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Strategy for

Harnessing Hybrid Technology for Enhanced Crop Productivity

Policy Brief

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ACSEN Agriscience
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Preamble

Global food insecurity concerns have lately been deepening unabated on account of economic inequality, poverty, climate change, economic slowdown and political conflicts. The shocks of the COVID 19 epidemic in 2019-20 and the Russia-Ukraine and Israel-Palestine war going on since early 2022 and 2023, respectively, greatly intensified these concerns by severely disrupting the global food supply chain. These incidents threaten food security with strong implications on achieving sustainable development goals (SDGs), especially to reduce poverty and end hunger, including all forms of malnutrition, by 2030. According to the Food and Agricultural Organization of the United Nations (FAO), the global population is estimated to reach 8.19 billion by 2025 and approximately 8.55 billion by the end of 2030. Further, global food and nutritional needs are diversifying due to overall economic development and changing food habits. This would require greater emphasis on improving crop productivity and the production, and providing access to diversified foods with better nutritional quality.

Among various available options, hybrid technology has tremendous potential for genetic enhancement of yield, nutritional quality, resistance/ tolerance to biotic/abiotic stresses, adaptation to climate change, etc. Hybrid technology, further aided by genomics-assisted selection, genetic engineering, genome/gene editing, precise phenotyping, and doubled haploid (DH) technology, etc. can significantly address the present and future food and nutritional needs of the burgeoning population in the country.

The historical success of hybrid crops, particularly in maize, pearl millet, cotton and a few other staple crops in India, underscores the potential of hybrid technology in transforming agricultural productivity. The cultivation of hybrids in maize started on a large scale in the 1930s in the USA. Because of its superiority over open-pollinated varieties, hybrids spread fast across the world after the second world war. In India, the first systematic hybrid breeding program also 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, many 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 the late 1980s under a unique hybrid breeding program initiated in a mission mode on nine crops, including maize and rice. As a result, the first single-cross maize hybrid was released in 1995, followed by many others. These hybrids, besides those introduced by multinational seed companies, helped in the increase of area (~10 mha) and productivity (from 1.0 to 3.5 t/ha) and production (37.5 mt) of maize with an annual growth rate of >4.0 per cent over the previous two decades. Similarly, the high rate of adoption of pearl millet hybrids in arid and drier semi-arid regions of India especially in western India dispelled the myth that hybrids are more suited to favourable environments. The hybrid adoption led to more than 4.5 per cent growth in pearl millet productivity in the last two decades. This strongly supports the case for scaling hybrid technology in rainfed areas.

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). India has also made great strides in hybrid breeding in other crops, including rice, safflower, tomato, cauliflower, cabbage, muskmelon, watermelon, brinjal, chilly, etc. Hybrid pearl millet and *kharif* sorghum initially created an impact but later had a setback due to the incidence of downy mildew and grain mold, respectively. However, plant breeders overcame these problems by developing new hybrids with good resistance/tolerance for both biotic and abiotic stresses.

It is now well established that hybrid technology can increase productivity significantly, and the farmers are happy to embrace it. However, the maximum potential of hybrid technology is yet to be realized in various foodgrain and vegetable crops as the area under hybrid varieties 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 reflects an excellent opportunity to harness the potential of hybrid technology by adopting a well-planned research and development (R&D) strategy at the national level.

With the implementation of the New Seed Policy in 1988, the bulk import of quality hybrid seeds was permitted. Also with enactment of the Protection of Plant Varieties and Farmers Rights Act (PPV&FRA) in 2001 by the Government of India, the intellectual property rights (IPRs) got strengthened. With these policy measures, adopting the cultivation of hybrids of different crops got real impetus, leading to faster growth in both the public and private seed sectors.

This Policy Brief highlights the important role of hybrid technology for enhancing crop productivity critical for our food and nutrition security. It also includes the specific recommendations for harnessing hybrid technology to accelerate crop productivity.

Current Challenges

Despite significant potential, faster adoption of improved crop hybrids is still facing several constraints.

One significant issue is the limited access to seeds of hybrid varieties, particularly for small-scale farmers, owing to the higher costs associated with their production. Although, seed costs average only 3-7 per cent of the total input costs, the financial constraints of small and marginal farmers (constituting 86% of the agricultural population in India) can make even this relatively small percentage prohibitive. Inadequate agri-input distribution networks, especially in remote areas, exacerbate this problem, limiting the reach of hybrid technology. Further hampering progress are research gaps that need to be addressed to broaden the scope of hybrid seed development beyond just yield. There is a pressing need to incorporate nutritional quality and climate resilience into new hybrids to combat the effects of climate change such as drought, heat stress, and flooding. Additionally, the rapid evolution of insect-pest and disease scenarios necessitates the development of resistant hybrids to minimize chemical interventions and promote sustainable agricultural practices.

Weak enforcement of intellectual property rights (IPR) also poses a significant barrier, discouraging investment from both public and private sectors. Seed piracy and unauthorized production undermine the economic viability of developing and distributing high-quality hybrid seeds. The absence of robust IPR protection hinders innovation and the development of new varieties with improved genetic architecture. Policy barriers further impede the adoption of hybrid technology. These include insufficient support for research and development, lack of incentives for farmers to adopt hybrids, and complex seed certification and registration processes. Varied state-specific licensing requirements also create obstacles for the seed industry, which could be resolved through a harmonized One-Nation-One-License policy. Furthermore, difficulties in the adoption of genetic modification (GM) technology and issues such as no objection certificates (NOCs) from state governments add to costs and delays, hindering research and development.

Opportunities

Hybrid technology presents significant opportunities for enhancing agricultural productivity and ensuring food security. Increased yields are the primary benefit, as hybrid varieties consistently outperform traditional open-pollinated crop varieties. This technology allows farmers to maximize productivity on existing farmland, thereby, contributing to food security without necessitating the expansion of cultivated land. Moreover, hybrid breeding can improve nutritional quality, enhancing the protein, vitamin, and mineral content of crops. Greater focus on hybrid breeding is crucial in regions facing malnutrition, to address both food quantity and quality challenges. Additionally, hybrids can be developed with enhanced stress resilience, tolerating drought, heat, disease, and insect-pests, which is vital for adapting to climate change. By reducing reliance on chemical inputs, these resilient varieties promote the use of sustainable agricultural practices. The adoption of hybrid technology also supports sustainable agriculture by increasing yields on existing farmland and minimizing the need for deforestation or habitat conversion. This approach helps preserve biodiversity and ecosystem services while improving soil health over time. Overall, hybrid technology not only boosts productivity but also aligns with SDGs related to food security and nutrition.

Some Past Successes

Maize is the most successful example of exploitation of heterosis for increasing productivity at the global level. In India, 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, resulting in an increased 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. Despite adopting single-cross hybrid cultivars, there is still not only wide variation in maize productivity in the country but also a substantial gap between average productivity at the global level (5.75 t/ha) compared to that in India (3.44 t/ha).

The strategy of breeding high-yielding disease-resistant hybrids of pearl millet has led to an increase in yield from 303 kg/ha to 1,219 kg/ha between the year 1960 to 2020.

Hybrid rice technology is an extremely promising option for boosting productivity by approximately 15-20 per cent that of pure line varieties of rice. Over the decades of rigorous research, Dr Yuan Long Ping, the father of hybrid rice, was the first to develop male sterility, which enabled exploitation of heterosis in rice in 1975 in China. Through hybrid rice technology, covering almost 50 per cent of the area (about 15.0 mha), China has been harvesting 15 mt of extra rice annually over the past four decades, resulting one ton/ha additional yield. India, in collaboration with the International Rice Research Institute (IRRI), initiated systematic hybrid rice research in 1989, and became the second country in the world to cultivate hybrid rice commercially. The hybrid rice adoption area covered in the past three decades has not yet exceeded to 4.0 mha, which is mostly the rainfed upland rice in eastern India. Unlike China, hybrid rice technology in India has yet to make significant impact in the irrigated areas. It would require extensive investment and strong commitment of researchers to develop appropriate rice hybrids and economically viable hybrid seed production technology engaging both public and private institutions.

The introduction of *Bt* cotton hybrids – Bollgard I in 2002 and Bollgard II in 2006 – marked a turning point for India's cotton sector, which had been struggling with stagnating production and low yields. Between 2001-02 and 2022-23, the area under cotton cultivation increased significantly from 8.5 mha to 12.92 mha. Coinciding with this expansion, the average cotton yield in India increased from 278 kg/ha in 2001-02 to 443 kg/ha in 2022-23. By 2024, *Bt* cotton hybrids accounted for 96 per cent of the total cotton area, a remarkable increase from 45 per cent in 2001. This shift highlights the pivotal role of hybrid and *Bt* technology in revitalizing India's cotton industry.

About the Symposium

To address the challenges and harness the opportunities for increased hybrid adoption, a 3-day *National Symposium on Hybrid Technology for Enhanced Crop Productivity* (NSHT), was organized at the National Agriculture Science Complex (NASC), Pusa Campus, New Delhi, on 8-10 January 2025 by the Trust for Advancement of Agricultural Sciences (TAAS) in collaboration with the Indian Council of Agricultural Research (ICAR) and CGIAR Institutes, namely, the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), International Maize and Wheat Improvement Centre (CIMMYT), the International Rice Research Institute (IRRI), and the Indian Society of Plant Genetic Resources (ISPGR), with sponsorship of 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 (P) Ltd. The Symposium was inaugurated by Dr PK Mishra, Principal Secretary to the Prime Minister, and the inaugural session was chaired by Padma Bhushan awardee Dr RS Paroda, Chairman, TAAS and Former Secretary, Department of Agricultural Research and Education (DARE), and Former Director General, ICAR, New Delhi. The Symposium had six technical sessions, two evening lecture sessions, a panel discussion on the Way Forward, and a concluding session. In all, 32 keynote and invited lectures, two evening lectures, 20 rapid oral presentations and 51 poster presentations were made. The Symposium was attended by 274 participants (175 in-person and 99 virtually), representing researchers/ breeders from the ICAR institutes, State Agricultural Universities (SAUs), CGIAR Centers, policymakers, seed sector representatives and students.

The objectives of the Symposium were to: (i) understand the current status of hybrid research in various crops; (ii) discuss current scientific and policy constraints in scaling hybrid breeding and seed production for increased productivity; (iii) foster closer public-private partnership for promoting hybrid breeding and seed production; (iv) develop strategies and the Way Forward for accelerating adoption of hybrid technology on a large scale in the national interest.

The expected outcomes of the symposium included: (i) identification of key constraints to scaling hybrid breeding; (ii) assessment of molecular tools and modern innovations for accelerating hybrid breeding; (iii) a clear understanding of the economic and social benefits of using hybrid technology; (iv) a developed strategy for strengthening public-private partnerships; and (v) recommendations for enabling policies to strengthen hybrid R&D and improve crop productivity and production.

The Symposium provided a neutral platform for discussing existing challenges associated with faster adoption of hybrid technology and how to harness the existing potential of hybrid technology in the greater national interests.

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 pigeon pea.

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 $<(\sim 120$ days) and pearl millet hybrids ($\sim$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.

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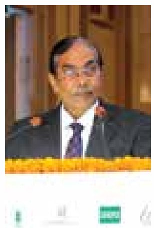
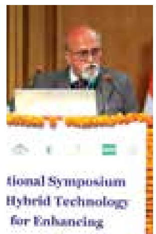





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