixis to enhance the development, efficiency and effectiveness of hybrid seed supply chains.
- Continue to strengthen genetic diversity through robust breeding schemes and heterotic pooling in hybrid research to improve crop resilience and yield potential.
- Biofortified maize needs to be taken up by private sector which may be a mandatory trait for releasing new variety.
- FSII and NSAI and public sector institutions may develop a model/mechanism to protect IPRs related to hybrid seed technologies.

CONCLUDING SESSION

Co-Chairs: **Dr RS Paroda**, Chairman, TAAS, New Delhi
Dr Himanshu Pathak, Secretary, DARE and Director General, ICAR, New Delhi

Convener: **Dr RK Tyagi**, Senior Consultant, TAAS, New Delhi

Rapporteurs: **Dr Akshay K Talukdar**, Principal Scientist, ICAR-IARI, New Delhi
Dr KK Vinod, Principal Scientist, ICAR-IARI, New Delhi

Dr RK Tyagi, Convener of the session and Organizing Secretary of the symposium presented the summary and key recommendations of the National Symposium on *Hybrid Technology for Enhancing Crop Productivity,* based on the 3-day deliberations. The key recommendations are appended in this document on page 54 onwards.

Dr RS Paroda, Chairman, TAAS made concluding remarks, which are summarized as below:

- The National Symposium on Hybrid Technology effectively served as a vital platform to assess advancements and challenges in hybrid research and adoption within India. It successfully highlighted our progress in crop hybrid development and commercialization technology across both cross- and self-pollinated crops while identifying actionable steps to address critical gaps.
- He emphasized the necessity for documentation of proceedings, and using recommendations from this symposium to guide future initiatives. To ensure follow-up, he also expressed the need to convene a roundtable meeting with key personnel from both the public and private sectors to discuss these recommendations and their implementation.
- Among the pivotal areas identified for development are the creation of cost-effective technologies, such as one-line or two-line breeding systems, alongside prioritizing research on apomixis. Public sector investments are crucial in advancing these areas. Additionally, strengthening the germplasm base and implementing heterotic pooling across crops are essential for sustainable progress.

- A robust PPP framework must be established to focus on trust-building to maximize mutual benefits arising from advancements in hybrid technology. Clear guidelines for PPPs should be formulated in consultation with the seed sector, including a thorough review of licensing systems to ensure equitable access and foster innovation.
- Policies regarding plant variety protection should extend to private entities, incorporating mutually agreed benefit-sharing mechanisms. Furthermore, gene editing technologies must be prioritized through collaborations with global leaders while ensuring that end-users can fully benefit from advanced technologies.

- It is imperative to revisit regulatory frameworks, including the PPV&FRA and NBA approval processes, to eliminate outdated barriers. Easing restrictions on the movement of hybrids and parental pools is vital for facilitating timely delivery of improved crop varieties.
- The Symposium has underscored the necessity of enhancing capacity-building infrastructure to support modern hybrid research. Regular critical reviews are essential to prevent complacency in breeding research and avoid stagnation.
- Moving forward, Dr Paroda called for a missionary approach that unites all stakeholders in driving the hybrid revolution and an urgent need for a policy framework that fosters collaboration, innovation, and investment. To maintain momentum, ICAR should take the lead in organizing hybrid technology conferences every three years.
- Finally, Dr Paroda expressed his satisfaction with the discussions and recommendations generated during the Symposium. He expressed his confidence that by implementing the recommendations and fostering trust between public and private sectors, India can enhance its hybrid technology landscape, ensuring food security and sustainable agricultural growth for the future.

Dr Himanshu Pathak, Secretary, DARE and Director General, ICAR, New Delhi, in his concluding remarks highlighted a few important points which are summarized below:

- Seeds are fundamental to the future of agriculture as they drive productivity, sustainability, and food security. This National Symposium has provided an excellent opportunity to evaluate the current state of hybrid technologies and chart a road map for their advancement.
- He expressed satisfaction with the productive discussions that have taken place during the Symposium and mentioned that achieving sustainable agricultural development requires quality seeds, advanced technologies, trained personnel, and effective coordination among all stakeholders.
- He highlighted several key initiatives and policy actions undertaken by ICAR and other agencies aimed at strengthening our seed system.
- Hybrid technology has significantly boosted agricultural productivity. To sustain this momentum, we must strengthen production systems by expanding our technology base with active participation from both public and private sectors.

- The Seed Act and PPV&FR Act require urgent review and amendments to address emerging technologies and stakeholder needs. ICAR is actively working towards revisiting these frameworks to ensure that they remain relevant.
- Timely supply of quality seeds is critical and, hence, we need to strengthen seed systems to enhance the reliability and efficiency of our public sector seed production system while exploring mechanization opportunities.
- The issue of GM crops is currently being deliberated in the Supreme Court. ICAR is committed to pursuing resolutions that benefit all stakeholders while fostering confidence in GM technologies.
- Strengthening partnerships with private industries, CGIAR systems, and other stakeholders is essential for knowledge exchange and innovation. ICAR has also focused on capacity building through training initiatives aimed at achieving our sanctioned strength in agricultural research.
- Ongoing discussions with Corteva regarding genome editing are progressing well. These discussions are expected to pave the way for breakthroughs in seed technology supported by proactive government engagement.
- It is crucial that the outcome of deliberations will result in actionable recommendations to guide future actions. There is need to formulate 10-15 key action points for submission to ICAR and relevant agencies, followed by smaller-scale review meetings to monitor progress.
- In closing, Dr Pathak reiterated the need for context-specific road map tailored to stakeholders within our agricultural ecosystem. He reiterated that by addressing infrastructure challenges, policy needs, collaboration opportunities, and capacity-building efforts, ICAR is poised to lead the transformation of India's seed system — ensuring a resilient and sustainable agricultural future.

This Session was concluded with the Co-Chairs presenting awards for the best oral and poster presentations, as evaluated by a panel of eminent scientists.

Dr JL Karihaloo, Treasurer and Trustee, TAAS, proposed a vote of thanks to the co-chairs, speakers, conveners, rapporteurs, committee members, and all symposium participants and organizers. He also acknowledged the logistical and financial support provided by co-organizers and sponsors.

RECOMMENDATIONS

The following key recommendations emerged after extensive discussions:

Germplasm Management

1. There is an urgent need to develop a robust germplasm management system, encompassing the development and maintenance of heterotic pools enriched with hybrid-oriented source germplasm, leveraging the collaborative strengths of public and private sectors.
2. It will be desirable to develop and maintain mini-core and core collections of germplasm in different hybrid crops. This justifies to have a national/regional consortium to exchange quality germplasm, including breeding lines, mini-core and core collections, and associated data with breeders in different research institutions. This requires simple standard operating procedures (SOPs) avoiding bureaucratic hurdles. Consortium approach must be one of the top priorities for the government. The recent announcement of setting-up of a duplicate safety Gene Bank by the Government is a welcome move.
3. We must urgently prioritize and strengthen regional germplasm collections, focusing on climate-resilient materials (drought, cold and heat-tolerant) of crops including dryland crops such as sorghum, millets and pigeonpea.
4. There is an urgency to develop and implement a long-term strategy for sustainable conservation and utilization of crop wild relatives and landraces, recognizing their value in enhancing genetic diversity and adaptability in crop breeding programs.

Strengthening Hybrid Research

5. Greater thrust is needed on scaling genetic innovations, including doubled haploidy (DH)/rapid generation advancement, molecular markers, marker assisted selection (MAS), genomic selection, genome/gene editing tools (e.g., CRISPR-Cas), high-throughput phenotyping, artificial intelligence (AI), machine learning, internet of things (IoT), remote sensing, etc. Also, we need to utilize genomic prediction models to efficiently select and pyramid multiple traits (e.g., yield, disease and pest resistance) into hybrid varieties. This will allow faster development of superior hybrids through accelerated breeding processes. Efficient data management emanating from the All-India Crop Research Projects would enhance much needed hybrid breeding efficiency.
6. Concerted efforts are urgently needed to utilize new sources of cytoplasmic male sterility (CMS), restorer genes, and the gynoecious lines (female plants) for facilitating hybrid breeding. Also, the use of marker-assisted reverse breeding

(MARB) techniques to efficiently convert hybrids back into homozygous inbred lines, maintaining the desirable traits will facilitate the development of new inbred parental lines.

7. Greater emphasis is also needed on research to develop new techniques to overcome limitations in recombination, particularly in genomic regions with low recombination rates. In this context, it will be helpful to explore the potential of genes like *BBM1*, *WOX9A*, and the *CENH3* to manipulate recombination and enhance genetic diversity for creating superior hybrids and heterotic pools.
8. There are new options to utilise synthetic apomixis — a process of asexual seed production — to significantly shorten the breeding cycle, facilitate hybrid seed production, and ensure its genetic uniformity. For this, effective involvement of private sector as research partners will ensure faster dissemination of this technology.
9. The option to optimize and improve the two-line hybrid system that simplifies hybrid breeding and enables cost-effective seed production, particularly in rice, needs to be explored urgently. Also, there is need to implement robust pre-breeding programs in major crops focused on enriching heterotic pools, developing superior inbred lines with desirable traits to enhance the performance of resulting hybrids.
10. To incorporate water-use efficiency traits (root architecture, osmotic adjustment, transpiration efficiency) into hybrids developed for rainfed and marginal environments, accelerating selection *via* precision phenotyping (e.g., drone-based imaging, thermal sensors) and leveraging ICRISAT's Crop Simulation Models to predict performance under future climate scenarios will be highly desirable.
11. It will be helpful to develop trait-spectral libraries using hyperspectral drones/satellites to create spectral signatures for stress tolerance or enhanced nutrient content to accelerate hybrid selection process and reduce phenotyping cost. For root phenotyping, there is a need to have underground imaging systems to evaluate hybrid root architecture for drought resilience.
12. It is highly critical to develop and improve hybrid rootstocks for horticultural crops to enhance productivity, disease and pest resistance, and overall plant performance. Also, we need to develop hybrids suitable for high-density planting systems (HDPS) and appropriate equipment, including cost-effective planters, harvesters, pre-cleaners, and standardized canopy management and defoliation protocols to improve production system efficiency.

Development Initiatives

13. Hybrid technology needs to be exploited to serve as a key enabler in achieving the twin goals of food security and farmer profitability. This necessitates a multi-pronged strategy focused on promoting hybrid technology in crops suitable for different agroecosystems and improved technology access for smallholder farmers.
14. Expanding the existing Consortium Research Platform on Hybrid Technology into a more comprehensive Mega Program focusing on important crops and traits, enhancing its impact and outreach would be highly desirable. To achieve this, a Hybrid Mission-2.0 be initiated urgently by ICAR. Development of early maturing pigeon pea hybrids <(~120 days) and pearl millet hybrids (~65-70 days) for North-Western Plain Zone should be our current priority.
15. Advanced forecasting tools and technologies e.g. weather prediction models, AI-based simulations, etc. need to be developed to accurately predict weather patterns and environmental conditions impacting hybrid seed production, enabling proactive adjustments in seed production strategies.
16. It will be desirable to develop user-friendly digital platforms and tools to streamline seed marketing, enhance communication, and facilitate data-driven decision-making regarding seed supply chain optimization, demand prediction, and inventory management using AI and big data analytics.

Seed Production and Management

17. Greater thrust on pollinator-mediated hybrid seed production practices (e.g., for mustard hybrids) will be needed. Also, it will be helpful to deploy AI-guided drones for precise pollination in hybrid seed production fields, replacing currently used labour-intensive manual approach.
18. There is a need to establish efficient seed production systems and technology transfer mechanisms to ensure that high-quality hybrid seeds are readily available to smallholder farmers at fair prices. Also, there is need for identifying and developing alternative plant reproductive mechanisms and seed production locations to cope-up with climatic variability and regional agroclimatic differences.
19. The seed technology research and production infrastructure across ICAR institutes, state agricultural universities, and state seed testing laboratories require further strengthening and modernization to ensure standardized seed quality and reliable testing. Also, it will decentralize the seed production programs in dryland regions by utilizing farmer cooperatives/FPOs for on-farm

seed multiplication. For this, the development of drought-resilient hybrid seed production protocols (optimized planting windows and pollination strategies) would ensure timely access to quality seeds in climate-vulnerable areas.

20. It is urgent to establish Centers of Excellence on hybrid seed production, emphasizing especially capacity building for maintenance breeding, improved hybrid seed production techniques, proper seed handling, value addition and post-harvest management. Such Centers could serve as hubs for training, technology dissemination, and adoption of best practices for hybrid seed production.
21. Digital-Twins need to be developed which will be very useful for: (i) tracking the hybrid performance from laboratory to field, enabling refinement of breeding strategies, and (ii) developing model hybrid seed production systems to optimize workflows, predicting potential bottlenecks, and simulating the impact of varying climate conditions.

Enabling Policies

22. To incentivize R&D investments by private sector, restoration of the 200 per cent income tax deduction on R&D expenditure is highly justified. It is a long pending request by the Indian seed industry to the Government. Hence, if approved, it will go a long-way in ensuring higher investments flowing back towards R&D by the Indian seed and biotech sector.
23. There is a need for undertaking regularly a comprehensive review of all seed regulations, policies, and orders (including the Seed Act, Rules, Policies, Orders, and the PPV&FR Act) to ensure alignment with current and future food and nutritional security goals. Such revisions be aimed to streamline the procedures, ensure better transparency and improve regulatory efficiency. For this, priority attention is needed for strengthening the protection of parental lines and hybrids under the existing PPV&FR Act.
24. It is important to determine proper pricing of seeds — whether hybrids or conventional varieties — based on market forces to encourage healthy competition and fairness, while ensuring competitiveness, and innovation in the seed sector. Such a balanced approach will ensure win-win situation through easy access to high-quality seeds at fair prices by the farmers enhancing their productivity and sustainability while the industry continues to invest in research for innovative solutions.
25. Policies/laws/acts from different ministries need to be complementary and not be as hindrance for farmers to use best available quality seeds of superior

hybrids that give higher yield and returns to farmers. For implementing the provisions of Seed Act, National Biological Diversity Act (NBA) and PPV&FRA, an inter-ministerial coordination mechanism is critical for effective harmonization and implementation in the best national interest.

26. The intellectual property rights (IPR) protection mechanisms need to be strengthened to encourage investment in R&D of crop hybrids. For this, it will be helpful to develop blockchain-based systems to enhance transparency, efficiency and traceability in the hybrid seed supply chain, anti-counterfeit seed tracking, and IP protection mechanisms.
27. It is important to foster strong and mutually beneficial public-private partnerships (PPPs) for collaborative research and development on new hybrids, their seed production, and availability for timely harnessing their potential by farmers. To ensure this, there is need to develop innovative licensing models and guidelines that are transparent, inclusive and based on principles of access and benefit sharing as win-win on both sides.
28. The ICAR-owned commercial entity, *viz.*, Aginnovate India Limited needs to be suitably strengthened for monitoring breeder seed production, licensing (with proper pricing) and to organize needed multi-environmental trials in collaboration with industry partners. This entity should also facilitate partnerships with universities (availing profit-sharing model).
29. There is urgent need to develop and implement policies for accelerated varietal turnover, including incentivization of the timely release and dissemination of improved varieties/hybrids and replacing obsolete ones. Develop flexible pricing mechanisms for hybrid seeds and provide technical and financial support [tax rebate (e.g., GST) on hybrid seeds to make them more affordable] to resource-constrained smallholder farmers to facilitate the adoption of hybrid technologies.
30. The private seed industry needs to be encouraged for putting more efforts and funds in hybrid research by issuing clear guidelines to the states to allow the testing and sale of hybrids developed by private sector seed companies, which are not notified but meet the prescribed quality standards as outlined in the Seeds Act and the Seed (Control) Order, 1983.
31. There is urgent need to implement the dedicated funding schemes e.g. AgriSure launched by the Ministry of Agriculture and Farmers Welfare for long-term support of agri-biotech start-ups and rural enterprises, fostering innovation. The agri-biotech start-ups need to be given a special status to streamline funding mechanisms and processes and reduce regulatory hurdles. This will encourage private sector involvement and innovation in the sector.

32. More concerted efforts are required to convince the policymakers and all stakeholders, including farmers, regarding the benefits of using genetically modified (GM) crops in agriculture. There is urgency for developing transgenic crops, particularly for oilseeds and pulses to address current food security challenges. It is also necessary to fast-track scientifically-proven innovative technologies (including GM) that are currently in pipeline but waiting for approval due to one or the other reasons. This existing regulatory logjam must end at the earliest thus significantly reducing the time taken for innovations to reach the farmers.
33. There is full justification for ICAR to organize a National Conference on Hybrid Technology every three years to review the on-going research on hybrid breeding in different crops and chart future directions. This should include research relating to GM crops as well.
34. The Ministry of Agriculture and Farmers Welfare and ICAR need to convene on priority a Roundtable dialogue with key public and private sector stakeholders to develop strategies for implementing the recommendations of this National Symposium on Hybrid Technology in the best national interest.

Annexure I

Technical Program

DAY 1: 08 JANUARY 2025 (WEDNESDAY)

09.30-10.00	**Registration**	
10.00-12:15	**Inaugural Session**	
10:30-10:10	**Arrival of Dignitaries and Lighting of Lamp**	
10:10-10:20	Welcome and Introduction about the Symposium	**T Mohapatra**, Vice-Chairman, TAAS and Chairperson, PPV&FRA, New Delhi
10:20-10:30	Remarks by Co-organizers	**Ajai Rana**, Chairman, FSII, New Delhi
10:30-10:40		**Stanford Blade**, Director General – Interim, ICRISAT, Hyderabad
10:40-10:50		**Bram Govaerts**, Director General, CIMMYT, Mexico
10:50-11:00	Address by Guest of Honour	**Himanshu Pathak**, Secretary, DARE and Director General, ICAR, New Delhi
11:00-11:15	Address by Chairperson	**RS Paroda**, Chairman, TAAS, New Delhi
10:45-11:00	Honouring Eminent Hybrid Crop Breeders	**PK Mishra**, Principal Secretary to Prime Minister, PM Office, New Delhi
11:15-11:35	Address by Chief Guest	**PK Mishra**, Principal Secretary to Prime Minister Office, New Delhi
11:35-11:45	Felicitation and Vote of Thanks	**Bhag Mal**, Secretary, TAAS
11:45-12:15	***Group Photo and Tea/Coffee***	

12.15-13.35	***Technical Session I* :** **Hybrid Crops Research and Development – An Overview**	
	Co-Chairs **: RB Singh**, Former President, NAAS, New Delhi **: Renu Swarup**, Former Secretary, DBT, New Delhi	
	Convener **: GP Mishra**, Head, ICAR-IARI, New Delhi	
	Rapporteurs **: Shailendra K Jha**, Senior Scientist, ICAR-IARI, New Delhi **: Chandan Kapoor**, Senior Scientist, ICAR-IARI, New Delhi	
12:15-12:25	Welcome and Introduction	**GP Mishra**, Head, ICAR-IARI, New Delhi
	Keynote Lectures	
12:25-12:45	Accelerating Hybrid Crop Breeding: CIMMYT's Experience and General Perspective	**BM Prasanna**, CIMMYT-India office, New Delhi
12:45-13:05	Hybrid Research in Dryland Crops: Progress and Future Prospects	**Ephrem Habyarimana**, ICRISAT, Hyderabad
	Invited Lecture	
13:05-13:20	Hybrid Crops Research by Private Sector: Recent Advances	**Venkatram Vasantwada**, Seed Works International, Hyderabad
13:20-13:35	General Discussion and Co-Chairs' Remarks	
13:35-14:20	***Lunch***	
14.20-16.35	***Technical Session II* :** **Germplasm Management for Hybrid Crop Breeding**	
	Co-Chairs **: SK Vasal**, World Food Laureate and Former Distinguished Scientist, CIMMYT, Mexico **: PL Gautam**, Chancellor, RPCAU, Pusa, Samastipur	
	Convener **: Kuldeep Singh**, Head, Genebank, ICRISAT, Hyderabad	
	Rapporteurs **: Dharminder Pathak**, Senior Plant Breeder, PAU, Ludhiana **: Rama Prashat G**, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi	
14:20-14-30	Welcome and Introduction	**Kuldeep Singh**, ICRISAT, Hyderabad

	Keynote Lecture	
14:30-14:50	Genetic Resources for Hybrid Development	**HD Upadhayay**, Plant Genome Mapping Laboratory University of Georgia, Athens, USA
	Invited Lectures	
14:50-15:05	Hybrid-oriented Source Germplasm for Improvement of Hybrids	**S Gopala Krishnan**, ICAR-IARI, New Delhi
15:05-15:20	Consortia Approach for Germplasm Improvement and Hybrid Development	**Ephrem Habyarimana**, ICRISAT, Hyderabad
15:20-15:45	***Tea/Coffee***	
	Rapid Oral Presentations	
15:45-15:52	Development and Characterization of *lpa1* and *lpa2*-based Low Phytate Double Mutants for Kernel Quality, Yield, and Agro-morphological Traits for Utilization in Low Phytate Maize Hybrid Breeding	**Vinay Rojaria** *et al* ICAR-IARI, New Delhi
15:52-15:59	Expanding the Arsenal of Male Sterile Germplasm for Accelerating Hybrid Pigeonpea Research and Breeding	**Abhishek Bohra** *et al* IARI-IIPR, Kanpur
15:59-16:06	Development of Popcorn DH Lines for Augmenting Popcorn Germplasm Base and Development of High Yielding Popcorn Hybrids	**RK Khulbe** *et al* ICAR-VPKAS, Almora
16:06-16:13	Mapping BMR Trait and Introgression into Different Genetic Backgrounds for Developing Low Lignin and High Biomass Pearl Millet Genotypes	**Shashikumara P** *et al* ICAR-IGFRI, Jhansi
16:13-16:30	General Discussion and Co-Chairs' Remarks	

16.35-18.30	***Technical Session III* :** **Biotechnology for Accelerating Hybrid Crop Breeding**	
	Co-Chairs	**: Dr Deepak Pental**, ANRF-National Science Chair, Centre for Genetic Manipulation of Crop Plants and Former VC University of Delhi, Delhi **: Dr RC Bhattacharya**, Director, ICAR-NIPB, New Delhi
	Convener	**: BM Prasanna**, CIMMYT Distinguished Scientist & Regional Director for Asia, New Delhi, India
	Rapporteurs	**: Firoz Hossain**, Principal Scientist, ICAR-IARI, New Delhi **: BS Vivek**, Maize Breeder, CIMMYT, Hyderabad
16:35-16:45	Welcome and Introduction	**BM Prasanna**, CIMMYT Distinguished Scientist & Regional Director for Asia, New Delhi, India
	Keynote Lecture	
16:45-17:05	Reproductive Strategies for Hybrid Crops (Pre-recorded)	**Venkatesan Sundaresan**, UC-Davis, USA (TBC)
	Invited Lectures	
17:05-17:20	Disruptive Innovations in Hybrid Breeding	**Ravi Maruthachalam**, IISER, Trivandrum
17:20-17:35	Data-driven Predictive Breeding in Crop Plants: Progress and Prospects	**Raman Babu**, Corteva Agriscience, Hyderabad
17:35-17:50	Learnings from Apomictic Grasses Towards Fixation of Hybrid Vigour	**P Kaushal**, IGFRI, Jhansi
	Rapid Oral Presentations	
17:50-17:57	Revisiting floury2 gene after 50 years: Development of Subtropically Adapted Maize Hybrids with Enhanced Methionine in Maize Kernels Using Genomics-assisted Breeding	**Hriipulou Duo** *et al* ICAR-IARI, New Delhi

17:57-18:04	Introgression of Pi9, a Broad-spectrum Gene into Elite Rice Cultivar of CO 51+Pi54 through Marker-assisted Selection	**S Subburaj** *et al* TNAU, Coimbatore
18:04-18:11	Making Sweetcorn Hybrids Healthier with Vitamins, Amino Acids and Antioxidants through Genomics-assisted Breeding	**Rashmi Chhabra** *et al* ICAR-IARI, New Delhi
18:11-18:25	General Discussion and Co-Chairs' Remarks	
18:25-18:35	***Comfort Break***	
18.30-19.30	***Evening Lecture I* :** **Hybrid Breeding for Unstoppable Genetic Gains** ***Chairs*** **: T Mohapatra**, Chairperson, PPV&FRA, New Delhi ***Convener*** **: S Gopala Krishnan**, Head, Division of Genetics, ICAR-IARI, New Delhi ***Rapporteurs*** **: H Prashanth Babu**, Senior Scientist, ICAR-IARI, New Delhi	
18:35-18:45	Welcome and Introduction of Speaker	**S Gopala Krishnan**, ICAR-IARI, New Delhi
18:45-19:25	Hybrid Breeding for Unstoppable Genetic Gains	**SK Vasal**, World Food Laureate and Distinguished Scientist, CIMMYT, Mexico
19:25-19:30	Chair's Remarks	**T Mohapatra**, Chairperson, PPV&FRA, New Delhi
19:30-19:35	Vote of Thanks	**S Gopala Krishnan**, ICAR-IARI, New Delhi
19:35-21:00	***Welcome Dinner***	

DAY 2: 09 JANUARY 2025 (THURSDAY)

09.30-14.35	***Technical Session IV* :** **Current Status and Future Prospects in Hybrid Crop Breeding I (Food and Fiber Crops)**	
	Co-Chairs : **BS Dhillon**, Former VC, PAU, Ludhiana : **M Ramasami**, Chairman, Rasi Seeds (P) Ltd., Coimbatore	
	Convener : **C Tara Satyavathi**, Director, ICAR-IIMR, Hyderabad	
	Rapporteurs : **SP Singh**, Principal Scientist, Division of Genetics, ICAR-IARI, New Delhi : **Rajkumar Zunjare**, Scientist, Division of Genetics, ICAR-IARI, New Delhi	
09:30-09-40	Welcome and Introduction	**C Tara Satyavathi**, Director, ICAR-IIMR, Hyderabad
	Keynote Lecture	
09:40-10:00	Advances in Hybrid Rice Breeding	**Jauhar Ali**, IRRI, Philippines
	Invited Lectures	
10:00-10:15	India's Maize Improvement Program: Challenges, Progress and Road Map	**HS Jat**, ICAR-IIMR, Ludhiana
10:15-10:30	Development and Scaling of Hybrid Rice by Private Sector in India	**Venkatesh Hubli**, Savannah Seeds(P) Ltd, Hyderabad
10:30-10:45	Breeding for Nutritional Quality Traits in Maize: Status and Prospects	**Firoz Hossain**, ICAR-IARI, New Delhi
10:45-11:00	Hybrid Wheat Breeding: Current Status, Challenges and Way Forward Strategies	**Nimesh Lad**, Mahyco (P) Ltd., Jalna
11:00-11:15	Hybrid Millets and Sorghum Breeding	**C Tara Sathavathi**, ICAR-IIMR, Hyderabad
11:15-11:30	Hybrid Pigeonpea Breeding in India: Retrospect, Status and Prospects	**A Bohra**, ICAR-IIPR, Kanpur
11:30-11:50	***Tea/Coffee***	

11:50-12:05	The Hybrid Mustard Breakthrough: Bridging Innovation and Farmer Profitability	**KV Subbarao**, Partner - Agvaya LLP, Hyderabad
12:05-12:20	Heterosis Breeding in Oilseed Crops (Sunflower, Castor, Safflower)	**RK Mathur**, ICAR-IIOR, Hyderabad
12:20-12:35	GM Cotton Hybrid Breeding	**N Kannan**, Rasi Seeds (P) Ltd, Salem
12:35-12:50	Hybrid rice in India: Public sector perspectives	**P Senguttuvel**, ICAR-IIRR, Hyderabad
12:50-13:05	Hybrid Breeding for Quality Protein Maize (QPM) and other traits for bio-fortification	**Lakshmi Kant**, ICAR-VPKAS, Almora
13:05-13:45	***Lunch***	
	Rapid Oral Presentations	
13:45-13:53	Utilizing Genomics-assisted Breeding to Develop Provitamin A-Rich Low Phytate Quality Protein Maize (QPM) Hybrids	**Vinay Bhatt** *et al* ICAR-IARI, New Delhi
13:53-14:01	Transforming Agriculture with Hybrid Pigeonpea: A Success Story	**Satheesh Naik** SJ *et al* ICAR-IIPR, Kanpur
14:01-14:09	A Comprehensive Meta-QTL Analysis for Selected Nutritional Traits in Maize	**Shrikant Yankanchi** *et al* ICAR-IIMR, Ludhiana
14:09-14:35	General Discussion and Co-Chairs' Remarks	

14.35-17.30	***Technical Session V* :** **Current Status and Future Prospects in Hybrid Crop Breeding II (Horticultural Crops)**	
	Co-Chairs **: HP Singh**, Former DDG (Hort.), ICAR, New Delhi **: Bijendra Singh**, VC, NDUAT, Ayodhya, UP	
	Convener **: TK Behera**, Director, ICAR-IIHR, Bengaluru	
	Rapporteurs **: P Naveen Kumar**, Head, Division of Flower & Medicinal Crops, ICAR-IIHR, Bengaluru **: SS Dey**, Principal Scientist, Division of Vegetable Crops, ICAR-IARI, New Delhi	
14:35-14:45	Welcome and Introduction	**TK Behera**, ICAR-IIHR, Bengaluru
	Keynote Lecture	
14:45-15:05	Hybrid research in horticultural crops	**TK Behera**, ICAR-IIHR, Bengaluru
	Invited Lectures	
15:05-15:20	Hybrid breeding in fruit crops: Current status and future prospects	**Prakash Patil**, ICAR-IIHR, Bengaluru
15:20-15:35	Breeding Tomorrow's Vegetables: Integrating Technology, Nutrition, and Sustainability	**Girish Patil**, ACSEN Agri-science Pvt. Ltd., Bengaluru
15:35-15:50	Breeding for New Hybrids in Flower Crops	**KV Prasad**, ICAR-DFR, Pune
15:50-16:30	***Tea/Coffee***	
	Rapid Oral Presentations	
16:30-16:38	Exploitation of CMS Line in Hybrid Development in Long-day Onion (*Allium cepa* L.) at ICAR-VPKAS, Almora	**NK Hedau** *et al* ICAR-VPKAS, Almora

16:38-16:46	Current Status and Future Prospects of Hybrid Breeding in Indian Cauliflower for Higher Yield, Nutraceuticals and Disease Resistance	**Shrawan Singh** *et al* ICAR-IARI, New Delhi
16:46-16:54	Development of CMS Lines and Hybrids of Early Cauliflower for Better Curd Quality, Shorter Duration and Higher Yield	**BK Singh** *et al* ICAR-IIVR, Varanasi
16:54-17:30	General Discussion and Co-Chairs' Remarks	
17:30-18:00	***Comfort Break***	
18:00-19:10	***Evening Lecture II***	
	Chair : **RS Paroda**, Chairman, TAAS and Former Secretary, DARE & DG, ICAR, New Delhi	
	Convener : **Anuradha Agrawal**, Project Director, DKMA, ICAR, New Delhi	
	Rapporteur : **Vartika Srivastav**, Senior Scientist, ICAR-NBPGR, New Delhi	
18:00-18:10	Welcome and Introduction of Speaker	**Anuradha Agrawal**, ICAR-DKMA, New Delhi
18:10-18:55	Technological Advances for Hybrid Crop Breeding to Ensure Food and Nutrition Security	**Deepak Pental**, ANRF-National Science Chair, Centre for Genetic Manipulation of Crop Plants, and Former Vice Chancellor, University of Delhi, Delhi
18:55-19:05	Chairs' Remarks	
19:05-19:10	Vote of Thanks	
19:10-21:10	***Cultural Program and Dinner***	

DAY 3: 10 JANUARY 2025 (FRIDAY)

09.30-12.45	***Technical Session VI* :** **Strategies for Hybrid Seed Production and Management** ***Co-Chairs*** **: HS Gupta**, Chairman, Agriculture Commission, Assam **: Raju Barwale**, Chairman, MAHYCO, Mumbai ***Convener*** **: DK Yadav**, ADG (Seed), ICAR, New Delhi ***Rapporteurs*** **: Vignesh M**, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi **: Prolay K Bhowmick**, Senior Scientist, Division of Genetics, ICAR-IARI, New Delhi	
09:30-09-40	Welcome and Introduction	**DK Yadava**, ADG (Seed) ICAR, New Delhi
	Keynote Lecture	
09:40-10:00	National Policies and Strengthening Public-Private Partnership for Hybrid Crop Development	**DK Yadava**, ICAR, New Delhi
	Invited Lectures	
10:00-10:15	National Initiatives in Hybrid Seed Production	**Sanjay Kumar**, ICAR-IISS, Mau, UP
10:15-10:30	Hybrid Breeding and Maintenance of Parental Lines	**RS Mahala**, Seed Works International, Hyderabad
10:30-10:45	Development of Hybrid seed Production Technology and Management of Male Sterile Line	**SK Chakrabarty**, ICAR-IARI, New Delhi
10:45-11:00	Agribiotech Start-up Ecosystem - Present Status *vis-a-vis* Hybrid Development	**AR Sadananda**, Agreeva Genetics Pvt. Ltd., Bengaluru
11:00-11:30	***Tea/Coffee***	
11:30-11:45	Regulating Seed Pricing and its Implications	**Paresh Verma**, Bioseed Genetics India Ltd., Hyderabad

	Rapid Oral Presentations	
11:45-11:55	Standardisation of Seed Production Technology of Parthenocarpic Gynoecious Cucumber; Pusa Gynoecious Parthenocarpic Cucumber Hybrid–1 under Nethouse Conditions	**Sudipta Basu** *et al* ICAR-IARI, New Delhi
11:55-12:05	Breaking Barriers in Maize Seed Production: The Success Story of DMRH 1308 & DMRH 1301 Hybrids	**SL Jat** *et al* ICAR-IIMR, Ludhiana
12:05-12:15	High Yield CGMS-based Safflower Hybrid : ISH-402	**Jawahar Lal** *et al* ICAR-IIOR, Hyderabad
12:15-12:25	Impact of Exogenous GA_3 Application on Morphological Traits and Flowering Synchronization in *Or* Gene Introgressed in Indian Cauliflower	**Anamika Chandel** *et al* ICAR-IARI, New Delhi
12:30-12:45	General Discussion and Co-Chairs' Remarks	
12:45-13:45	***Lunch***	
13:45-17:30	***Panel Discussion on*** **Way Forward and Concluding Session**	
	Co-Chairs : **RS Paroda**, Chairman, TAAS, New Delhi : **Himanshu Pathak**, Secretary, DARE and Director General, ICAR, New Delhi	
	Convener : **RK Tyagi**, Senior Consultant, TAAS, New Delhi	
	Rapporteurs : **Akshay K Talukdar**, Principal Scientist, ICAR-IARI, New Delhi : **KK Vinod**, Principal Scientist, ICAR-IARI, New Delhi	
13:45-13:55	Welcome and Introduction	**RK Tyagi**, Senior Consultant, TAAS, New Delhi

13:55-16:00	**Panel Discussion** • **PL Gautam**, Chancellor, RCPAU, Pusa, Samastipur • **AK Singh**, Former Director, ICAR-IARI, New Delhi • **Raju Barwale**, Chairman, MAHYCO, Mumbai • **Ram Kaundinya**, Senior Advisor, FSII, New Delhi • **OP Yadav**, Director, ICAR-CAZRI, Jodhpur • **Deepak Prem**, Regulatory Affairs Lead, Seeds and Traits, Bayer CropScience India Ltd., New Delhi • **Sain Dass**, Former Director, ICAR-DMR, New Delhi	
16:00-16:30	***Tea/Coffee***	
16:30-16:45	Summary of Major Recommendations	**RK Tyagi**, Senior Consultant, TAAS, New Delhi
16:45-17:00	Open Discussion	
17:00-17:20	Co-Chairs' Remarks	**Himanshu Pathak**, Secretary, DARE and Director General, ICAR, New Delhi **RS Paroda**, Chairman, TAAS, New Delhi
17:20-17:30	Vote of Thanks	**JL Karihaloo**, TAAS, New Delhi

Awards and Appreciation

BEST ORAL PRESENTATION AWARDS

Technical Session	Authors and Title
Technical Session-I **Germplasm Management for Hybrid Crop Breeding**	**RK Khulbe**, Devender Sharma, GS Bisht and MC Pant Development of Popcorn DH Lines for Augmenting Popcorn Germplasm Base and Development of High Yielding Popcorn Hybrids.
Technical Session-III **Biotechnology for Accelerating Hybrid Crop Breeding**	**Hriipulou Duo**, Rajkumar U Zunjare, Rashmi Chhabra, Subhra J Mishra, Gulab Chand, Amitkumar D Kyada, Suman Dutta, Vignesh Muthusamy and Firoz Hossain Revisiting floury2 gene after 50 years: Development of Subtropically Adapted Maize Hybrids with Enhanced Methionine in Maize Kernels Using Genomics-assisted Breeding.
Technical Session-IV **Current Status and Future Prospects in Hybrid Crop Breeding I (Food and Fiber Crops)**	**Vinay Bhatt**, Vignesh Muthusamy, Rajkumar U Zunjare, Shridhar Ragi, Aanchal Baveja, Rashmi Chhabra, Ravindra K Kasana, Brijesh K Mehta, Satish K Guleria, Kusuma Kumari Panda and Firoz Hossain Utilizing Genomics-assisted Breeding to Develop Provitamin A-Rich Low Phytate Quality Protein Maize (QPM) Hybrids.
Technical Session-V **Current Status and Future Prospects in Hybrid Crop Breeding II (Horticultural Crops)**	**Shrawan Singh** Current Status and Future Prospects of Hybrid Breeding in Indian Cauliflower for Higher Yield, Nutraceuticals and Disease Resistance.
Technical Session-VI **Strategies for Hybrid Seed Production and Management**	**Sudipta Basu**, SK Lal, M Athar, Rohit Chandi, AD Munshi, SS Dey Standardisation of Seed production technology of parthenocarpic gynoecious cucumber; Pusa gynoecious parthenocarpic cucumber hybrid-1 under nethouse conditions.

BEST POSTER PRESENTATION AWARDS

Technical Session	Authors and Title
Technical Session-I Germplasm Management for Hybrid Crop Breeding	**Amitkumar D Kyada**, Vignesh Muthusamy, Rashmi Chhabra, Botta T Ganesh, Gulab Chand, Gaurav Sharma, Hriipulou Duo, Govinda R Sarma, Jayanthi Madhavan, Rajkumar U Zunjare and Firoz Hossain Development of sub-tropically adapted indeterminate gametophyte1 (ig1)-based paternal haploid inducer line for CMS conversion in maize hybrids. **T Manjunath**, S Senthilvel, J Jawaharlal and Ramya KT Stable Pistillate lines for improving castor hybrids yields in the context of climate change.
Technical Session-III Biotechnology for Accelerating Hybrid Crop Breeding	**S Manonmani**, R Nivedha, T Kalaimagal, M Raveendran, S Kavitha, R Suresh and M Umadevi Identification of promising three-line hybrids through heterosis and grain quality assessment in rice (*Oryza sativa* L.) **Prashant Vasisth**, Omkar Maharudra Limbalkar, Mohit Sharma, Gokulan D, Mohan Lal Meena, Mir Asif Iquebal, Anshul Watts and Naveen Singh Identification of genomic segments and candidate genes conferring yield heterosis in Brassica carinata-derived *Brassica juncea* introgression lines.
Technical Session-IV Current Status and Future Prospects in Hybrid Crop Breeding I (Food and Fiber Crops)	**Ishika Verma**, Vineeta Kaila and Pankaj Sharma Predicting the hybrid performance in sunflower based on mixed model analysis incorporating relationship information. **RS Raje**, Abhishek Bohra, Inderjit Singh, DK Patil, Satheesh Naik SJ, VK Gite, Suruchi Vij, Gyanendra Singh, Kumar Durgesh, Rama Prashat, TR Das, Upasana Rani, Ajinder Kaur, Harish Chandra, Gopi Krishan Gaur, Anuj Malik, Rekha Joshi and Himanshi Saraswat Exploitation of heterosis for productivity enhancement in pigeonpea (*Cajanus cajan* L. Millspaugh)

Technical Session	Authors and Title
Technical Session-V Current Status and Future Prospects in Hybrid Crop Breeding II (Horticultural Crops)	**Kalieswari K**, Kanhaiya Singh, Jai Prakash and Vignesh M Nutritional Profiling and Antioxidant Activity of Carotenoids in Papaya (*Carica papaya* L.) Hybrids.
Technical Session-VI Strategies for Hybrid Seed Production and Management	**Subramanian Poomani**, Parameshwaran Mathavaraj and Atul Kumar Phytohormone-mediated male fertility restoration: A game changer in hybrid seed production.

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	Affiliation	*ICAR-Indian Agricultural Research Institute, New Delhi-110012, India
	Title	Development of sub-tropically adapted indeterminate gametophyte1 (ig1)-based paternal haploid inducer line for CMS conversion in maize hybrids

2.	**Authors**	Parameshwaran Mathavaraj, Ashvin Kumar Katral, Vignesh Muthusamy*, Suman Dutta, Amit Kumar, Rajkumar Uttamrao Zunjare and Firoz Hossain
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	Title	Exploring variability in LOX activity to enhance germplasm for developing rancid-free high-oil maize hybrids for superior bioavailability of fat-soluble vitamins

3.	**Authors**	Sudhir Kumar*, B Vishnu Nanda Reddy, G Prasanthi and M Ramabhadra Raju
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	Title	Mapping phenomic variability for yield attributing & quality traits in saffron (*Crocus sativus* L.)

5.	**Authors**	Ravina Beniwal[*], M Nagarajan, Prolay Bhowmick, Gopala Krishnan S, Ranjith K Ellur, Haritha Bollindi, Sakshi Tomar, AK Singh, KK Vinod
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6.	**Authors**	K Victor Paul[*], Rajkumar U Zunjare, Firoz Hossain, Vignesh Muthusamy, Subhra J Mishra, Ashvinkumar Katral and Prafulla Kumar
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	Title	Genetic variation of folate composition and accumulation pattern in developing kernels of maize (*Zea mays* L.) inbreds

7.	**Authors**	Maninderpal Singh[*] and KK Dhatt
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	Title	Evaluation of inbred lines and F1 hybrids of periwinkle (*Catharanthus roseus* (L.) G. Don) for their growth and flowering characteristics

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	Title	Molecular screening of bacterial blight resistance genes in improved CMS line of rice

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	Title	Phenotypic evaluation of fall armyworm resistance in F2 maize populations: Unveiling the path to pest-resilient crops

13.	**Authors**	Amit Kumar[*], Rajkumar U Zunjare, Rashmi Chhabra, Amitkumar D Kyada, Govinda R. Sarma, Gaurav Sharma, Gulab Chand, Ashvinkumar Katral, Parameshwaran Madhavaraj, Vignesh Muthusamy and Firoz Hossain
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	Title	Teosinte (*Zea mays* ssp. *parviglumis*) as a source for protein enhancement in maize

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	Title	Predicting the hybrid performance in sunflower based on mixed model analysis incorporating relationship information

26.	**Authors**	KR Yathish[1*], C Susmita[1], Santosh Kumar[2], K Pardeep[3], GK Chikkappa[3], Abhijit K Das[3], JC Sekhar[1] and HS Jat[3]
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	Title	Genotype × environment interaction and stability analysis of baby corn hybrids for grain yield using AMMI and GGE Biplot

27.	**Authors**	Rakhi Singh[1], Pushpender Kumar[1], Prahlad Piyal[1], Debjyoti Sarkar[1], Shrikant Yankanchi[1], Praveen Bagaria, Sumit Agarwal, Priti Sharma[2], Harbinder Singh[2], Ajay Kumar[3], Pardeep Kumar, Mukesh Choudhary, BS Jat, HS Jat and Bhupender Kumar[1*]
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	Title	Study of gene actions and mapping quantitative trait loci (QTLs) for resistance to maydis leaf blight and flowering in maize (*Zea Mays* L.)

28.	**Authors**	R.S. Raje[1], Abhishek Bohra[2], Inderjit Singh[3], D.K. Patil[4], Satheesh Naik S.J.[2], V.K. Gite[4], Suruchi Vij[3], Gyanendra Singh[1], Kumar Durgesh[1], Rama Prashat[1], T.R. Das[1], Upasana Rani[3], Ajinder Kaur[3], Harish Chandra[1], Gopi Krishan Gaur[1], Anuj Malik[1], Rekha Joshi[1] and Himanshi Saraswat[1]
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	Title	Exploitation of heterosis for productivity enhancement in pigeonpea (*Cajanus cajan* L. Millspaugh)

29.	**Authors**	G Usharani[1*], D Sravani[1], G Manjulatha[1], MV Nagesh Kumar[2], E Rajanikanth[3], P Madhukar Rao[1], A Vijaya Bhaskar[1] and G Sreenivas[3]
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	Title	Large scale combining ability analysis of test cross hybrids of maize to foster food grain production in maize (*Zea mays* L.)

30.	**Authors**	Devender Sharma*, RK Khulbe, RS Pal and Lakshmi Kant
	Affiliation	ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan Almora, Uttarakhand-263601, India
	Title	Advancing hybrid maize breeding: accelerating nutritional enhancement through multi-trait doubled haploid lines

31.	**Authors**	Ikkurti Gopinath[1], Firoz Hossain[1], Rajkumar U Zunjare[1], Selvakumar Thambiyannan[2], Santosh Kumar[3], Vinay Bhatt[1], Gulab Chand[1], Sathya S.K.R. Veluchamy[2], Bhupender Kumar[4], Javaji C Sekhar[5], Gyanendra Singh[1], Ravikesavan Rajasekaran[6] and Vignesh Muthusamy[1*]
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	Title	Breeding superior stable popcorn hybrids by combining exotic and indigenous popcorn germplasm for a sustainable popcorn breeding program

32.	**Authors**	Brijesh K Mehta[1*], Shashikumara P.[1], Anup Kumar[1], Firoz Hossain[2], Santosh Kumar[3], KK Dwivedi[1], Manisha Purwar[1], Surabhi Bansal[1] and Shahid Ahmed[1]
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	Title	Estimation of heterosis, combining ability and gene effects for forage quantity and quality traits in maize

33.	**Authors**	HP Meena and RK Mathur
	Affiliation	ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030
	Title	Hybrid research in sunflower: progress and future thrusts

34.	**Authors**	Bikkasani Mythri[1*], KVSV Prasad[2], Krithika Anbazhagan[2], Tosh Garg[1], Surinder K Sandhu[1] and BS Vivek[3]
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	Title	Prediction of silage quality traits in maize using near infrared reflectance spectroscopy in an F1 hybrid population

35.	**Authors**	Ankita Sharma*, Shiv Pratap Singh, Arun Kumar and Pratibha Dogra
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	Title	Improvement of cucumber (*Cucumis sativus* L.) through heterosis breeding

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	Title	Combining ability studies in ridge gourd [*Luffa acutangula* (L.) Roxb.] for identifying better parents and hybrids

37.	**Authors**	Kalieswari K[1*], Kanhaiya Singh[1], Jai Prakash[1] and Vignesh M[2]
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	Title	Nutritional Profiling and Antioxidant Activity of Carotenoids in Papaya (*Carica papaya* L.) Hybrids

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	Title	Impact of genotype innovation on physiological parameters of *ber* (*Ziziphus mauritiana* Lamk.) in the Awadh region

40.	**Authors**	Pratibha Dogra*, Deepa Sharma, Balbir S Dogra and Ankita Sharma
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	Title	Heterosis and combining ability studies in tomato (*Solanum lycopersicum* L.)

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	Title	Comparative studies on stigma receptivity, pollen viability and seed setting in parental lines of pearl millet as affected by different seasons

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