



National Symposium on Harnessing PGR of Peninsular India (NSPPI) From Biodiversity Hotspot to Sustainable Bioresource Hub

Souvenir

September 17-19, 2026

Organizers



Indian Society of Plant
Genetic Resources (ISPGR)
New Delhi



ICAR-Indian Institute of
Horticultural Research
(ICAR-IIHR) Bengaluru



Trust for Advancement of
Agricultural Sciences (TAAS)
New Delhi

Co - Organizers



Protection of Plant Varieties and
Farmers Rights Authority (PPV&FRA)
New Delhi



Society for Promotion
of Horticulture (SPH)
Bengaluru



Alliance of Bioversity
International and CIAT



University of
Agricultural Sciences (UAS)
Bengaluru



University of
Horticultural Sciences (UHS)
Bagalkot



International Crops Research
Institute for the Semi-Arid
Tropics (ICRISAT)
Patancheru, Telangana

**Venue: ICAR-Indian Institute of Horticultural Research
Hesaraghatta, Bengaluru**

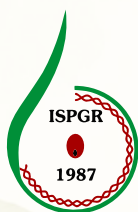
National Symposium on Harnessing PGR of Peninsular India (NSPPI)

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September 17-19, 2026

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PREFACE

It gives us immense pleasure to present the Souvenir of the National Symposium on *Harnessing Plant Genetic Resources of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI–2026)*, being held from 17–19 September 2026 at ICAR–Indian Institute of Horticultural Research, Bengaluru.

Peninsular India is endowed with remarkable biological and agricultural diversity, shaped by its varied landscapes, agro-ecological conditions, farming traditions and rich reservoir of indigenous knowledge. This diversity represents not only an invaluable heritage but also a significant resource for addressing contemporary challenges related to climate change, food and nutritional security, sustainable agriculture and emerging bioeconomies. The symposium provides an important forum for bringing together scientific knowledge, institutional experience, policy perspectives and community insights towards realizing the potential of these resources.

NSPPI–2026 brings together researchers, academicians, students, policy makers, practitioners, farmers, entrepreneurs and other stakeholders to exchange ideas on the discovery, conservation, characterization and responsible utilization of plant genetic resources. The deliberations encompass diverse dimensions, including genetic resource conservation and management, governance and access and benefit sharing, biosecurity, genomics and digital technologies, climate resilience, nutrition, innovation, value addition and livelihood development.

The Souvenir captures the spirit of this national gathering and provides a glimpse of the people, institutions, ideas and activities that have come together to make NSPPI–2026 possible. More than a scientific record, it reflects the collective commitment of the plant genetic resources community towards transforming the rich biodiversity of Peninsular India into a sustainable and shared resource for the future.

We hope that the symposium will encourage new partnerships, stimulate interdisciplinary research and strengthen the linkages between conservation and utilization. Above all, we hope the interactions and ideas emerging from NSPPI–2026 will contribute to ensuring that India's plant genetic heritage remains conserved, accessible and meaningfully utilized for generations to come.

- Core Organizing Committee
NSPPI–2026

ACKNOWLEDGEMENT

The successful realization of NSPPI-2026 has been made possible through the combined commitment, encouragement and cooperation of a large number of institutions and individuals. We gratefully place on record our appreciation to everyone whose contribution, whether through guidance, resources, scientific inputs or organizational support, has helped shape this symposium.

We express our sincere gratitude to the leadership of the Indian Council of Agricultural Research (ICAR), Indian Society of Plant Genetic Resources (ISPGR), ICAR–Indian Institute of Horticultural Research (ICAR–IIHR) and Trust for Advancement of Agricultural Sciences (TAAS) for their encouragement and institutional support.

Our deepest appreciation is extended to our Chief Patrons: Padma Bhushan Dr. R.S. Paroda, President, ISPGR and Chairman, TAAS, New Delhi; Dr. Mangi Lal Jat, Secretary, DARE and Director General, ICAR, New Delhi; and Dr. T. Mohapatra, Chairperson, Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), New Delhi. Their continued encouragement and vision have been a source of strength in bringing this national initiative to fruition.

We gratefully acknowledge the support of our Patrons—Dr. Sanjay Kumar Singh, Deputy Director General (Horticultural Sciences), ICAR, New Delhi; Dr. Devendra Kumar Yadava, Deputy Director General (Crop Sciences), ICAR, New Delhi; Dr. S.V. Suresha, Vice Chancellor, University of Agricultural Sciences, Bengaluru; and Dr. Vishnuvardhana, Vice Chancellor, University of Horticultural Sciences, Bagalkot.

We sincerely thank our Co-organizers – Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), New Delhi; Alliance of Bioversity International and CIAT, India Office, New Delhi; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad. Society for Promotion of Horticulture (SPH), Bengaluru; University of Agricultural Sciences (UAS), Bengaluru and University of Horticultural Sciences (UHS), Bagalkot for their support and valuable cooperation towards the successful organization of NSPPI-2026.

We specifically acknowledge and express our sincere gratitude for the financial support extended by the Indian Council of Agricultural Research (ICAR), New Delhi; Indian Society of Plant Genetic Resources (ISPGR), New Delhi; Trust for Advancement of Agricultural Sciences (TAAS), New Delhi; Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), New Delhi;



Alliance of Bioversity International and CIAT, India Office, New Delhi and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad.

Our special appreciation goes to Dr. T.K. Behera, Director, ICAR-IIHR, Bengaluru, for extending the facilities of the Institute and for his constant encouragement and support. We also acknowledge Dr. R.C. Agrawal and Dr. R.K. Tyagi, Vice Presidents, and Dr. Anuradha Agrawal, General Secretary, ISPGR, New Delhi, for their guidance and cooperation.

We gratefully recognize the dedicated contributions of Dr. Sherry Rachel Jacob, Organizing Secretary, NSPPI-2026 and Joint Secretary, ISPGR; Dr. ES Rao, OIC, PME Cell, IIHR and Organizing Secretary, NSPPI-2026; Dr. M.R. Rohini, Co-organizing Secretary, NSPPI-2026 and Councillor (SZ), ISPGR; Dr. Smitha G.R., PS, ICAR-IIHR and Co-Organizing Secretary, NSPPI; Dr. K. Pradheep, OIC, ICAR-NBPGR Regional Station, Thrissur; N. Sivaraj, Councillor (SZ), ISPGR, New Delhi; Dr. Joseph John, former OIC, ICAR-NBPGR Regional Station, Thrissur and Dr. Kuldeep Tripathi, Treasurer, ISPGR. Their scientific inputs, coordination and sustained involvement have contributed substantially to the development and execution of the symposium programme.

We extend our warm appreciation to all the invited speakers and experts who have generously contributed their knowledge and experience. Their perspectives and scholarly contributions have added depth and diversity to the scientific discourse. We also acknowledge with gratitude the Local Organizing Committee of ICAR-IIHR, whose tireless efforts, coordination and teamwork have supported the smooth conduct of the symposium. Our thanks extend equally to the editorial and compilation team, as well as the administrative, technical and communication personnel who worked behind the scenes in preparing the symposium materials, coordinating with participants and attending to the many details involved in organizing this event.

The enthusiastic participation of more than 250 delegates representing ICAR institutes, PPV & FRA, Alliance for Bioversity International and CIAT, ICRISAT, State Agricultural Universities, CSIR institutions, private organizations, farmers, entrepreneurs and other stakeholder groups is deeply appreciated. We thank all authors, delegates and contributors whose scientific engagement and participation have given NSPPI-2026 its breadth and vibrancy.

Finally, we acknowledge the support of every individual, institution, sponsoring agency and well-wisher associated with NSPPI-2026. The coming together of such a diverse community around the shared purpose of conserving and sustainably utilizing plant genetic resources is, in itself, a significant achievement. We sincerely hope that the relationships established and ideas exchanged during the symposium will continue to inspire meaningful collaboration and action well beyond these three days.

**- Editors
NSPPI-2026**



ಥಾವರ್ಚಂದ್ ಗೆಹ್ಲೋಟ್
थावरचंद गेहलोत
THAAWARCHAND GEHLOT
Governor of Karnataka

No. GOV/KAR/MSG/258/2026

MESSAGE

I am delighted to know that the Indian Society of Plant Genetic Resources (ISPGR), in association with the ICAR–Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, and the Trust for Advancement of Agricultural Sciences (TAAS), is organizing the National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI) during 17–19 September 2026 at ICAR-IIHR, Bengaluru.

Peninsular India, particularly the Western Ghats, is one of the world's richest repositories of plant diversity and genetic wealth. Conserving and sustainably utilizing these invaluable resources is essential for ensuring food and nutritional security, enhancing climate resilience, protecting ecological balance, and promoting sustainable agricultural development. Scientific innovations, coupled with effective conservation strategies, will play a pivotal role in safeguarding this natural heritage for future generations.

The interactions and recommendations emerging from the symposium will contribute significantly towards strengthening India's biodiversity conservation efforts and advancing sustainable agricultural development. I extend my warm greetings and best wishes to the organizers, participants and delegates for the grand success of the symposium.


15.9.26
(Thaawarchand Gehlot)

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MESSAGE

I It gives me immense pleasure to welcome you to the National Symposium on Harnessing Plant Genetic Resources of Peninsular India: From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI), being organized jointly by the Indian Society of Plant Genetic Resources (ISPGR), ICAR-IIHR, PVPFRA, BI and CIAT Alliance and the Trust for Advancement of Agricultural Sciences (TAAS) at the ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru on 17-19 September 2026.

The symposium is plant genetic resources constitute the very foundation of sustainable agriculture, food and nutritional security, and climate-resilient crop improvement. Peninsular India, encompassing the globally renowned Western Ghats biodiversity hotspot and diverse agro-ecological regions, is endowed with an extraordinary wealth of genetic diversity. This invaluable natural heritage provides immense opportunities for developing resilient, productive, and nutritious crop varieties capable of addressing the challenges posed by climate change, emerging pests and diseases, and evolving consumer needs. Conserving, characterizing, and effectively utilizing these resources is therefore vital for ensuring sustainable agricultural development and the well-being of future generations.

The theme of this symposium is forward-looking and it highlights the need to transform our rich biological diversity into sustainable bioresources through scientific innovation, advanced technologies, value addition, and enabling policy support. The technical sessions have been thoughtfully designed to showcase recent advances in plant genetic resources research, genomics and digital technologies, conservation strategies, pre-breeding, and innovative approaches for enhancing the utilization of indigenous genetic diversity in crop improvement. The symposium also provides an excellent opportunity for scientists, breeders, policymakers, students, and other stakeholders to exchange knowledge, strengthen collaborations, and develop a shared vision for the future of India's plant genetic resources programme.

I am confident that the deliberations and recommendations emerging from this symposium will help shape future research priorities, strengthen conservation and sustainable utilization strategies, and contribute significantly to achieving resilient, climate-smart, and nutrition-sensitive agricultural systems.

On behalf of ISPGR and TAAS, I express my sincere appreciation to ICAR-IIHR, the collaborating institutions, distinguished speakers, sponsors, and the organizing committees for their dedicated efforts in organizing this important event. I extend a warm welcome to all delegates and wish you stimulating scientific deliberations, productive networking, and a memorable stay in Bengaluru.

I wish the symposium a great success and I am confident that its outcomes will make a lasting contribution to conserving and harnessing India's invaluable plant genetic resources for sustainable agricultural growth, enhanced food and nutritional security, and the realization of a resilient and prosperous Viksit Bharat.

RS Paroda

(Padma Bhushan Awardee)

Chairman, TAAS and

Former Secretary, DARE & DG, ICAR

त्रिलोचन महापात्र

अध्यक्ष

पौधा किस्म और कृषक अधिकार संरक्षण प्राधिकरण

(संसद के अधिनियम द्वारा निर्मित सांविधिक निकाय)

कृषि एवं किसान कल्याण मंत्रालय

भारत सरकार



सत्यमेव जयते

Trilochan Mohapatra

Chairperson

Protection of Plant Varieties and Farmers' Rights Authority

(A Statutory body created by an Act of Parliament)

Ministry of Agriculture and Farmers Welfare

Government of India



Message

It is a matter of great pleasure that the National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI) is being organized during 17–19 September 2026 at ICAR–Indian Institute of Horticultural Research (ICAR–IIHR), Bengaluru, jointly by the Indian Society of Plant Genetic Resources (ISPGR), ICAR–IIHR, the Trust for Advancement of Agricultural Sciences (TAAS), and partnering State Agricultural Universities.

Plant genetic resources and the associated traditional knowledge systems are vital national assets that underpin agricultural resilience, food security, and sustainable development. India, being one of the world's foremost centers of crop diversity, carries a special responsibility in conserving, documenting, and sustainably utilizing this biological wealth. In this context, the role of robust policy frameworks, particularly those related to plant variety protection, farmers' rights, and biodiversity conservation, becomes extremely significant in ensuring both innovation and equity in the agricultural system.

The Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) has been playing a crucial role in strengthening the plant variety protection regime in the country, safeguarding the rights of farmers and breeders, and encouraging the development of new and improved crop varieties. Its efforts in promoting registration, awareness, and institutional linkages have significantly contributed to a balanced system that supports innovation while protecting traditional knowledge and genetic resources.

This symposium will provide a meaningful platform for scientists, policymakers, breeders, and other stakeholders to deliberate on critical issues related to plant genetic resources, their conservation, and their legal and policy frameworks. Such interactions are essential for aligning scientific progress with regulatory systems that support sustainable agricultural development.

As Chairperson of PPV&FRA, it is a privilege to note this important initiative. I commend the organizers—ISPGR, ICAR–IIHR, TAAS, and all collaborating institutions—for convening this timely and relevant symposium.

I extend my best wishes for the success of the event and am confident that the deliberations will contribute to strengthening India's plant variety protection system and advancing the sustainable use of plant genetic resources for the benefit of farmers and the nation.

Date: 20th July, 2026


(T. Mohapatra)

प्लांट अथॉरिटी भवन, एन.ए.एस.सी. कॉम्प्लेक्स के निकट, टोडापुर के सामने, नई दिल्ली-110012 (भारत)

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डॉ. एम.एल. जाट

DR. M. L. JAT

सचिव (डेयर) एवं महानिदेशक (आईसीएआर)

**Secretary (DARE) &
Director General (ICAR)**

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भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली-110 001

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INDIAN COUNCIL OF AGRICULTURAL RESEARCH (ICAR)
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MESSAGE

It is a matter of great pleasure to know that the Indian Society of Plant Genetic Resources (ISPGR), in collaboration with ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, and the Trust for Advancement of Agricultural Sciences (TAAS), is organizing the **National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI)** during 17–19 September 2026 at ICAR-IIHR, Bengaluru.

Plant genetic resources are the biological foundation and a vital national asset. Their systematic conservation and effective utilization are, therefore, central to food and nutritional security of India and to the long-term sustainability of its agricultural systems. Peninsular India is endowed with exceptional biological and agricultural diversity, shaped by its varied agroecologies, rich farming traditions and generations of farmer-led selection and conservation. However, this valuable diversity is also under increasing pressure from changing land use, climate variability and the erosion of traditional production systems.

The symposium is both timely and highly relevant in drawing attention not only to the conservation of these resources, but also to their characterization, evaluation, pre-breeding, value addition and responsible use for the benefit of farmers and society. Building on this rich diversity, ICAR has played a pivotal role in the collection, conservation, characterization and utilization of the country's plant genetic resources through its institutes, gene banks and research partnerships. Integrating genomics, phenomics, digital technologies and traditional knowledge will further accelerate their effective and equitable use.

I am confident that the symposium will provide a valuable platform for scientists, policymakers, academicians, development organizations and other stakeholders to exchange knowledge and develop practical strategies for transforming biodiversity wealth of Peninsular India into a sustainable bioresource base. Its deliberations and recommendations will further strengthen national efforts towards promoting biodiversity conservation, accelerating agricultural innovation, and supporting the vision of a resilient, sustainable and farmer-centric agricultural sector.

I congratulate ISPGR, ICAR-IIHR, TAAS, Bioversity International and all collaborating organizations for this important initiative. I extend my best wishes to the organizers and participants for a highly productive and successful symposium.

**Dated the 3rd August, 2026
New Delhi**

(M. L. Jat)



डॉ. देवेन्द्र कुमार यादव
उप महानिदेशक (फसल विज्ञान)
Dr. Devendra Kumar Yadava
Deputy Director General (Corp Science)

भारतीय कृषि अनुसंधान परिषद
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Indian Council of Agricultural Research
Department of Agricultural Research & Education
Ministry of Agriculture and Farmers Welfare
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MESSAGE

I am delighted to note that the Indian Society of Plant Genetic Resources (ISPGR), in collaboration with ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, and the Trust for Advancement of Agricultural Sciences (TAAS), is organizing the **National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI)** from **17–19 September 2026** at ICAR-IIHR, Bengaluru.

Plant genetic resources are essential for crop improvement, climate resilience, food and nutritional security. The agro-ecological landscapes of Peninsular India host a rich repository of genetic variability across cultivated crops, wild relatives, and indigenous landraces. These resources offer immense opportunities to develop high-yielding, stress-resistant, and nutrition-rich crop varieties.

The theme of this symposium is highly relevant today. It emphasizes conserving and harnessing plant genetic resources to build resilient, sustainable cropping systems. I am confident these scientific deliberations will encourage knowledge exchange, strengthen interdisciplinary collaborations, and yield innovative strategies for crop breeding. The symposium's outcomes will modernize crop breeding, protect agricultural biodiversity, and accelerate India's transition to climate-smart farming.

I congratulate ISPGR, ICAR-IIHR, TAAS, and all partner organizations for organizing this milestone symposium. I extend my warmest wishes to the organizers, speakers, and delegates for a highly successful event that will successfully define future research directions in crop science.

Dated: July 20, 2026
Place: New Delhi

(Handwritten signature)
24/07/2026
(D. K. Yadava)

E-mail : ddgcs.icar@nic.in, dkygenet@gmail.com Phone : 91-11-23382545, 23046560, Mobile : 9868537641

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Prof. S.K. Singh
FNAAS, FIAHS, FDBT
Deputy Director General (Horticultural Science)



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Message

It gives me immense pleasure to know that the Indian Society of Plant Genetic Resources (ISPGR), in collaboration with ICAR–Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, and the Trust for Advancement of Agricultural Sciences (TAAS), is organizing the **National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI)** during **17–19 September 2026** at ICAR-IIHR, Bengaluru.

Horticultural crops contribute significantly to nutritional security, livelihood enhancement and agricultural diversification. The rich genetic diversity of fruits, vegetables, spices, plantation crops, ornamentals and medicinal plants found in Peninsular India represents an invaluable national asset. Systematic conservation, characterization and sustainable utilization of these plant genetic resources are fundamental to developing climate-resilient, high-yielding and quality cultivars capable of addressing emerging challenges posed by climate change, evolving pests and diseases, and changing consumer preferences.

The theme of the symposium aptly underscores the need to harness the immense biodiversity of Peninsular India for sustainable bioresource development. I am confident that the deliberations will facilitate meaningful exchange of scientific knowledge, foster interdisciplinary collaborations, and identify innovative approaches for strengthening conservation and enhancing the utilization of plant genetic resources, particularly in the horticultural sector. The recommendations emerging from this symposium will provide valuable inputs for research, policy and technology development aimed at ensuring sustainable growth of Indian horticulture.

I congratulate ISPGR, ICAR-IIHR, TAAS and all the collaborating organizations for organizing this timely scientific event. I extend my best wishes to the organizers, speakers and delegates for the grand success of the symposium and hope that its outcomes will significantly contribute to strengthening India's horticultural research and biodiversity conservation efforts.


(Sanjay Kumar Singh)

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Dr. S.V. SURESHA
Vice-Chancellor

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MESSAGE

It gives me immense pleasure to learn that the National Symposium on *Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI)* is being organized during 17-19 September 2026 at ICAR–Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, jointly by the Indian Society of Plant Genetic Resources (ISPGR), ICAR-IIHR, the Trust for Advancement of Agricultural Sciences (TAAS), and the collaborating State Agricultural Universities.

Plant genetic resources form the foundation of sustainable agriculture, food and nutritional security, and climate resilience. Peninsular India, endowed with extraordinary biological diversity across varied agro-climatic regions and globally significant ecosystems such as the Western Ghats, represents an invaluable reservoir of genetic wealth. Scientific conservation, characterization, and sustainable utilization of these resources are vital for developing resilient crop varieties, safeguarding biodiversity, and ensuring agricultural sustainability in the face of climate change, natural resource degradation, and evolving production challenges.

State Agricultural Universities have made significant contributions to the conservation of indigenous germplasm, crop improvement, seed system development, and capacity building, thereby addressing both regional and national agricultural priorities. I am confident that this **symposium will serve as an important platform for scientists, academicians, students, policymakers, and other stakeholders to exchange knowledge**, foster interdisciplinary collaborations, and formulate innovative strategies for the effective conservation, enhancement, and sustainable utilization of plant genetic resources.

As a **Co-organizer, the University of Agricultural Sciences, Bangalore**, is privileged to be associated with this prestigious scientific event. **I congratulate the Indian Society of Plant Genetic Resources (ISPGR), ICAR-IIHR, TAAS**, and all partnering institutions for organizing this timely and significant symposium. I extend my warm welcome to all delegates and wish the symposium every success.

I am confident that the deliberations and recommendations emerging from this symposium will make a lasting contribution to strengthening research, innovation, conservation, and policy interventions for the sustainable management of India's invaluable plant genetic resources, thereby supporting the nation's vision of resilient and sustainable agricultural development.


(S. V. Suresha)

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MESSAGE

I am delighted to learn that the **National Symposium on “Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub” (NSPPI)** is being held from **17–19 September 2026** at the **ICAR–Indian Institute of Horticultural Research (ICAR–IIHR), Bengaluru**. This significant scientific event is being jointly organized by the **Indian Society of Plant Genetic Resources (ISPGR), ICAR–IIHR, and the Trust for Advancement of Agricultural Sciences (TAAS)** and partnering State Agricultural Universities.

Plant genetic resources constitute the foundation of sustainable agriculture, crop improvement, ecological resilience, and nutritional security. Peninsular India, endowed with exceptional agro-ecological diversity and globally significant ecosystems such as the Western Ghats, represents a rich reservoir of genetic wealth with immense potential for crop improvement, climate resilience, and sustainable bioresource utilization. However, the growing challenges posed by climate change, environmental degradation, depletion of natural resources, and changing agricultural needs underscore the urgent need for systematic exploration, characterization, conservation, sustainable utilization and value addition of these invaluable resources. In this endeavour, State Agricultural Universities have a pivotal role to play in conserving indigenous germplasm, characterizing and utilizing genetic diversity, developing climate-resilient and high-performing crop varieties, advancing location-specific technologies, and nurturing scientific and human resources. Their efforts are instrumental in translating scientific knowledge and genetic wealth into practical innovations and field-level impact for the benefit of farmers and society.

I am pleased to note that this symposium will bring together eminent scientists, researchers, academicians, students, policymakers, and other stakeholders on a common platform to deliberate on emerging challenges, opportunities and innovations in the conservation and sustainable utilization of plant genetic resources. The exchange of scientific knowledge, experiences, and ideas during the symposium is expected to foster meaningful collaborations, strengthen research networks, and facilitate the development of actionable strategies for the effective management and utilization of plant genetic resources. As a co-organizing institution, the **University of Horticultural Sciences, Bagalkot**, feels privileged to be associated with this important academic and scientific endeavour. I sincerely appreciate the **ISPGR, ICAR–IIHR, TAAS** and all collaborating institutions for their concerted efforts in organizing this timely and significant symposium.

I extend my best wishes for the grand success of the **NSPPI–2026** and trust that the deliberations will lead to meaningful outcomes and contribute to strengthening research, conservation strategies, policy frameworks and sustainable utilization of plant genetic resources for the benefit of present and future generations.

With my best wishes for a fruitful and successful symposium.

Best Regards

Place: Bagalkot
Date: 27-07-2026

(VISHNUVARDHANA)
VICE-CHANCELLOR



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ICAR- Indian Institute of Horticultural Research

Hesaraghatta Lake Post, Bengaluru - 560089, Karnataka



ISO 9001 : 2015

ಡಾ. ತುಷಾರ್ ಕಾಂತಿ ಬೆಹೆರಾ
Dr. Tusar Kanti Behera
ನಿರ್ದೇಶಕ/Director



MESSAGE

It gives me immense pleasure to welcome all delegates, distinguished speakers, scientists, academicians, policymakers, students, and stakeholders to the National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI), being organized during 17–19 September 2026 at ICAR–Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru. The symposium is jointly organized by the Indian Society of Plant Genetic Resources (ISPGR), ICAR-IIHR, and the Trust for Advancement of Agricultural Sciences (TAAS).

Peninsular India is endowed with extraordinary plant diversity and encompasses unique agro-ecological regions, including the Western Ghats—one of the world's renowned biodiversity hotspots. This rich repository of plant genetic resources holds immense potential for developing climate-resilient, nutritionally enriched, and high-yielding crop varieties while promoting ecological sustainability. The scientific conservation, characterization, and sustainable utilization of these invaluable resources are essential for addressing the emerging challenges of food, nutritional, and environmental security in the face of climate change.

As one of the premier horticultural research institutes under the Indian Council of Agricultural Research, ICAR-IIHR is committed to advancing research, innovation, and capacity building for the sustainable development of Indian horticulture. We are privileged to host this national symposium, which will serve as a vibrant platform for deliberating on recent scientific advances, fostering interdisciplinary collaborations, and formulating strategies for the effective conservation and utilization of plant genetic resources. I am confident that the technical sessions and interactions among experts will generate valuable insights and strengthen our collective efforts towards sustainable agricultural development.

I sincerely appreciate the Indian Society of Plant Genetic Resources (ISPGR), the Trust for Advancement of Agricultural Sciences (TAAS), collaborating institutions, sponsoring organizations, members of the organizing committees, and all contributors for their dedicated efforts in making this symposium possible.

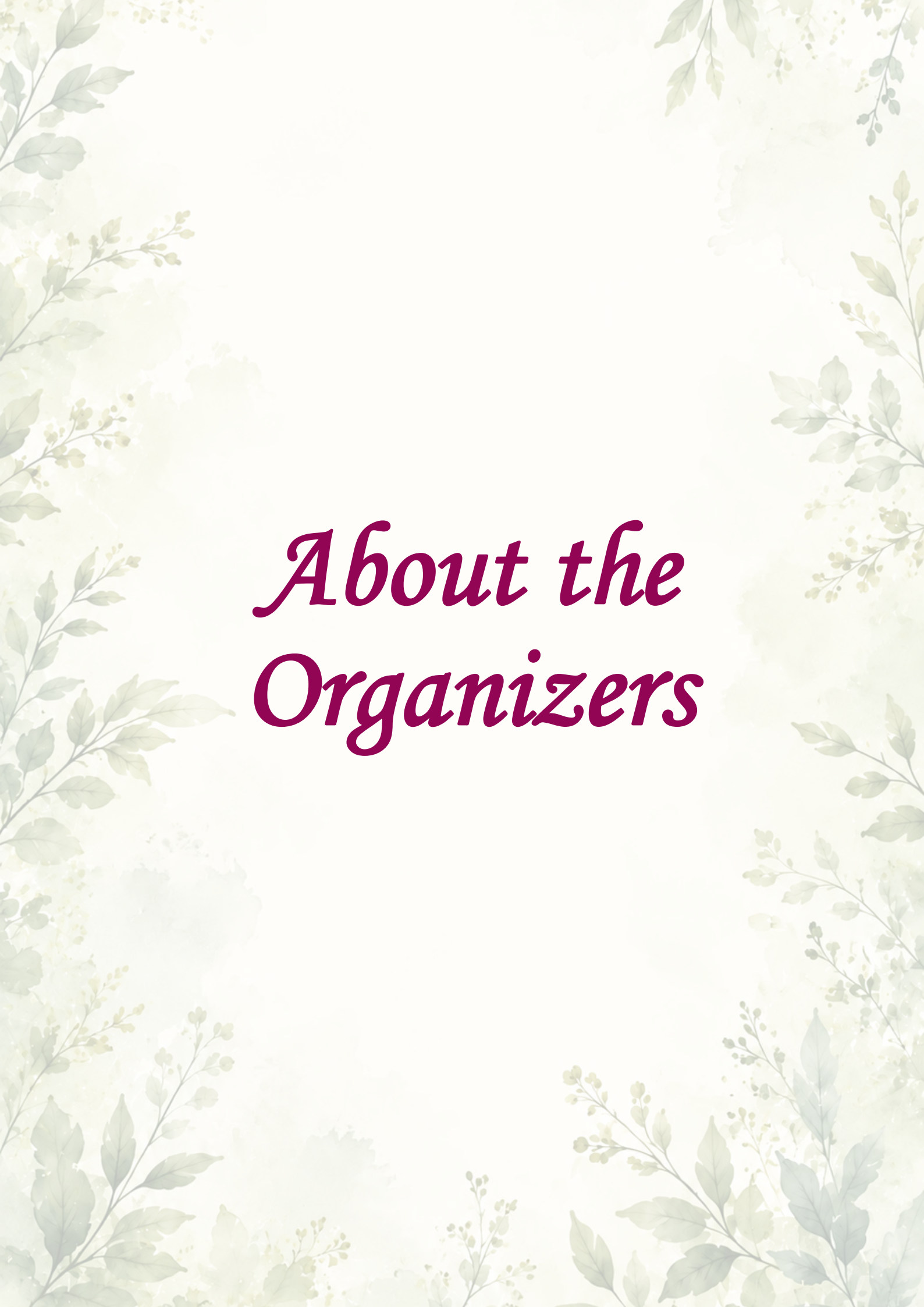
I extend my warmest welcome to all participants to Bengaluru and wish you a rewarding scientific experience, meaningful interactions, and a pleasant stay. I am confident that the deliberations and recommendations emerging from this symposium will make a significant contribution towards harnessing the rich plant genetic resources of Peninsular India for building a resilient, sustainable, and prosperous agricultural future.

I wish the National Symposium every success.

Dr. Tusar Kanti Behera,
Director, IIHR, Bengaluru

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A decorative border of green leaves and small yellow flowers frames the central text. The leaves are detailed with veins, and the flowers are small and clustered.

About the Organizers

INDIAN SOCIETY OF PLANT GENETIC RESOURCES (ISPGR)

The Indian Society of Plant Genetic Resources (ISPGR), New Delhi, was established in 1987 as a multidisciplinary scientific society dedicated to the study, conservation and sustainable utilization of plant genetic resources (PGR). The Society was founded by scientists of the National Bureau of Plant Genetic Resources (NBPGR) under the leadership of Dr R.S. Paroda, with the vision of bringing together researchers and stakeholders working across diverse dimensions of plant genetic resources.

ISPGR provides a national platform for scientific exchange, interdisciplinary interaction and informed discussion on issues concerning PGR. Its mandate encompasses exploration and collection, characterization and evaluation, conservation, utilization, exchange, quarantine, documentation and information management. The Society also promotes collaboration among scientists from diverse disciplines and contributes scientific perspectives to national and international policies and programmes related to plant genetic resources.

With its headquarters at ICAR–NBPGR, New Delhi, ISPGR has a membership of more than 1000, comprising life, ordinary, institutional, student and donor members from India and abroad. Through its scientific programmes, interactions and professional network, the Society continues to foster collaboration among researchers, institutions and other stakeholders engaged in PGR conservation and use.

An important contribution of ISPGR has been its role in advancing dialogue on agricultural biodiversity and plant genetic resources at national and international levels. The Society has provided platforms for discussion on emerging areas including access and benefit sharing, digital sequence information, climate adaptation, nutrition and sustainable use of agrobiodiversity. Its initiatives have also contributed to broader policy discussions and strengthened the visibility of PGR as a critical component of agricultural sustainability.

ISPGR recognizes excellence and sustained contributions to the field through a range of awards, including the Dr Harbhajan Singh Memorial Award, Dr S.K. Vasal Award for Efficient Use of PGR, Dr B.R. Barwale Award for Application/Excellence in PGR, Dr R.S. Paroda Young Scientist Award, Dr R.K. Arora Best Paper Award and Dr K.L. Mehra Memorial Award for the Best PGR Student. The Society also recognizes distinguished contributions through its Fellowship programme.

The Indian Journal of Plant Genetic Resources (IJPGR), the official publication of ISPGR, serves as an important platform for disseminating original research, reviews and information on

plant genetic resources. In addition to the journal, the Society brings out books, proceedings and other publications relevant to PGR research and management.

The Society is presently guided by its Executive Council for 2025–2027, with Dr R.S. Paroda as President; Dr R.C. Agrawal and Dr R.K. Tyagi as Vice Presidents; and Dr Anuradha Agrawal as General Secretary. The Executive Council, supported by its other office-bearers and zonal representatives, provides leadership for advancing the scientific, professional and policy-oriented activities of ISPGR.

ISPGR continues to serve the PGR community by facilitating scientific exchange, recognizing excellence, supporting policy-oriented discussions and promoting responsible management and utilization of plant genetic resources. As challenges to agricultural biodiversity continue to evolve, the Society remains committed to providing a multidisciplinary platform for knowledge, collaboration and collective action towards sustainable agriculture and food, nutrition and environmental security.

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TRUST FOR ADVANCEMENT OF AGRICULTURAL SCIENCES (TAAS)

The Trust for Advancement of Agricultural Sciences (TAAS) has its genesis in the 88th Session of Indian Science Congress held at IARI, New Delhi on 3-6 January 2001 under the presidency of Dr RS Paroda. The then Prime Minister, Shri Atal Bihari Vajpayee who was the Chief Guest exhorted in his inaugural speech, “Our goal to make India a leading nation in the world in the new century hinges critically on how successfully we take science to the people and create a stronger scientific temper in our society”. In response, the National Organizing Committee of the Congress decided to establish a neutral Think Tank, namely, TAAS which was established on 17 October 2002 with its Headquarters at IARI, New Delhi.

Vision

India becomes a prosperous nation through harnessing agricultural sciences while addressing concerns of poverty, hunger and malnutrition

Goal

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

Mission

Promoting growth and advancement of agriculture through science based policy advocacy, public awareness and effective research and development partnerships

Strategy

TAAS to act as a neutral Think Tank to debate on issues relating to strengthening agricultural research and innovation for development (ARI4D) and catalyse policy makers, research leaders and farmers for needed reorientation and strengthening of systems for faster scaling-up of innovations and growth of national agriculture.

Activities

- To act as a Think Tank to deliberate on key issues relating to agricultural research and innovation for development (ARI4D) and to influence policy decisions.
- To organize workshops, conferences, brainstorming sessions, seminars, policy dialogues and special lectures on emerging issues and new developments in agricultural sciences.
- To disseminate knowledge among stakeholders through publication of proceedings, strategy papers, policy briefs and success stories.
- To confer awards on the scientists and farmers of Indian and foreign origin for their outstanding contributions in the field of agriculture.
- To facilitate scientific interaction and partnerships among diverse stakeholders.

Major Achievements

- TAAS was instrumental in getting maize included in the National Food Security Mission (NFSM) to ensure increased maize production. TAAS has created greater awareness of soybean as a food crop and for use of soya milk and tofu, being rich in protein.
- For a single window clearance of regulatory processes for testing and release of GM crops, TAAS was the first to recommend the creation of Biotechnology Regulatory Authority of India (BRAI), and the draft of BRAI Bill - 2013 is under consideration for approval of the Parliament.
- On the recommendation of TAAS “Ranchi Declaration” was brought out which resulted in developing a national plan of action on management and conservation of farm animal genetic resources with special focus on valuable indigenous breeds and the establishment of a “National Mission on Livestock”.
- Through various expert consultations and dialogues, the stakeholders have been sensitized for diversification of agriculture in a “farming systems” mode; soil test based use of fertilizers; efficient use of water through micro-irrigation systems and laser levelling, and promotion of IPM through use of biopesticides.
- Considering the current challenge of motivating and attracting youth in agriculture (MAYA), TAAS through national and regional conferences has catalyzed the National Agricultural Research System (NARS) to initiate the program on attracting and retaining youth in agriculture (ARYA).
- Researchers, policy makers, and development officials have been sensitized through success stories to promote farmer led innovations, adopt cost-effective and sustainable regenerative agriculture (RA) and climate-smart agriculture.
- To strengthen public-private partnerships, using different PPP models and train enterprising farmers, especially women and youth, an Agriculture Innovation Fund has been created by the ICAR to scientifically validate new technologies that can reduce cost of inputs, and increase production and income of farmers by linking directly to markets.
- Based on recommendations of national conferences organized by TAAS, the government has initiated National Mission on Seeds (with emphasis on hybrid seeds), National Mission on Cotton, and approved the process for developing genome edited crop hybrids/varieties.
- UN Food Systems Summit had recognized TAAS as a vibrant neutral Policy Advocacy Think Tank and suggested the need for establishing similar Think Tanks in other developing countries for both policy advocacy and public awareness.
- The conference proceedings, strategy papers and success stories published by TAAS on diverse topics have drawn wide-spread attention of the farmers and other stakeholders to embrace new innovations around sustainable agriculture.

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ICAR–INDIAN INSTITUTE OF HORTICULTURAL RESEARCH

Six Decades of Research Contributions to the Development of Horticulture in India

ICAR–Indian Institute of Horticultural Research (ICAR–IIHR), Bengaluru, is a premier national institute of the Indian Council of Agricultural Research dedicated to advancing horticulture through basic, strategic, anticipatory and applied research. Its research portfolio encompasses fruits, vegetables, flowers, medicinal and aromatic plants, and mushrooms, with a focus on developing improved varieties, technologies and scientific solutions for a productive, sustainable and resilient horticulture sector.

Established on 5 September 1967 at ICAR Headquarters, New Delhi, the Institute was shifted to Hessaraghatta, Bengaluru, on 1 February 1968. Its main campus extends over approximately 263 hectares and serves as a major centre for horticultural research, technology development, training and dissemination. To strengthen its regional outreach, ICAR–IIHR has established Regional Experiment Stations at Chettalli, Karnataka, and Bhubaneswar, Odisha, along with Krishi Vigyan Kendras at Gonikoppal in Kodagu and Hirehalli in Tumakuru. The Institute also houses the Project Coordinating Cell of the All India Coordinated Research Project on Fruits.

Over the past six decades, ICAR–IIHR has made significant contributions to Indian horticulture through varietal improvement, crop management, plant health, post-harvest technologies, mechanization and value addition. The Institute undertakes research on 54 major horticultural crops, and its varieties and technologies are promoted under the registered trademark “ARKA”. More than 337 high-yielding and disease-resistant varieties and hybrids have been developed, covering vegetables, flowers, fruits and medicinal crops. These include several widely recognized technologies and varieties that have contributed to crop diversification, productivity enhancement and improved quality in horticultural production.

A major strength of ICAR–IIHR is its rich horticultural genetic resource base. As a National Active Germplasm Site (NAGS) for major horticultural crops, the Institute maintains 16,757 accessions comprising fruit, vegetable, flower, medicinal and mushroom germplasm. Additional collections of under-utilized vegetables and fruits are conserved at its regional stations at Bhubaneswar and Chettalli. This extensive repository provides an important foundation for conservation, characterization, research and utilization of horticultural genetic diversity.

The Institute has also developed strong systems for production and dissemination of quality seed and planting material. Through the Seed Village concept, farmers are involved in seed multiplication under scientific supervision, while an online seed portal and multiple ordering

channels facilitate wider access to IIHR-developed varieties and planting materials. In 2025, substantial quantities of vegetable and flower seeds and planting materials, medicinal crop planting material, mushroom spawn and fruit planting material were supplied to farmers across the country.

ICAR–IIHR has developed 155 innovative technologies covering areas such as nutrient management, microbial inputs, plant protection, farm mechanization, processing and protected cultivation. Several of these technologies have been transferred for commercial production and adopted on a large scale, demonstrating the Institute’s commitment to translating research into practical benefits for farmers and the horticultural industry.

Technology dissemination, commercialization and entrepreneurship form an important part of the Institute’s mandate. Its Agricultural Technology Information Centre (ATIC) provides a single-window platform for farmers, entrepreneurs and other stakeholders to access information, technologies, planting materials and technical guidance. The Institute conducts training programmes, field demonstrations, industry interactions and horticultural fairs to facilitate technology adoption. Its Institute Technology Management Unit and Agri-Business Incubation facility support commercialization and entrepreneurship, while BESST–HORT provides incubation and mentoring support to start-ups and enterprises based on horticultural technologies. As of March 2026, ICAR–IIHR had commercialized 157 technologies through 1,701 licensing agreements with 788 clients.

The Institute is expanding its research frontiers through emerging technologies and interdisciplinary approaches. Current initiatives include genome editing in horticultural crops, the Clean Plant Programme for disease-free planting material, drone-based precision horticulture, and research on natural farming. ICAR–IIHR also contributes to areas of national importance including seed and planting material systems, quarantine, food safety, biodiversity-based livelihoods and nutritional security. Its farmer-participatory initiatives have supported the identification, documentation and registration of farmers’ varieties, linking conservation of local biodiversity with livelihood and nutritional security.

The Institute houses specialized facilities and nationally accredited laboratories supporting research and services in food safety, residue analysis, honey quality, protected cultivation and other areas. It also undertakes capacity building and provides advanced research infrastructure for horticultural science. Since 2014, ICAR–IIHR has functioned as an Outreach Campus of ICAR–Indian Agricultural Research Institute (IARI), New Delhi, offering postgraduate education and research opportunities. The Institute currently offers Ph.D. and M.Sc. programmes in horticulture-related disciplines and has established academic and research collaborations with more than 50 national and international institutions.

Looking ahead, ICAR–IIHR is committed to developing horticultural solutions that address climate change, nutritional security, resource-use efficiency and emerging production challenges.



Conservation and characterization of indigenous germplasm, particularly landraces and wild relatives of fruit and vegetable crops, remain important priorities. The Institute is also pursuing approaches involving precision horticulture, climate-resilient varieties, advanced breeding, integrated pest management, post-harvest management, value addition and digital technologies. These efforts are aimed at strengthening horticulture as a source of nutrition, livelihood and sustainable agricultural growth.

With its rich germplasm resources, multidisciplinary research capabilities, strong technology development and dissemination systems, and extensive engagement with farmers, entrepreneurs and scientific institutions, ICAR–IIHR occupies a significant position in the development of Indian horticulture. Its mandate and activities closely align with the objectives of NSPPI–2026, particularly in advancing the conservation, characterization and sustainable utilization of plant genetic resources for a resilient and bioresource-rich future.

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THE PROTECTION OF PLANT VARIETIES AND FARMERS' RIGHTS AUTHORITY

In order to provide for the establishment of an effective system for the protection of plant varieties, the rights of farmers and plant breeders and to encourage the development of new varieties of plants, the Govt. of India enacted “The Protection of Plant Varieties and Farmers’ Rights Act, 2001” adopting a *sui generis* system. The Indian legislation has sufficient provisions to protect the plant varieties developed by breeders working in either private sector or in public sector breeding institutions, researchers and the farmers. To implement the provisions of the Act, the Government of India established the Protection of Plant Varieties and Farmers’ Rights Authority (PPVFRA) on 11th November, 2005.

General Functions of the PPVFR Authority

1. Registration of new plant varieties, essentially derived varieties (EDV), extant varieties;
2. Developing DUS (Distinctiveness, Uniformity and Stability) test guidelines for new plant species;
3. Characterization, documentation of varieties registered;
4. Cataloging facilities of all variety of plants;
5. Documentation, indexing and cataloguing of farmers’ varieties;
6. Recognizing and rewarding farmers, farming community, particularly tribal and rural community engaged in conservation, improvement and preservation of plant genetic resources its economic plants and their wild relatives;
7. Maintenance of the National Register of Plant Varieties; and
8. Maintenance of National Gene Bank.

Rights provided under the Act

1. Breeders’ Rights

Breeders will have exclusive rights to produce, sell, market, distribute, import or export the protected variety. Breeder can appoint agent/ licensee and may exercise for civil remedy in case of infringement of rights.

2. Researchers’ Rights

Researcher can use any of the registered variety under the Act for conducting experiment or research. This includes the use of a variety as an initial source of variety for the purpose of developing another variety but repeated use needs prior permission of the registered breeder.



3. Farmers' Rights

Farmers' Rights are ensured in India through several enabling provisions in the *PPVFR Act*, and the formulated rules and regulations thereof. These rights are being implemented by the PPVFRA, which include the following: i) A farmer who has evolved or developed a new variety is entitled for registration and protection in like manner as a breeder of a variety. ii) Farmers' Variety can also be registered as an extant variety. iii) A farmer can save, use, sow, re-sow, exchange, share or sell his farm produce including seed of a variety protected under the PPV&FR Act, 2001 in the same manner as he was entitled before the coming into force of this Act provided farmer shall not be entitled to sell branded seed of a variety protected under the PPV&FR Act, 2001. iv) There is also a provision for compensation to the farmers for non-performance of a variety under Section 39 (2) of the Act, 2001; and v) Farmer shall not be liable to pay any fee in any proceeding before the Authority or Registrar or or the High Court under the Act.

DUS Testing

PPVFR Act provides for registration of both new and extant plant varieties. The new variety is the one which has not been sold for more than year at the time of submitting application for its registration. The extant category includes farmers varieties, varieties of common knowledge and also the varieties notified under the Seeds Act 1966. All varieties to be registered have to undergo the distinctiveness, uniformity and stability (DUS) test. For the varieties notified under Seeds Act 1966, the DUS data from AICRP of ICAR is used. The crop species in which new varieties are to be registered, are required to be notified in the Gazette of India. DUS guidelines are also to be developed for each crop species, which are followed while conducting DUS tests of candidate varieties applied for registration. So far, plant varieties can be registered in 220 crop species for which DUS guidelines have been notified.

Plant Genome Saviour Awards

Farmers, particularly the tribal and rural communities, who are engaged in the conservation of genetic resources of land races and wild relatives of economic importance and their improvement, shall be entitled to recognition and reward from the Gene Fund. So far, a total of 202 Awards, Rewards and Recognitions have been conferred which include 45 Plant Genome Saviour Community Awards, 69 Plant Genome Saviour Farmer Rewards and 88 Plant Genome Saviour Farmer Recognitions.

Variety Registration

Authority has received a total of 20820 applications so far, of which 10511 certificates have been issued. More than five thousand registration certificates have been issued to the farmers. Out of total applications of the farmers varieties received more than 600 applications had been filed by the Women farmers, thereby indicating an important role of women in conservation and use of agro-biodiversity.

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INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS (ICRISAT)

The **International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)** is a globally recognized agricultural research-for-development organization working to build sustainable, resilient agri-food systems in the drylands of Asia and sub-Saharan Africa. Founded in 1972 through a partnership between the Government of India and CGIAR, ICRISAT is headquartered in Patancheru, Hyderabad, India. It collaborates with national, regional, and international partners to tackle poverty, hunger, malnutrition, environmental degradation, and climate change affecting more than two billion people in the world's drylands.

ICRISAT works across Asia, Eastern and Southern Africa, and West and Central Africa, using multidisciplinary science and strategic partnerships to improve livelihoods and strengthen dryland food systems. Its research is organized into three connected programs: Accelerated Crop Improvement, Resilient Farm and Food Systems, and Enabling Systems Transformation, which together support innovation suited to diverse agroecological and socioeconomic contexts.

The institute conducts advanced research on dryland cereals, grain legumes, and sustainable farming systems, focusing on crops such as chickpea, pigeonpea, groundnut, sorghum, pearl millet, and small millets. Over five decades, ICRISAT has produced major scientific advances, including improved crop varieties, climate-resilient technologies, integrated natural resource management practices, and market-oriented innovations that boost productivity, nutrition, income, and resilience for millions of smallholder farmers.

As part of the CGIAR global research partnership, ICRISAT connects science, innovation, capacity strengthening, policy engagement, and scaling pathways to accelerate agricultural transformation. Guided by its vision of prosperous, food-secure, and resilient drylands and its mission to reduce poverty, hunger, malnutrition, and environmental degradation in the dryland tropics, ICRISAT continues to advance global food and nutrition security through evidence-based solutions and inclusive development.

Through collaborations with governments, universities, research institutions, development agencies, farmer organizations, civil society, and the private sector, ICRISAT remains a leading force in sustainable agricultural development and in improving lives across the drylands of Africa and Asia.

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ALLIANCE OF BIOVERSITY INTERNATIONAL AND CIAT

The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) is a global research-for-development organization and a member of CGIAR, working at the intersection of agriculture, environment and nutrition. Established in 2019 through the integration of Bioversity International and CIAT, the Alliance brings together decades of expertise in agricultural biodiversity, plant genetic resources, crop improvement, climate action, nutrition and sustainable food systems.

The Alliance advances research-based solutions that harness agricultural biodiversity and sustainably transform food and land systems to improve livelihoods and human and planetary well-being. Its work spans agrobiodiversity, multifunctional landscapes, climate action, food environments and consumer behaviour, digital inclusion, crops for nutrition and health, and gender, youth and inclusion.

A key strength of the Alliance is its commitment to conserving, characterizing and using agricultural biodiversity as a foundation for resilient, nutritious and sustainable agriculture. Its global genebanks FUTURE SEEDS safeguard major collections of crop genetic resources, while its research and partnerships help translate diversity into improved varieties, climate adaptation, better nutrition and sustainable livelihoods.

The Alliance works closely with national agricultural research systems, universities, farmers, civil society, development organizations and private-sector partners across Asia, Africa and Latin America, connecting scientific knowledge with local innovation and farmer priorities. Alliance is pleased to join ISPGR as a co-organiser, contributing its global experience and partnerships to advance dialogue and action on the conservation, sustainable use and adaptive management of plant genetic resources for resilient agriculture and food systems.

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SOCIETY FOR PROMOTION OF HORTICULTURE

The Society for Promotion of Horticulture (SPH) is committed to promoting horticultural science, research, education and development in India. Hosted at the ICAR–Indian Institute of Horticultural Research (ICAR–IIHR), Bengaluru, SPH provides a platform for scientists, academicians, researchers, students and professionals to exchange knowledge, foster scientific excellence and contribute to the advancement of horticulture. SPH is one of the partner in organising the National Symposium on Harnessing Plant Genetic Resources (PGR) of Peninsular India – From Biodiversity Hotspot to Sustainable Bioresource Hub (NSPPI 2026), scheduled to be held from 17–19 September 2026 at ICAR–IIHR, Bengaluru.

Over the years, SPH has made significant contributions to scientific exchange and capacity building in horticulture. The Society has conducted 7 International and 30 National seminars/symposia, along with 13 interactive and brainstorming meetings and 19 workshops and training programmes. SPH has also contributed to institutional infrastructure by constructing and donating permanent structures worth ₹75 lakh to ICAR–IIHR. The Society has strengthened its membership base through the incorporation and implementation of Corporate Membership and the introduction of Associate Fellowship. Its membership presently includes 146 Founder Members, 26 Patrons, 2 Corporate Members, 1,022 Life Members, 58 Zonal Members and 96 Student Life Members, with 1,340 total Life Members. The Society has also facilitated the induction of Vice-Chancellors as Honorary Executive Committee members, further strengthening its institutional and academic outreach.

A major achievement of SPH is the publication of the Journal of Horticultural Sciences (JHS). The journal promotes horticultural research and development in India and disseminates research findings and developments in the sector. SPH has regularly published 40 issues constituting 20 volumes of the journal, with an increasing number of research papers being accommodated in each issue. The journal is a Global Diamond Open Access Journal, free to read and publish, and carries ISSN 0973-354X and eISSN 2582-4899. It is published biannually in June and December, with no Article Processing Charges (APCs) for authors. The journal's NAAS rating has increased from 6.04 to 6.4 in 2025.

SPH recognizes excellence and encourages young researchers through its Fellowship and Awards programmes, including the Fellow of SPH (FSPH), Associate Fellowship of SPH (AFSPH), Dr. G. S. Randhawa Best Thesis Award, and Smt. Anne Shikhamany Best Paper Award. The Best Thesis Award has been expanded to three categories, providing wider recognition for outstanding postgraduate and doctoral research.

Through its scientific programmes, scholarly publishing, awards and fellowships, infrastructure support, expanding membership, dedicated committees and institutional partnerships, SPH continues to contribute significantly to the growth and promotion of horticultural science in India.

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Plant Genetic Wealth of Peninsular India

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India is one of the megadiversity countries with invaluable plant genetic resources. The peninsular India has Western and Eastern ghats with high concentration of bioresources for food, fodder, timber, medicinal, ornamental values. Western ghats, a treasure of plant wealth is under explored. It is store house of wild relatives of cultivated plants, ornamental and medicinal plants. These Ghats are the important areas for plant resources. Valleys of Western Ghats are very characteristic in their composition. Hooker and Thomson (1855) have considered them as botanically special sub-provinces or regions and have stressed their importance. There are more than 2000 species endemic to Western Ghats. Very little is known about their potential uses. An extensive and intensive field trips in search of rare and endemic flowering plants of Western Ghats for last three decades have revealed that there are number of endemics, endangered plant species with great potential as genetic resources which need immediate attention for their propagation, multiplication, bioprospecting and conservation. Plant resources of peninsular India, a biological strength of the region is of great significance in sustainable development of the country. Thoughtful and critical field observations have indicated that each of the wild species has ornamental, medicinal, commercial or botanical importance. Number of these plant species could be put to use as ornamentals, medicines and some of them are of commercial value. There is urgent need to know and evaluate plant resources of the region and well thought plan of action for their utilization and conservation.

Potential plant resources of Peninsular India can be categorized as 1. Plants of ornamental potential, 2. Plants of medicinal potential, 3. Plants of commercial and industrial importance, 4. Plants yielding minor products, 5. Plants with edible fruits, 6. Plants of food value, 7. Wild plants of vegetable value, 8. Plants of timber value, 9. Plants of fodder value, 10. Plants of botanical importance, 11. Wild relatives of crop plants (Genetic resources), 12. Plants of fuel value, 13. Petrocorp, 14. Plants suited as aquatics in aquariums, 15. Plants of academic interest.

There is a need to survey wild plant species through extensive field studies, know their present status and potentials as commercial, medicinal, ornamental plants or any other use. In addition to in-situ and ex-situ conservation, there is need to propagate, cultivate, domesticate and introduce these plants in horticultural trade. Some of the wild plants can be introduced as food crops through domestication. Some of them are of industrial importance. Once the plant

species are made useful to man, people will cultivate them to reap the benefits. This will help not only in conservation of rare, endemic plants but also their utilization in sustainable development of the country.

The present lecture conveys about some of the importance genetic resources of peninsular India and their utilization for various purposes supported by successful stories from Lead Botanical Garden (LBG), Shivaji University, Kolhapur. It states the role of introduction of wild plants in Botanical Garden, study of their potential and utilization. Examples include species of *Barleria*, Palms, *Delphinim*, *Zingiber*, *Musa*, *Iphigenia*, *Crinum*, *Erinocarpus*, *Artocarpus*, *Aponogeton*, *Garcinia*, *Salacia* and many more.

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Identifying Geographical and Taxonomic Gaps in PGR Exploration and Collection in Peninsular India

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Introduction

Peninsular India is bound by the Vindhyan Hill ranges in the north, the Arabian Sea in the west, the Indian Ocean in the south, and the Bay of Bengal in the east, covering nearly half of India's terrain. Geographically, this region can be broadly divided into three zones: the Deccan Plateau and the Eastern and Western Ghats, each with distinct geological and ecological features reflected in unique biodiversity. The Western Ghats form part of one of the world's 36 biodiversity hotspots. Peninsular India exhibits almost the full spectrum of climatic regimes, ranging from tropical through subtropical to near-temperate, with corresponding changes in floristic composition, and witnesses 12 major vegetation types. About 2,500 endemic plant species (40 endemic genera) are reported here, with rich species diversity in economic plant genera such as *Garcinia*, *Piper*, *Cinnamomum*, *Curcuma*, *Syzygium*, *Elaeocarpus*, *Impatiens*, *Solanum*, *Ficus*, *Strobilanthes*, *Barleria*, *Andrographis*, etc. In fact, crops such as jackfruit, black pepper, small cardamom, and kokum, curry leaf, ivy gourd, and moringa originated/domesticated from here; and there are many semi-domesticated species at the interface (e.g. *Netidonta*, Malabar tamarind), and this region has contributed tremendously to the crops that originated from the Indian Gene Centre (Hindustani Centre of Origin). Richness in crop diversity is attributed to wide topographic and climatic niches, ethnic diversity (hence selection for various uses and traits), a long history of overseas contacts, a personal craving to experiment with new crops, and the practice of diverse cropping systems. This has led to a wide array of germplasm/landraces evolving over time, differing in morphological and agronomic traits within the crop. Needless to say, the ex-situ conservation of the crop genepool is crucial in the wake of rampant genetic erosion at the crop, variety, and allele levels, primarily driven by anthropogenic factors, climate change, and natural calamities, which compromise our food security and nutrition.

In this context, the ICAR-National Bureau of Plant Genetic Resources is the nodal institution at the national level, entrusted with managing plant genetic resources nationwide. Germplasm collection activity is being undertaken in collaboration with crop-based institutes, SAUs, KVKs, and other stakeholders. Perusal of collections from Peninsular states/UT (Maharashtra, Karnataka, Goa, Telangana, Andhra Pradesh, Tamil Nadu, Kerala, Puducherry, Lakshadweep Islands) in the

Germplasm Collection/National Genebank (Seeds) Database [after proper data cleaning and synchronisation, removal of breeding lines in NGB database, etc.] indicates that 65,504/50,917 germplasm samples were collected/conserved [Maharashtra-16,361/14,131 (25.01/27.72%), Karnataka-8,228/7,348 (12.56/14.41%), Goa-241 (0.36%), Telangana-9,857/7,968 (15.04/15.63%), Andhra Pradesh-12,690/11,003 (19.37/21.59%), Tamil Nadu-7,363/6,143 (11.24/12.05%), Kerala-10,577/4,231 (16.15/8.30%), Puducherry-29/38, Lakshadweep Islands-158/50] in 1,580/917 species (1,617/943 taxa) across 19/14 crop-groups. Gaps between collected and conserved accessions are mainly attributable to the entire germplasm collection vis-à-vis (only) orthodox seed conservation, direct stakeholder contributions to NGB, and collection-to-conservation gaps. During implementation of the World Bank-aided NATP mission-mode sub-project “Sustainable Management of Plant Diversity” (1999-2005), a considerable proportion of germplasm (30 %) was collected.

Overview of PGR Collection Gaps

It is to be noted that about 7.03/13.42% of the total collected/conserved accessions [4,648/6,832 acc., viz. – Tamil Nadu-531/1,162; Kerala-515/457; Karnataka-366/811; Andhra Pradesh incl. Telangana-2,032/3,191, Maharashtra-1,204/1,117] have no specific geographical location available, making it difficult to identify the geographical gaps within the state. Nevertheless, given the area and agrarian population, the collected data indicate that Tamil Nadu and Karnataka were largely under-collected, underscoring the need to strengthen collection activities outside the home states where NBPGR regional stations are located. Overall analysis of geographical gaps in collection/conservation (vis-à-vis area and population) indicated that the following potential districts (formed before 1997; with <35 acc. per 1000 km² and/or <100 acc. per 10 lakh people) require more attention: **Tamil Nadu:** Cuddalore, Kanchipuram, Karur, Nagappattinam, Perumbalur, Pudukkottai, Sivagangai, Thanjavur, Thiruvavur, Viluppuram; **Karnataka:** Bagalkote, Ballari, Gadag, Haveri, Kalaburagi, Kolar, Koppal, Mandya, Raichur; **Maharashtra:** Beed, Thane, Solapur, Gadchiroli; **Andhra Pradesh:** Krishna, Nellore; **Telangana:** Nalgonda; and **Goa.** Many of these collection-deficit areas experience semi-arid climatic conditions, which could offer opportunities to collect abiotic stress-tolerant germplasm. Overall, ecological coverage in germplasm collection is incomplete, especially in the Protected Areas across the region. It may not be out of context that unusually large collections (>1500 collected or >1000 seed conserved accessions) were made in some districts (Adilabad-2,970/1,005; Hyderabad-2,510/3,867; Bengaluru-403/2,251, Amravati-2,181/1,411; Akola-2,104/2,093; Palakkad-2,030/1,009, Visakhapatnam-2,127/1,501, Srikakulam-1,515/ 1,238, Palakkad-2,030/1,009, Jalgaon-514/1,237), indicating the need for rationalisation of collections, and entry of exact collection locality details (not the collecting centre locality) in the passport data.

Crop-group-wise collected/(seed) conserved accessions (in descending order) includes: Vegetables (16,363/5,235), Grain legumes (8,736/8,880), Cereals (7,380/6,828), Oilseeds



(6,864/8,062; incl. tree-borne oilseeds), Millets (6,603/13,402), Spices and condiments (3,569/220), Medicinal and aromatic crops (3,098/2,388), Tuber crops (1,964), Fruits and nuts (1,561/85), Agroforestry spp. (267), Forages (543/1,331), Fibre crops (587/3,177), Green manure/cover crops (67), Minor fruits (249), Ornamentals (382/112), Plantation crops (309), Pseudocereals (808/733, mainly grain amaranth), Sugar crops (298) and Others (850/462). This indicates a large direct germplasm contribution from ICAR-crop-based institutes, ICRISAT, and SAUs, especially in crop groups: grain legumes, millets, oilseeds, fibres, and forages. The highest number of collected/conserved samples (>1000) were in crops like rice (5,878/5,874), sorghum (2,030/4,822), pigeon pea (1,923/3,930), safflower (533/1,797), pearl millet (383/1,673), finger millet (1,272/1,773), sesame (2,529/1,660), foxtail millet (1,256/1,622), kodo millet (235/1,458), little millet (601/1299), cotton (338/1,299), chilli (2,034/1,282), chickpea (894/1,066), cowpea (1,974/488), brinjal (1,513/902), onion (1,293/270), okra (1,171/585), horse gram (1,443/843), black gram (1,190/371), and green gram (1,538/587). In some of these crops, over-collection is inferred, as they permit easier augmentation at source and conservation in the seed genebank, while in others a substantial collection-to-conservation gap is found.

Analysis of available data reveals that germplasm collections are incomplete in almost all the crops/species. This is accentuated by the issue of identification only up to the genus level, thus hampering taxon-level gap analysis (e.g., *Amaranthus* sp.-527 collected /258 conserved acc.) as well as misidentification (e.g., *Sesamum laciniatum* vs *prostratum*; *Solanum incanum* vs *insanum*). Yet, the situation is much better for major crops such as rice, grain legumes, millets, cotton, vegetables (esp. brinjal, cucurbits, okra, onion), mango, banana, tree spices, coconut, arecanut, and tuber crops. Even in rice, 48 potential districts (formed before 1997; Tamil Nadu-17; Andhra Pradesh-7; Maharashtra-14; Karnataka-5; Kerala-3; Telangana-3) have only <10 collected/conserved accessions in place. For perennial horticultural crops, preference has been given to elite germplasm over genetic variability due to constraints in land, manpower, and infrastructure. Large gaps exist in crop groups such as minor fruits, ornamentals, agroforestry spp., forages, and M&APs, as well as in crop wild relatives, for which systematic collection efforts are needed. Out of 943 taxa conserved in the Seed Gene Bank from this region, 409 are represented with just one accession, and 772 are represented with <10 accessions. About 140 prioritised wild relatives of crops that occur in peninsular India have yet to be found in the collections (even as single germplasm), along with wild forms/populations of many crops. A detailed gap analysis is needed, integrating multiple layers of information on climate, vegetation, soil types, crops, landraces, and ethnic diversity.

Profound gaps in the collected-to-conserved germplasm are experienced in vegetables and perennial horticultural crops that are mainly conserved other than through seeds. Collection-to-conservation gaps occur for numerous reasons, including small sample sizes gathered during exploration, low viability, poor survival of vegetative propagules, poor adaptability, pest and disease incidence, damage from wild animals, and a lack of expertise/interest, regeneration plans

and facilities. This gap can be meaningfully reduced through coordination, active monitoring and reporting systems, and strengthening regeneration facilities at the multiplication site, especially for cross-pollinated crops. It is strongly advised to obtain an adequate sample size in the field, wherever possible.

As a substantial proportion of horticultural crops propagate vegetatively and/or exhibit recalcitrant/intermediate seed storage behaviour, alternative conservation strategies, viz., Field Genebanks (FGB), in vitro, and cryo-conservation, play a vital role in their conservation. Twenty-one designated National Active Germplasm Sites (NAGS) (out of 48) are located in peninsular India, catering to the needs of diverse crops/crop-groups. In the case of Western Ghats, there are 11 field genebanks (for instance, NBPGR RS Thrissur – 2,338 acc.; CTCRI-5,234 acc. of tuber crops; IISR-6,745 acc. of spices; CPCRI-1,163 acc. of plantation crops), one seed genebank (NBPGR RS Thrissur – 3,636 acc. in vegetables), and one in vitro genebank (CTCRI-465 acc. of tuber crops) under the ICAR system, which cater to different crop groups. The in vitro and cryo genebank of NBPGR also houses collections (1,693 accessions) from peninsular India. Apart from these, various horticultural colleges and research stations under 16 SAUs in peninsular India, as well as central government institutes (e.g., Coffee Board), state government-run institutes/universities (e.g., JNTBGRI for *Piper* and *Garcinia* spp., University of Calicut for *Musa* and Zingiberaceae germplasm), and non-governmental organisations such as MSSRF maintain crop-specific genebank collections. Additionally, germplasm from this region also got conserved in general and crop-specific genebanks located in other areas. The exact number of crop- or species-wise accessions from peninsular India maintained in genebanks remains unknown because a unified database is lacking across stakeholders.

Some emerging issues in PGR management that need attention include land shortage in FGBs to allow for accommodating more germplasm collections, disinclination among researchers for multiplication/regeneration/purification of germplasm of cross-pollinated crops, and apparently unregulated introduction of ornamentals, fruit plants, and other economic species by gardeners and private nurseries without proper quarantine. Heritage fruit orchards and plantations, as well as FGBs owned by state governments and private owners, are also often in peril. As farmers become increasingly aware of the scope of registration for elite germplasm/unique landraces under the PPVFRA regime, convincing them to acquire germplasm for conservation is often an emerging challenge. Other concerns include taxonomic misidentification of wild species/relatives and the neglect of infraspecific classification in crops (i.e., non-recognition of infraspecific taxa by taxonomists), which results in the loss of valuable information that would otherwise aid in grouping a larger number of germplasm collections. Diligence in filling in as many passport data fields as possible is warranted, and given the momentum of wild species collection, it is suggested to include the author's name for the taxa, as different authors may propose the same name for different species.



Suggested line of work that would strengthen PGR conservation includes the need for a unified collection database (that would enable meaningful gap analysis); preparation of PGR map at district level (incl. introduced crops/spp. in botanical gardens, nurseries, private gardens); studies on improving storage conditions for vegetative propagules and live plants during transit from exploration sites; wide hybridization and graft compatibility studies involving wild relatives; studies on the conservation/storage behaviour; and protocol standardisation for in vitro and pollen cryopreservation of non-traditional crops, minor fruits, and CWR spp. Germplasm conservation for utilisation is the prevailing trend, and breeders and horticulturists are interested in a few carefully chosen materials that exhibit desirable traits, which require thorough knowledge of habitat/ecological/micro-climate conditions, (pest) hotspot areas, and morphological characteristics associated with the trait of interest. Hence, it is necessary to adopt recent technologies, such as the use of FIGS in identifying sites for exploration, encouraging the use of portable equipment/kits (TSS meter, PH meter, lysimeter, chlorophyll fluorescence meter, NIR food analyser, seed dryers, etc.) to maximise the coverage and efficiency of germplasm collection. It is suggested to create a separate field gene bank that focuses exclusively on niche-specific germplasm (temperate horticultural crops, CWR spp., minor fruits) from high-altitude areas (>1500 m MSL) of the Western Ghats, which are not represented in the existing FGBs situated in the mid and low hills.

Strong networking among all institutes working on PGR management and line departments, such as state forest departments, is essential given the paucity of land, resources, and expertise. Considering the uncertainties associated with germplasm management, it is recommended to conserve a duplicate set for safekeeping, either through alternative conservation strategies or at different sites. Raising public awareness of the importance and necessity of germplasm conservation is another critical area. In this context, there is a ray of hope in the on-farm conservation of specific crops or crop groups by hundreds of voluntary custodian farmers, particularly in the state of Kerala. In situ conservation needs strengthening through identifying more gene sanctuaries and biodiversity heritage sites, along with active monitoring and regular assessment of PGR plant populations in protected areas.

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Role of Botanical Survey of India in Plant Diversity Documentation and Conservation

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Introduction

Botanical Survey of India (BSI) is the custodian of the floral wealth of the country. It was established on 13th February 1890 with a mandate to explore, collect, identify and document the rich plant wealth of the erstwhile British India. Being the apex research organization of the country on floristic studies and plant taxonomy, BSI possesses great history and legacy. During British period, the research activities of BSI were mainly focused at the Royal Botanic Garden, Howrah. After the independence, BSI was reorganized in 1954, and presently the organization has 11 Regional Centers, covering all the geographical region belts of the country, namely Andaman and Nicobar Regional Centre at Port Blair, Arunachal Pradesh Regional Centre at Itanagar, Arid Zone Regional Centre at Jodhpur, Central Regional Centre at Prayagraj, Deccan Regional Centre at Hyderabad, Eastern Regional Centre at Shillong, High Altitude Western Himalayan Regional Centre at Solan, Northern Regional Centre at Dehradun, Sikkim Himalayan Regional Centre at Gangtok, Southern Regional Centre at Coimbatore and Western Regional Centre at Pune, with its headquarters at Kolkata. Besides, BSI has administrative control over the two large botanic gardens, such as Acharya Jagdish Chandra Bose Indian Botanic Garden (AJCBIG), Howrah and Botanic Garden of Indian Republic (BGIR) at Noida.

Achievements

Botanical Survey of India has been providing scientific basis for conservation and sustainable utilization of wild plants through survey, inventory, documentation, taxonomic research and through conservation creating environmental awareness. Floristic survey of most of the states and union territories, including Protected Areas and Ramsar Sites have been completed. BSI has published 26 volumes (out of 32) of Flora of India, 30 volumes of Fascicles, 16 volumes of State Floras relating to 19 states and 34 volumes of District Floras. Since its reorganization in 1954, the scientists and other scientific staff of BSI have discovered 01 new family, 60 new genera, 2171 new species, subspecies and varieties and records. Every year, on June 5, World Environment Day, BSI publishes "Plant Discoveries", an annual compendium detailing with discovery of plants, fungi, algae, lichens and microbes (species/infraspecific taxa/genera) new to science, and new records or additions to Indian flora. According to "Plant Discoveries 2025"



released on June 5, 2026 by BSI, the scientific staff of BSI and other institutes have discovered 04 new genera, 213 new species and 08 infraspecific taxa as new to science from India, and 08 new genera, 126 new species and 06 infraspecific taxa as new records for Indian Flora. Accordingly, the latest compiled data of the plant diversity in India stands at 56530 taxa including 22522 Angiosperms, 83 Gymnosperms, 1328 Pteridophytes, 2863 Bryophytes, 3213 Lichens, 16079 Fungi, 9139 Algae and 1303 Microbes.

As an attempt to enumerate the taxa under consideration for conservation, especially the endemics, the Botanical Survey of India has also taken up studies on the endemic flora of India. The book titled “Endemic Plants of the Indian Region: Volume 1” published in 1986, which enumerated 1932 taxa endemic to the Peninsular India. Later, in 2015, BSI comprehensively enumerated a total of 4381 endemic vascular taxa belonging to 1007 genera and 176 families, which included 4303 angiosperms, 12 gymnosperms and 66 pteridophytes in its publication, “Endemic Vascular Plants of India”.

In the early 1980s, BSI gave serious thought to discuss the status of threatened plants in India and published a booklet titled “Threatened Plants of India – A State of Art Report”. This was followed by the publication of the book: “An Assessment of Threatened Plants of India” in 1983, which included contributions from various educational and research institutions all over the country. Concerted efforts on the study dealing with the threatened species were made in the years 1980–1985, through a programme: Project on Study, Survey and Conservation of Endangered Species of Flora (POSSCEF) in the Botanical Survey of India. The study resulted in gathering baseline information of the threatened plant species in India, which resulted in the publication of “The Indian Plant Red Data Book – I” with 125 data sheets of flowering plants in 1984.

The research and data collection on endemic and threatened plant species by the researchers of BSI as well as several other botanical institutions resulted in bringing out series of Red Data Books by the BSI. “The Red Data Book of Indian Plants – Volume 1” was published in 1987, which included 235 vascular plants, Volume 2 was published in 1988, which dealt with data sheets of 192 threatened vascular plant species and in 1990, Volume 3 was released, which dealt with 195 taxa of Indian flora. The book titled “Red List of Threatened Vascular Plant Species in India” published in 2003, by the ENVIS Centre of the Botanical Survey of India enumerated about 1255 taxa of threatened vascular plants in India. Besides, there are about 1000 plant species categorized under three different Appendixes of CITES and a total of about 1600 species under Negative List of Species Export.

As part of ex situ conservation of Indian plants, BSI maintains germplasm of thousands of species in its botanic and experimental gardens across the country including commercially viable plant groups, such as Orchids, Zingibers, Bamboos, Palms and Medicinal Plants. The BSI has its origin at AJCBIBG, Howrah which was established by Col. Robert Kyd in 1787. By virtue of its location, AJCBIBG acted as a platform for introduction, cultivation and distribution of

many economically and commercially important crops in India. In such a way it has played a greater role for the economic development of the country. Presently, AJCBIBG harbours 1400 species of plants comprising nearly 15000 in number in its 25 divisions representing the flora of 5 continents. It has a large collection of Rare, Endemic and threatened species of India covering all the groups. Palms being the icons of tropics, has always had a special place in AJCBIBG. There are about 110 species of palms conserved in its divisions including the prized ‘Double Coconut Palm’ [*Lodoicea maldivica* (J.F. Gmel.) Pers.]. It was a single female palm of 119-year-old existed in India and artificial hand-pollination was successfully carried out using imported pollen from Thailand in 2013, leading to historic fruit harvest in February 2020.

In October 2025, the Ministry of Environment, Forest and Climate Change, Government of India launched the National Red List Assessment, first-of-its-kind in India to evaluate the extinction risks of approximately 7,000 plants, with an aim to publish authoritative National Red Data Books of Indian Plants by 2030, with the field execution by BSI. So far, collectively 29 taxa have been assessed as Critically Endangered (CR), 11 as Endangered (EN), 02 as Vulnerable (VU), 41 Data Deficient (DD), 03 Near Threatened (NT) and 01 as Least Concerned (LC) following the current IUCN Red List Categories and Criteria.

Finally, it is hereby emphasised that the Botanical Survey of India, the nodal organisation of Government of India has been rendering its fine service for the past 137 years, in documenting and conserving the plant wealth of the country, as well as in disseminating various types of knowledge associated with the botanical resources of the country, and will continue to render its service dedicatedly.

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Measuring Landscape Dynamics to Monitor Changes in the Flora

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Introduction

A forested landscape comprises interconnected, diverse ecosystems that provide an array of ecosystem services to all dependent biota. Services essential for sustaining life include clean water supply, erosion control, food provision, climate regulation, and recreation of scenic beauty. Land use changes have been altering the structure and functions of forest ecosystems, threatening natural resource bases, and changing the climate. Insights into the spatio-temporal patterns of forest ecosystems are vital for evolving policies toward prudent management to sustain benefits and support livelihoods. Sustained anthropogenic pressure and over-exploitation of natural resources affect the self-regulating properties of landscapes. Landscape dynamics are quantified by assessing land cover (LC) and land use (LU). LC expresses the biophysical cover (LC) of a landscape, while land use highlights the extent of human usage for resource extraction and other purposes. Unplanned LU changes disrupt ecosystem structure and health through forest fragmentation, leading to the extirpation of endemic species. Management decisions are becoming increasingly significant and complex amid burgeoning resource demands. Natural resources management requires understanding the current landscape status by evaluating spatial extent and conditions that reflect the ecological, economic, and social dimensions of anthropogenic activities. The temporal landscape assessment is crucial for sustainable landscape management at local and global levels. The availability of remotely sensed satellite data acquired at regular intervals since 1970 has aided the assessment of LU changes at finer scales.

Tropical forests provide a wide range of benefits to humankind. Accounting for ecosystem services and estimating total ecosystem supply value (TESV) would aid decision-making by incorporating them into developmental projects. About 21.71% of India's spatial extent (329 million ha) is under forest cover, and about 43% is under cropland. Forest ecosystems in India include alpine, subtropical, temperate, and tropical, with a major share of dry deciduous tropical forests.

The Western Ghats, bestowed with the endemic biodiversity, is a mountain range of 1600 km from Kanyakumari to Gujarat along peninsular India, covering an area < 5% (1,60,000 sq.km.) of the geographical extent of India, and is among the 36 global biodiversity hotspots. Uttara Kannada district (also known as Karwar district) in the central Western Ghats is highly wooded

(76%) and covers an area of 10,290 sq. km. Forest ecosystems in the district bear centuries of history (slash and burn cultivation, the transition of climax evergreen forests to secondary) and now consist of fragmented forests (evergreen, deciduous – dry and moist in high rainfall regions, semi-evergreen) to scrub forests.

Vegetation in the district was classified broadly as a west coast evergreen to semi-evergreen forest, and an earlier vegetation map of 1: 250000 scale by the French Institute, Pondicherry, indicate that forests in the high to moderate rainfall areas consist mainly *Persea macrantha*-*Diospyros* spp.-*Holigarna* spp. along with fragments of *Dipterocarpus indicus*-*Diospyros candolleana*-*Diospyros oocarpa* types towards the southern portions, mainly in the Siddapur hills. The entry of agricultural and pastoral people led to the clearing of primary forests for shifting cultivation and human settlements, industrial usage, and several other human disturbances.

Land-use analyses using temporal and spatial data acquired through spaceborne sensors indicate that the district has lost 29% of evergreen forest cover from 1979 to 2021, with increases in built-up area from 0.95% to 8.2% and monoculture plantations from 8% to 18%. Field investigations using transect-based quadrats recorded 1068 unique species across 138 families, including diverse plant species (trees: 278, shrubs: 285, and herbs: 505). The study reveals that higher species richness and endemism in the region are correlated with the presence of perennial streams. A carbon sequestration rate of 154.3 t/ha indicates the potential of diverse tree cover. Sacred groves (kan forest) had the highest carbon storage of 363.07 t/ha in the tree biomass. *Myristica* swamps at Kathalekan and swamps in Siddapur and Honavar have threatened habitats with endemic species such as *Myristica magnifica*, *Gymnacranthera canarica*, *Syzygium travancoricum*, *Semecarpus kathalekanensis*, etc. *Dipterocarpus indicus* is present in the sacred groves, and relic forests of Siddapur, Honavar. The present communication, based on a temporal land-use assessment and field-based estimation of flora diversity, has provided invaluable insights for the conservation of fragile ecosystems and will aid in evolving policies for prudent management of natural resources to sustain them.

Strategies advocated for the conservation and enrichment of biodiversity: The Western Ghats are one of the hottest hotspots of biodiversity, with high endemism, and are under significant threat of imminent extinction due to escalating anthropogenic pressures. The temporal land use analyses provide valuable details, including the likely threat to the diverse flora. Recommendations to support/enrich the areas of high endemism in the Uttara Kannada district are:

- **Forests towards carbon mitigation:** Planting of native species of vegetation in the degraded forest patches in Uttara Kannada would enhance the capability to sequester carbon, which will aid in decarbonization and lower carbon footprint toward mitigating global warming
- *Myristica* swamps are endowed with the highest degrees of flora and fauna endemism. This necessitates inventorying, mapping and monitoring swamps with the respective catchment areas for prudent management

- Sacred groves or *kan* forests "are unique cultural identities and are seats of high endemism. Protection of *kan* forests would enhance the landscape's water retention capability and the sustenance of water for the dependent population.
- Conservation of Western Ghats tree endemism would aid in sustaining other taxa. A high percentage of forest tree endemism within stream catchments influences fish endemism.
- Afforestation of degraded forest patches with native species through the active participation of all stakeholders and village forest committees (VFC), which helps in enhancing biomass and diversity in the minor forest tracts.
- Conservation of lateritic hills: Coastal lateritic hills provide habitat for monsoon herbs that flower gregariously and help survive honey bees during the rainy season.
- Forestry-based alternative development plan to enhance the economic productivity through the creation of more forestry-based livelihoods, such as:
 - a. Decentralised forest nurseries of NTFP species would enhance job opportunities for women and enhance the scope for adoption of indigenous farming techniques in forestry.
 - b. The promotion of beekeeping as an essential enterprise would benefit the croplands and forests (through pollination)—planting species used by honey bees for foraging along roadsides and in the peripheral forests of villages.
 - c. Farmers to be incentivised to grow and market medicinal plants and their primary products for the betterment of local livelihoods. This would help in curtailing the smuggling of medicinal plants from the forests and unauthorised exploitation by outside agencies.
 - d. Preparation of bio-pesticides from local plant resources, harmless to humans and domestic animals, to be promoted as a cottage industry.
 - e. Numerous forest plants and mangroves are potential sources of dyes. Development of indigenous technology to extract vegetable dyes for colouring textiles or colouring food.
 - f. Production of plant-based cosmetics and nutraceuticals (e.g. from *Garcinias* and *Phyllanthus emblica* -amla).
 - g. Development and VFC managed sandalwood farms in Haliyal, and Mundgod, and the eastern zone of Yellapur, Sirsi, and Siddapur.
- Identification of local hotspots of biodiversity and management through VFCs/local Biodiversity Management Committees.
- Enrichment of food resources in degraded forest patches for forest herbivores to sustain wildlife and minimise instances of human-animal conflicts of crop raids.
- Scientific harvesting of NTFP and training to VFCs and forest dwellers

- Promotion of bamboo cultivation and harvesting for bona-fide use.
- Protection of riparian vegetation to enhance phytoremediation and carbon sequestration and to be considered as endangered ecosystems.
- Conservation of myristica swamps and promotion of forest endemism is evident from the occurrence of endemic taxa, amphibians (35 species), endangered primate Lion-tailed macaque, hornbills and Imperial pigeon, endemic fish (18 species including three new species *Batasio sharavathiensis*, *Schistura nagodiensis* and *S. sharavathiensis*).
- Enriching secondary deciduous forests (for biomass and diversity) of coastal taluks and developing the deciduous forest zone with basal areas exceeding 35 sq.m/ha.in Mundgod, Haliyal, the drier eastern parts, especially Joida, Yellapur, and Sirsi stands.
- Inventorying, mapping, and conservation of endemic trees such as *Myristica fatua*, *Dipterocarpus indicus*, *Syzygium travancoricum* etc.

Acknowledgement

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Diversity, Distribution and Conservation Priorities of PGR in the Nicobar Islands

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Situated southeast of the Bay of Bengal, between 6-10 °N and 92-94 °E the Nicobar district of Andaman & Nicobar administration comprising 22 islands with a total landmass of about 1841 Km² forms the Indian part of the Sunda land biodiversity hotspot. These islands are believed to be peaks of submarine mountain ranges standing above sea level, extending from Arakan Yoma ranges in Myanmar to Mettawai islands in Sumatra. Climate is humid tropical with more than 95% forest cover (mangroves, littoral, riverine and tropical evergreen). The three major divisions in Nicobar are Car Nicobar and Batti Malv Island in the north (unexplored), the Nancowrie group of islands (Bampuka, Champin, Chowra, Hitui, Kamorta, Nancowrie, Teressa, Tillangchong and Trinket) in the middle and the Great Nicobar Biosphere Reserve (including Little Nicobar and Kondul islands) in the south. Topography of most of the islands is hilly, with small undulating mountains and narrow valleys dominated by dense tropical evergreen forests. Mount Thullier (642 m above MSL) is the highest peak (largely unexplored). Diverse habitats, topographic and soil factors and millions of years of physical isolation from the mainland coupled with proximity to Southeast Asian Island nations had led to evolution of a unique plant diversity with high endemism, largely unavailable elsewhere in mainland India.

Denmark (1750-1869), followed by Britain, ruled the islands till Indian independence. Nicobaris (approx. 30,000 people) and the primitive aboriginal Shompens (200-300 people), both from the Mongoloid stock, are the original inhabitants. Nicobaris practices very primitive subsistence agriculture. Agroecosystem diversity comprises pure stands of coconut (with high genetic diversity) in the littoral zone, arecanut gardens as undergrowth in partially cleared lowland swampy wet forests, backyard vegetable gardens adjacent to Tsunami shelters and Tuhets. Tuhets are self-sustaining high density multispecies organic farms, owned and managed by joint families. Landrace diversity in Taro, Giant taro, Greater yam, Banana etc. is impressive (community was conferred with Plant Genome Saviour award for Dioscorea diversity conservation). Other tuber crops like potato yam, New Cocoyam, cassava, sweet potato, elephant foot yam, lesser yam and Fiji arrowroot are integral components of Tuhets. Tropical Citrus (lime, lemon, pummelo, loose-skinned oranges) diversity is unique. Crops with less diversity but unique traits were jackfruit, poly-embryonic mangoes, vegetable banana, red-fleshed guava, rose apple, hog plum; vegetables like breadfruit, tree cabbage, spleen amaranth, very primitive brinjal, and flavoring

herbs like Pandan, ginger, galangal, lemongrass, mango ginger, African coriander etc. *Pandanus lerram* is a semi-domesticated/wild gathered staple food (fruit pulp cake). According to a conservative estimate, useful flora of potential food and agricultural value includes 40 species of plywood and timber value, 10 for canoe and boat making, 15 for construction and furniture, 50 for ornamental and landscape use, 20 as wild edibles, 72 species as medicinal plants and 153 as crop wild relatives. CWR wealth in crop genera like *Piper*, *Artocarpus*, *Vigna*, *Dioscorea*, *Musa*, *Curcuma*, *Zingiber*, *Garcinia*, *Mangifera* etc. is unique with high endemism.

Unique and diverse ecosystem offers scope for discovery of trait-specific germplasm in adapted landraces and CWR taxa. Female flowering vine of lesser yam, saline-tolerant field bean growing near mangrove edges, Ber and Bael adapted to tropical humid regions, non-acrid Giant taro, Indian swamp taro and leafy taro, pigment-rich greater yam diversity, red skinned Bullock heart, red fleshed guava, loose skinned tropical green oranges, cluster bearing lime, eddoes and dasheen variability are unique. CWR taxa for rootstock use (salinity tolerance, inundation) for sapota, mango, nutmeg, garcinia, jamun etc. are worth studying. Wild Ashgourd (progenitor taxa), prolific and abiotic stress tolerant wild melon, heavily armed tuberous *Dioscorea piscatorum*, *Amorphophallus* species diversity, wild betel leaf, wild edible *Garcinia kurzii*, *G. nervosa* etc. have potential for crop improvement/diversification. Life support species for thatching (*Licuala* spp.) poles (*Myristica* and *Knema* spp.), wild edible Bamboos may find a place in Agroforestry systems for carbon sequestration. Wild ornamentals, foliage plants and avenue palms (*Caryota*, *Pinanga*, *Rhopaloblaste*, *Bentinckia nicobarica* etc.) tree ferns etc. have potential for nursery industry. Tropical grasslands of Nicobar are unique and worth studying for its grass and legume species diversity as fodder. Medicinal and flavouring herbs unique to the islands also need collection, conservation and utilization studies.

Due to logistical reasons and remoteness of the islands, the region was poorly explored, and many virgin forest tracts still await PGR exploration. Tsunami has caused havoc with a major part of the littoral forests and mangroves in Nicobar (Indira Point, southernmost land point was submerged). Environmental clearance given to the Great Nicobar Development project with four components; a transshipment terminal in Galathea Bay, an airport, a greenfield township and tourism project, and a gas-powered power plant may necessitate tree felling and deforestation in about 130 Km² of largely primary tropical rainforests leading to irreparable loss of CWR species and potential economic plants, many of them yet to be studied/described /conserved. Spread of invasive alien flora and fauna with human and traffic movement in the allotted 160 Km² area; the core area affected by the development project will wreak havoc on rare and endemic CWR taxa. Urgent rescue missions (different seasons) comprising experts from stakeholder institutions of ICAR (NBPGR; CIARI, Srivijayapuram; IISR, Kozhikode; CTCRI, Thiruvananthapuram; CPCRI, Kasaragod; IIHR, Bengaluru; IGfRI and CAFRI, Jhansi; DMAPR, Anand; NRC on Citrus, SBI, Coimbatore etc.) need to be undertaken on a war footing. Simulated in situ conservation in any one of the Agri. Department (A&N administration) farms in Nicobar Islands



under the supervision of NBPGR & CIARI needs to be ensured. Life support species for coastal bioshields, cultivable forage taxa for reducing man-animal conflict (wild *Musa*, wild palms etc.) need detailed study by line departments.

Biosystematics, wide hybridization and crossability studies for genetic enhancement (rare and unique CWR like variant populations of *Abelmoschus moschatus*, *Cucumis melo* subsp. *agrestis*) is worth attempting. Declaring unique pockets as genetic reserves (wild *Musa acuminata* habitats in Macachua, Little Nicobar, *M. indandamanensis* habitats in Galathea WLS, wild *Mangifera* habitats in Katchal island) needs to be considered after systematic studies as these CWR taxa are not available anywhere in mainland India. The northern Car Nicobar group of islands were explored only coarse grid. As most of the CWR taxa are related to vegetatively propagated horticultural crops, in vitro and cryo-conservation protocols need to be developed by NBPGR to conserve these genetic resources ex situ.

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Community-Centric Conservation of Plant Genetic Resources: Lessons from Traditional Knowledge Systems

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Introduction

For millennia, indigenous and rural communities across Peninsular India have served as the primary custodians of biodiversity, developing cultures deeply intertwined with the natural world. In India alone, a vast repository of knowledge regarding Plant Genetic Resources (PGR) is embedded within the oral traditions of over 3,600 ethnic communities. However, rapid environmental degradation, habitat fragmentation, and socio-economic shifts threaten both this plant wealth and the traditional knowledge systems (TKS) that sustain it.

Over the past three decades, primarily through action research at the Foundation for Revitalisation of Local Health Traditions (FRLHT) and TDU, our findings consistently demonstrate that long-term, in-situ conservation of PGR cannot succeed through top-down protectionist models alone. Instead, effective conservation requires placing local communities at the center. By combining traditional knowledge systems with modern botanical and legal tools through systematic documentation, capacity building, and statutory empowerment, communities can transition from passive onlookers into active conservation stewards.

COMMUNITY-CENTRIC PGR CONSERVATION FRAMEWORK	
1. Documentation & Scientific Validation	Systematizing Local Health Traditions (LHTs) & validating indigenous healing practices.
2. Ethnoveterinary Practice & Outreach	Scaling plant-based livestock healthcare with NDDB to curb AMR & promote plant security
3. Sustainable Harvesting & GFCP Implementation	Implementing Good Field Collection Practices (GFCPs) for wild plant bioresources.
4. PBRs & Statutory Incentive Mechanisms (PES)	Institutionalizing People's Biodiversity Registers to enable Payment for Ecosystem Services
5. Parataxonomy & Capacity Building	Operationalizing the "Village Botanists" program for frontline staff & local youth.



1. Documenting and Scientifically Validating Local Health Traditions (LHTs)

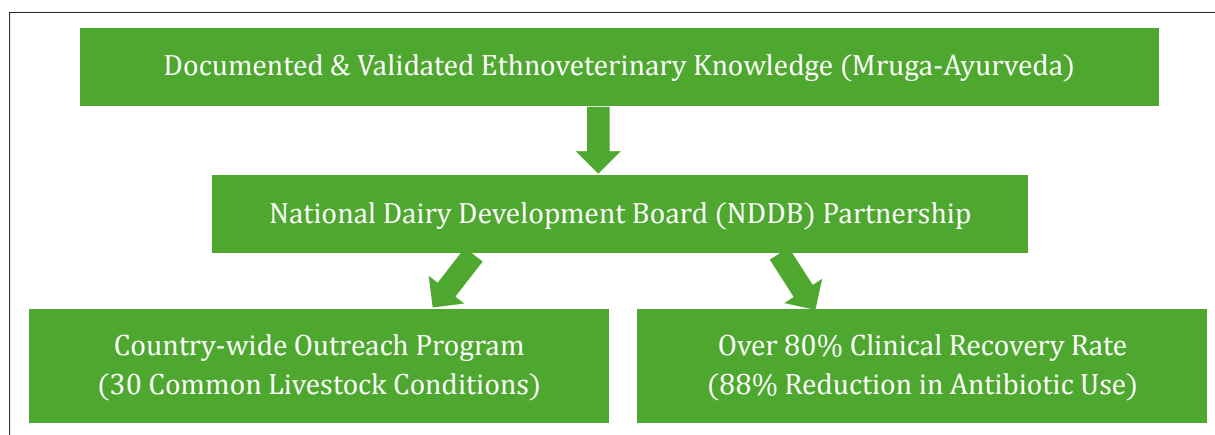
At the core of community-centric conservation is the recognition that local health traditions (LHTs) represent an extensive, orally transmitted pharmacopoeia. Rural populations depend directly on these health traditions for primary healthcare, holding deep experiential knowledge of plant identities, flowering schedules, and ecological niches.

Our work focuses on documenting traditional healing practices, specific medicinal uses, and field conservation techniques through structured ethnobotanical methodologies. Rather than treating this process as a passive archival exercise, we employ rigorous scientific cross-evaluation-referencing field data against classical Ayurveda texts, botanical taxonomy, and pharmacognosy. Scientifically validating LHTs achieves three key goals:

- It protects indigenous intellectual property against biopiracy.
- It elevates local healthcare practices into evidence-based community resources.
- It restores community pride in local botanical heritage, transforming surrounding flora into valued assets worth protecting in-situ.

2. Ethnoveterinary Practices (EVP): Demonstration and Large-Scale Application

Traditional knowledge systems extend beyond human healthcare into livestock management through Ethno-Veterinary Practices (EVP) rooted in Mruga-Ayurveda. Livestock healthcare in rural dairy ecosystems relies heavily on local medicinal plants, making the conservation of veterinary PGRs essential for rural livelihoods.



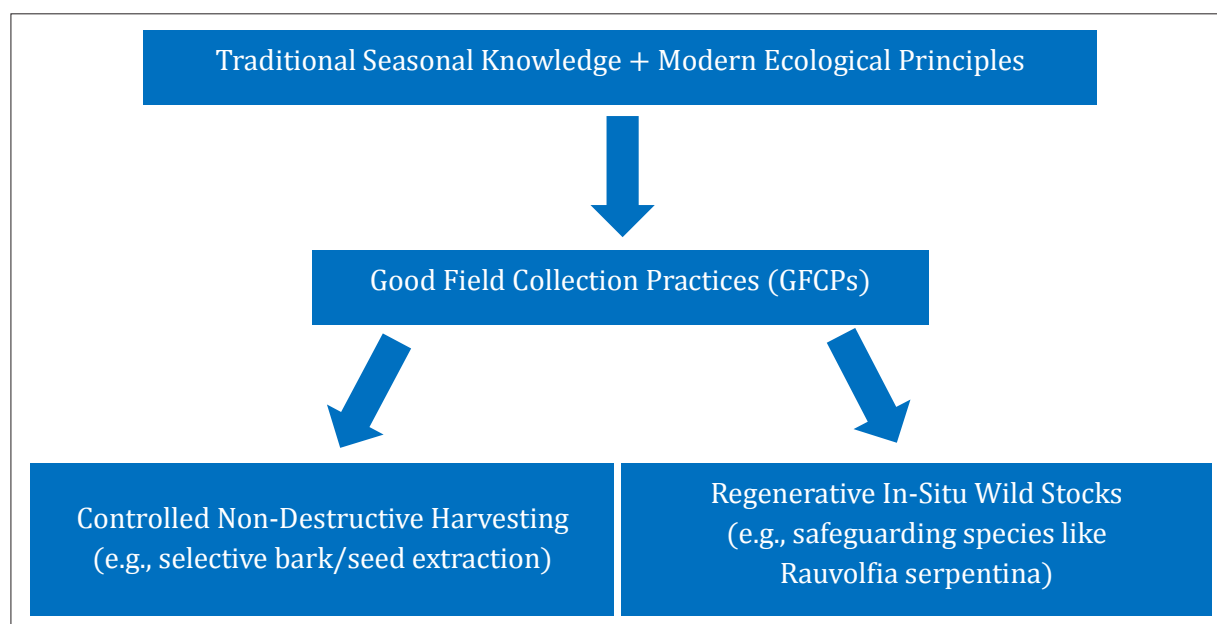
In partnership with the National Dairy Development Board (NDDB), TDU implemented the country's largest outreach program for livestock health security. This initiative deployed plant-based interventions for 30 common bovine conditions (including mastitis, enteritis, and tick infestation), treating over 1.2 million documented field cases with an average clinical recovery rate exceeding 80%.

Demonstrating cost-effective, herbal alternatives directly reduced antibiotic use in participating dairy cooperatives by up to 88% and significantly lowered antimicrobial resistance (AMR) risks and drug residues in milk. Scaling EVPs across dairy states creates massive demand for sustainable plant production, giving farmers a direct economic reason to conserve local flora.

3. Mainstreaming Sustainable Wild Collection via Good Field Collection Practices (GFCPs)

A significant proportion of wild medicinal PGRs in Peninsular India are harvested directly from forest ecosystems. Unregulated and destructive harvesting practices pose severe risks to endemic flora, crop wild relatives, and threatened medicinal taxa. To reconcile local livelihood needs with ecological integrity, we developed and implemented targeted programs in Good Field Collection Practices (GFCPs).

GFCP protocols merge modern ecological science with traditional seasonal collection rules. Collectors and frontline forest staff are trained in non-destructive techniques, such as avoiding the complete stripping of bark, leaving seed stocks for natural regeneration, and protecting root systems of perennial herbs like *Rauvolfia serpentina*. Linking GFCP compliance with primary processing, quality assurance, and direct market access demonstrates that sustainable collection safeguards bioresources while generating higher, long-term economic returns for local collectors.



4. Empowering Communities Through People's Biodiversity Registers (PBRs) and PES

India's Biological Diversity Act (2002) offers a statutory mechanism for decentralized governance through Biodiversity Management Committees (BMCs) and People's Biodiversity Registers (PBRs). Facilitating model PBR processes across states like Manipur, Chhattisgarh, Tripura, and Karnataka has shown how legal tools can translate directly into community empowerment.

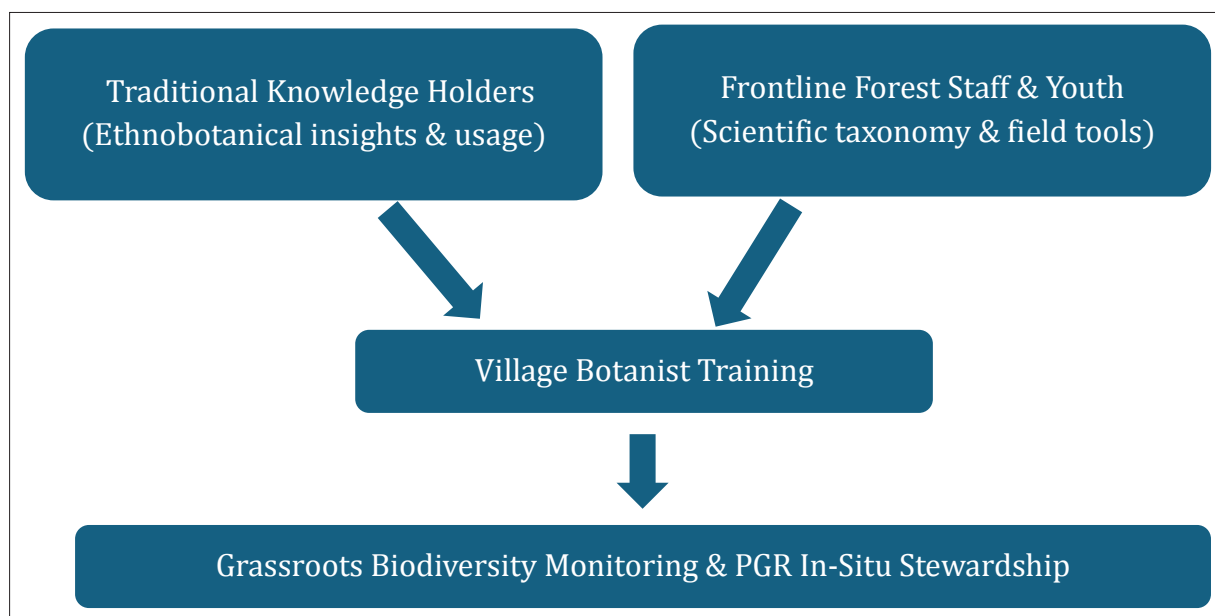
Participatory PBR preparation involves local community members as primary authors, mapping landraces, wild crop relatives, fauna, and local ecological knowledge. Beyond inventory creation, a robust PBR functions as a legal instrument for:

- **Access and Benefit Sharing (ABS):** Ensuring fair monetary and non-monetary returns when local biological resources or associated knowledge are accessed commercially.
- **Payment for Ecosystem Services (PES):** Enabling communities to claim direct economic incentives for maintaining critical habitats and wild plant genetic resources without destruction.

For instance, in Karnataka's Uttara Kannada district, organizing the PBR process empowered local collectors of *Garcinia gummigutta* to establish sustainable collection norms while securing higher market returns through collective bargaining. Connecting conservation directly to economic and statutory rights changes community perceptions of conservation from a restrictive obligation into a tool for self-reliance.

5. Building Cadres of "Village Botanists" for Grassroots Conservation

A persistent challenge in biodiversity conservation is the technical gap in plant identification among frontline forest officers, local youth, and community members. To bridge this gap, we initiated the "**Village Botanist**" program, a dedicated capacity-building module designed to train local parataxonomists.



To date, over 300 Village Botanists and frontline forestry staff across 12 Indian states have been trained in scientific plant identification, herbarium preparation, GPS mapping, vegetation monitoring, and sustainable harvesting. Equipped with field manuals and scientific concepts, these Village Botanists act as bridge-builders:

- They serve as local research anchors for BMCs during ethnobotanical surveys.
- They assist forest departments in developing realistic, flora-specific working plans.
- They provide early detection of ecological threats to vulnerable species in their immediate surroundings.

Conclusion

Harnessing Peninsular India's plant genetic resources requires moving away from top-down conservation towards community-owned stewardship. Integrating documented local health traditions, nation-scale ethnoveterinary livestock interventions, Good Field Collection Practices, statutory PBR-PES frameworks, and parataxonomic training through the Village Botanist program creates a comprehensive framework for community-led conservation. When local communities are legally empowered, scientifically equipped, and economically supported, traditional knowledge systems become dynamic drivers of biodiversity conservation and sustainable rural development.

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Recent Developments in the Global Policy Instruments on Access and Benefit Sharing Related to Plant Genetic Resources

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Introduction

Germplasm includes “plants in whole or in parts and their propagules including seeds, vegetative parts, tissue cultures, cell cultures, genes and DNA based sequences that are held in a repository or collected from wild as the case may be and are utilized in genetic studies or plant breeding programmes for crop improvement” (Plant Quarantine [Regulation of Import into India] Order, 2003). Plant genetic resources (PGR) are genetic material of plants having actual or potential value for research and breeding leading to food and agriculture as well as agro-industries. PGR include crop varieties, landraces, farmers' varieties, breeding lines, crop wild relatives, etc. occurring in agricultural systems, natural and urban forests, botanical gardens, kitchen gardens or conserved *ex situ* in genebanks. Because (i) crop diversity has historically moved across borders and (ii) modern crop improvement depends on genetic material originating from many regions—access and benefit-sharing (ABS) has become an important issue in international negotiations on biodiversity and agricultural governance.

It must be noted that the global ABS framework related to PGR is not governed by a single instrument. It consists of several interconnected (*and sometimes conflicting*) regimes, particularly the Convention on Biological Diversity (CBD), the Nagoya Protocol, the FAO International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and, increasingly, instruments dealing with digital sequence information (DSI), traditional knowledge (TK) and intellectual property (IP) such as WIPO Treaty.

The central negotiating point is that ABS is no longer simply a question of *access to genetic material*. Recent global policy developments are looking to find an answer a question of how nations governs the entire chain: Genetic Resource → Knowledge → Digital Information → Research → Innovation → Commercialization → Benefit-Sharing. For plant genetic resources, effective governance must balance the interests of disparate stakeholders on conservation, access, food security, scientific research, farmers' rights, indigenous and local community interests, technological innovation and distributive justice.

1. The CBD and Nagoya Protocol

The CBD established the fundamental international principles for ABS. It recognizes national sovereignty over genetic resources and links access to national legislation and the fair and equitable sharing of benefits. The Nagoya Protocol, which supplements the CBD, provides an implementational framework. Its principal mechanisms are prior informed consent (PIC) and mutually agreed terms (MAT). PIC requires authorization before access to genetic resources, while MAT establish the conditions governing access and benefit-sharing. Benefits can be monetary (royalties, licence fees, research funding and other payments) and non-monetary (technology transfer, training, capacity building, participation in research, sharing of scientific information and joint research). The Nagoya Protocol also introduced compliance measures, including national checkpoints and the ABS Clearing-House. These mechanisms seek to improve transparency and ensure that genetic resources are used in accordance with the rules of provider countries.

Why is this difficult for plant genetic resources?

The bilateral model of the Nagoya Protocol can be challenging when applied to agricultural genetic resources. Crop diversity has been exchanged between societies for centuries, and modern breeding frequently involves genetic material from several countries. Requiring separate negotiations for every exchange could create high transaction costs and impede research. Consequently, international policy increasingly recognizes that plant genetic resources for food and agriculture (PGRFA) have distinctive characteristics because of their importance to food security and their continual movement through research and breeding systems.

2. The International Treaty and the Multilateral System

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) provides a specialized multilateral approach. Its central innovation is the Multilateral System (MLS) of access and benefit-sharing. Rather than requiring individual bilateral agreements for every genetic resource, the MLS facilitates access to specified PGRFA while establishing mechanisms for sharing benefits arising from their utilization. Access is primarily implemented through the Standard Material Transfer Agreement (SMTA). The Treaty also recognizes Farmers' Rights, including the contribution of farmers and local communities to the conservation and development of crop genetic diversity.

Why recent Treaty negotiations illustrate a policy dilemma?

A major recent policy development has been the attempt to enhance the functioning of the MLS. Negotiations focused on issues such as: (i) expanding the material covered by the MLS; (ii) revising the SMTA; (iii) establishing more effective and predictable monetary benefit-sharing; (iv) improving the sustainability of the Benefit-sharing Fund; and (v) responding to technological developments, including genomic information.



The easier it is to access genetic resources, the greater the potential benefits for research and food security—but the more difficult it may be to ensure that benefits return fairly to providers, farmers and developing countries. The Governing Body's 2025 session did not reach agreement on the proposed enhancement package. Formal negotiations were subsequently paused for the 2026–2027 biennium. This does not mean that the MLS has ceased to operate; rather, it demonstrates the continuing difficulty of reaching consensus on the balance between access and benefit-sharing.

3. Digital Sequence Information: A Major New Frontier

One of the most important recent developments in ABS is the emergence of digital sequence information (DSI). Modern sequencing technologies allow researchers to obtain and exchange DNA and RNA sequence data digitally. A researcher may therefore obtain information about a plant's genetic characteristics without necessarily obtaining the physical seed or tissue.

The CBD has increasingly addressed this issue. At COP15 in 2022, Parties agreed to establish a multilateral mechanism for benefit-sharing from DSI. At COP16, decision 16/2 adopted modalities for operationalizing the mechanism, including a global fund known as the Cali Fund for the Fair and Equitable Sharing of Benefits from the Use of Digital Sequence Information on Genetic Resources. The Cali Fund was launched in February 2025. It is intended to receive contributions from private-sector entities making commercial use of DSI. Sectors identified as relevant include pharmaceuticals, cosmetics, plant and animal breeding, agricultural biotechnology and other biotechnology-related activities. By March 2026, the Cali Fund had completed its first year and had received its first contribution at the end of 2025, marking a transition from negotiation toward implementation.

For PGRFA, issue of DSI is particularly important because genomic databases are increasingly used to identify genes and traits associated with drought tolerance, disease resistance, nutritional quality and other characteristics relevant to crop improvement. Additional challenges include generation of DSI by global consortia that include CG genebanks raising questions of jurisprudence.

4. The 2024 WIPO Treaty

Another important development is the WIPO Treaty on Intellectual Property, Genetic Resources and Associated Traditional Knowledge, adopted on 24 May 2024. The Treaty establishes a mandatory *patent disclosure requirement for inventions based on genetic resources and/or associated traditional knowledge*. In relevant cases, patent applicants will have to disclose the country of origin or source of the genetic resource and, where applicable, the local community that provided the associated traditional knowledge. The Treaty is significant because it connects ABS concerns with the patent system. The Treaty is not itself a comprehensive benefit-sharing regime. Its major contribution is transparency and disclosure within intellectual-property governance. WIPO Treaty is yet to enter into force.

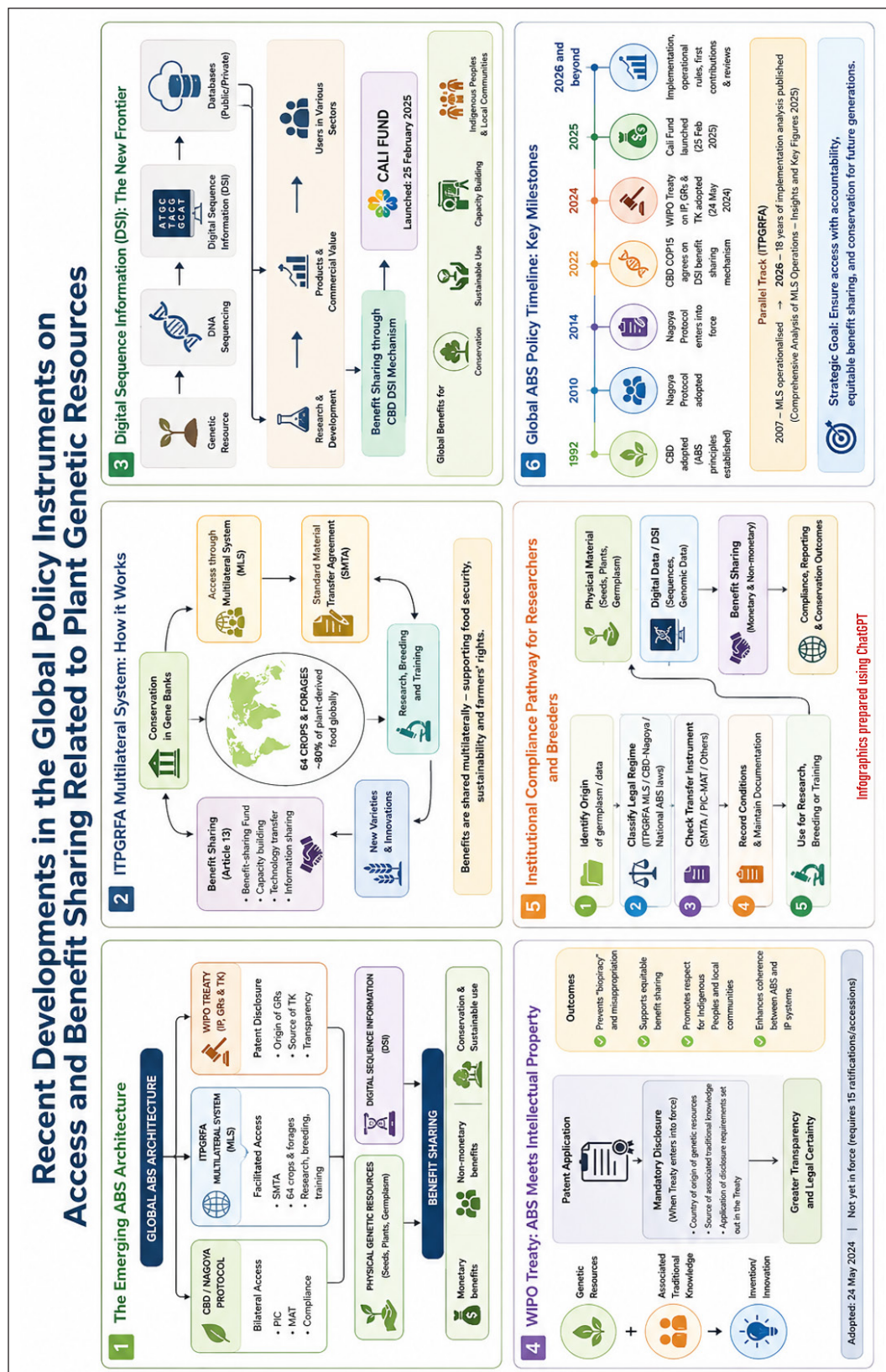
PGRFA cannot be understood only in terms of biological material. Many crop varieties and useful characteristics are associated with knowledge accumulated by farmers and Indigenous and local communities. Recent international developments therefore increasingly aim to connect ABS + traditional knowledge + intellectual property + farmers' rights. The WIPO Treaty is particularly relevant because it is the first WIPO treaty to address the interface between IP, genetic resources and associated traditional knowledge and specifically includes provisions concerning Indigenous Peoples and local communities.

5. The Emerging Policy Landscape

The overall direction of international policy is moving from a focus on physical access toward a more comprehensive governance of genetic resources, information, knowledge and innovation. Recent developments demonstrate that global ABS governance is becoming more complex and more closely connected with agricultural innovation and intellectual property. On one hand, there is a resistance to the enhancement of the MLS of the ITPGRFA. On the other, DSI is transforming the meaning of access itself. In one forum, strengthening an established multilateral mechanism of facilitated access to PGRFA has failed (inconclusive negotiations in the Treaty). Whereas, another forum has begun a major experiment in developing a multilateral benefit-sharing mechanism for DSI (The Cali Fund of the CBD). On a positive note, the WIPO Treaty adds another layer by connecting genetic resources and traditional knowledge with patent disclosure.

Without effective national legislations and operationalization of implementing agencies, global instruments bring no solace to PGRFA in general and conservers and users in particular.





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Enhancing Adaptive Management of Crop Diversity for Resilient Agriculture, Nutrition and Rural Livelihoods

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Introduction

India is one of the world's major centres of crop diversity and traditional agricultural knowledge. Peninsular India, encompassing the Western and Eastern Ghats, Deccan Plateau, coastal ecosystems, drylands and extensive tribal and rainfed farming landscapes, is particularly rich in cultivated diversity, landraces, crop wild relatives and associated indigenous knowledge. This diversity is not merely a biological and cultural heritage; it is a strategic resource for addressing some of the most pressing challenges confronting agriculture today.

Climate change, degradation of natural resources, emerging pests and diseases, dietary simplification, market volatility and changing rural livelihoods are increasingly exposing the vulnerability of uniform production systems. Crop genetic diversity provides agriculture with the biological options needed to adapt to such uncertainty. However, much of this diversity is disappearing from farmers' fields, while a substantial proportion of the diversity conserved in genebanks remains insufficiently characterized, evaluated and utilized.

The challenge before the plant genetic resources (PGR) community is therefore no longer conservation alone. We need to move towards adaptive management of crop diversity, connecting conservation with characterization, evaluation, crop improvement, seed systems, production landscapes, nutrition and markets. Such an approach can transform genetic resources from conserved biological materials into dynamic assets for climate resilience, food and nutrition security and sustainable rural livelihoods.

Experience of the Alliance of Bioversity International and CIAT and its partners in India and elsewhere demonstrates that agrobiodiversity can become an important instrument for sustainable development when farmers and communities are placed at the centre of its conservation, evaluation and use.

From Conservation to Adaptive Management: Conventional PGR programmes have made enormous contributions through exploration, collection, characterization and ex situ conservation. These efforts remain indispensable. India possesses one of the world's strongest institutional



systems for PGR management, with ICAR-NBPGR and its collaborating institutions playing a central role in safeguarding the country's genetic heritage. However, rapidly changing climatic, socioeconomic and food-system conditions require complementary approaches that enable genetic diversity to remain dynamic and responsive to farmers' needs.

Adaptive management recognizes that agricultural biodiversity is not static. Farmers continuously select crops and varieties according to rainfall, temperature, soils, pests and diseases, household requirements, culinary preferences and market opportunities. Climate change is now altering these selection environments at unprecedented speed.

A resilient PGR system should therefore establish continuous linkages among:

Conservation → Characterization → Evaluation → Seed Systems → Production → Nutrition & Markets → Rural Livelihoods

Importantly, this is not a one-way pathway. Information generated from farmers' fields, markets and changing environments should continuously feed back into conservation priorities, breeding objectives and decisions on which genetic resources require further evaluation. **Adaptive management is therefore a continuous learning cycle rather than a linear conservation-to-utilization process.**

Genebanks provide long-term security and access to genetic resources; on-farm conservation maintains evolutionary processes and traditional knowledge; participatory evaluation identifies diversity suited to particular environments and farmer preferences; community seed systems make this diversity accessible; and markets and food systems generate economic incentives for its continued cultivation.

The objective is ultimately to transform conserved genetic resources into living bioresources capable of continuously generating ecological, nutritional and economic benefits.

Mainstreaming Agricultural Biodiversity - Experience from India: The Alliance of Bioversity International and CIAT, working with ICAR institutions, State Agricultural Universities, civil-society organizations, farming communities and government agencies, has demonstrated an integrated approach to mainstreaming agricultural biodiversity within agricultural production systems.

A major initiative supported by the Global Environment Facility (GEF) and the United Nations Environment Programme (UNEP) focused on mainstreaming agricultural biodiversity conservation and sustainable use across contrasting agroecological regions of India, including the Western Himalaya, Northeast, hot-arid region and Central Plateau. The programme deliberately moved beyond documenting diversity. It established mechanisms through which farmers could evaluate, conserve, exchange, multiply and economically utilize locally adapted genetic resources.

A comprehensive baseline assessment involving 22,047 farming households documented approximately 4,491 native varieties of 20 crops. Importantly, the assessment indicated that more than half of the landraces encountered in several landscapes were under varying degrees of threat. This highlights an important concern for PGR management: crop diversity can disappear from production landscapes before its potential value for climate adaptation, nutrition, crop improvement or future markets is understood.

The priority of adaptive PGR management must therefore be to identify not only what diversity exists, but also where it occurs, how rapidly it is changing, why it is disappearing and what attributes may justify its continued cultivation and use.

Farmers as Co-researchers - Crowdsourcing the Evaluation of Diversity: One major constraint in PGR utilization is the enormous scale of diversity requiring evaluation. Conventional multilocation trials provide scientifically robust information but are expensive and cannot easily capture the enormous heterogeneity of smallholder production environments and farmer preferences. Participatory and citizen-science approaches provide an important complement.

The Alliance and partners have increasingly applied TRICOT (Triadic Comparison of Technologies), a crowdsourced approach in which large numbers of farmers evaluate small subsets of varieties under their own management conditions. Instead of every farmer evaluating a large number of entries, individual farmers compare a small set and identify which performs best or worst for locally important attributes such as yield, maturity, drought tolerance, taste, cooking quality, fodder value or marketability. Statistical approaches subsequently combine thousands of these observations to determine varietal preferences and environmental adaptation.

In India, crowdsourced evaluations involving more than 1,000 mother trials and nearly 6,000 farmer-managed baby trials enabled diverse native germplasm to be evaluated under heterogeneous production environments. Approximately 246 promising native varieties were identified through these processes.

This represents an important transformation in PGR management. Farmers cease to be passive recipients of varieties and become co-researchers generating evidence about the adaptive value of genetic diversity.

Digital platforms such as ClimMob make it increasingly possible to manage large, decentralized datasets. When farmer-generated observations are combined with climatic, geographic, soil and socioeconomic information, they can help answer one of the most important questions for climate-resilient agriculture: **Which variety performs best, where, under what conditions and for whom?**

Community Seed Systems - Turning Diversity into an Accessible Resource: Identifying useful genetic diversity has limited impact unless farmers can access seed. Formal seed systems necessarily concentrate on a relatively limited portfolio of crops and varieties. Many traditional



varieties, minor crops and locally adapted materials therefore circulate primarily through farmer seed networks.

Community-managed seed banks (CSBs) provide an important bridge between conservation and utilization. Through Alliance-supported initiatives in India, CSBs have conserved hundreds of locally adapted cultivars while simultaneously facilitating seed multiplication, exchange and restoration of threatened diversity. Around 50 community-managed seed banks are being managed by the alliance through collaborative programmes have maintained around 3000 cultivars of various crops. Seed Saver Committees and farmer organizations have strengthened community responsibility for maintaining varietal identity, seed quality and equitable access.

Community seed banks should therefore not be viewed simply as miniature genebanks. Their greater value is in functioning as local crop-diversity hubs connecting conservation, farmer experimentation, seed multiplication, traditional knowledge and rural enterprise. Linking community seed banks with the national genebank and research institutions creates a particularly powerful complementary conservation system. Threatened and promising materials maintained by communities can be securely conserved *ex situ*, while materials held in genebanks can be returned to production landscapes for evaluation, adaptation and use.

Crop Diversity for Better Nutrition: Agricultural modernization has significantly increased production of major staples, but dietary simplification has occurred simultaneously in many rural and urban communities. Numerous nutrient-rich traditional crops—including millets, pulses, indigenous vegetables, tubers and fruits—have declined in cultivation and consumption. Nutritional characterization therefore represents an increasingly important dimension of PGR management. Alliance-supported programmes have undertaken nutritional profiling of more than 5000 native varieties of >15 crops, revealing considerable diversity for nutritionally important attributes. This creates opportunities to select diversity not merely for agronomic performance but also for its contribution to healthier diets.

Crop diversity can consequently be linked with nutrition gardens, school meal programmes, public food procurement, local food enterprises and nutrition-sensitive agriculture.

Women-led nutrition garden initiatives implemented through collaborative programmes have reached approximately 20,000 households, demonstrating how diversity maintained at household and community levels can directly contribute to improved access to diverse foods. The future PGR agenda therefore needs to explicitly connect:

Genetic diversity → Crop diversity → Food diversity → Dietary diversity → Human nutrition.

Making Diversity Economically Competitive: One of the strongest determinants of whether farmers continue cultivating traditional varieties is economic viability. Farmers cannot be expected to maintain crop diversity indefinitely purely for conservation purposes if diverse

crops and varieties provide lower or uncertain returns compared with commercially dominant alternatives. Conservation must therefore increasingly be linked with processing, value addition, branding, geographical identity, institutional procurement and differentiated markets.

Alliance-supported programmes have facilitated value-chain development for native crops and varieties through farmer producer organizations, self-help groups, community institutions and local enterprises. At least 11 crop-diversity-based value chains have been strengthened, while selected aromatic native rice varieties have generated approximately 30–35% price premiums. Experience across India shows that appropriately differentiated native crop products can increase farmer returns while simultaneously generating economic incentives for maintaining genetic diversity. This represents an important transition:

Diversity as Heritage → Diversity as Resource → Diversity as Enterprise

The symposium's vision of moving “From Biodiversity Hotspot to Sustainable Bioresource Hub” is particularly relevant here. Genetic resources can underpin new climate-resilient seed enterprises, nutritious food products, premium traditional foods, processing industries and geographically differentiated agricultural commodities.

Commercialization, however, must be equitable. Recognition of farmers' contributions, Farmers' Rights, traditional knowledge, access and benefit-sharing arrangements and participation of communities in emerging value chains must remain integral to this transformation.

Lessons from Alliance Experience Beyond India: The Alliance's work across Asia, Africa and Latin America reinforces the importance of diversity-based approaches to agricultural resilience. Community seed banks in different countries have demonstrated their capacity to restore locally adapted diversity, improve access to planting materials and strengthen communities' ability to respond to climatic shocks. Participatory varietal evaluation has shown that farmers frequently identify useful genetic materials and adaptive traits that conventional evaluation systems may overlook.

Citizen-science approaches such as TRICOT increasingly enable thousands of farmers to participate directly in crop evaluation. Combined with climatic and environmental information, these distributed experiments can generate powerful evidence about genotype × environment × management interactions and farmers' preferences. The broader lesson from these experiences is that crop diversity must be managed at several interconnected levels:

Genes → Varieties → Farms → Landscapes → Markets → Food Systems

Resilience does not emerge from diversity at any one level. It emerges from interactions among diversity, people, institutions, environments and markets across these scales.

Peninsular India from Biodiversity Hotspot to Sustainable Bioresource Hub: Peninsular India provides exceptional opportunities to demonstrate this integrated approach. Its landscapes contain rich diversity of rice, millets, pulses, oilseeds, vegetables, spices, tuber crops, fruits and



crop wild relatives. Tribal and traditional farming communities have maintained not only genetic resources but also valuable knowledge associated with their selection, cultivation, processing, culinary use and adaptation.

The next step should be the establishment of regional crop-diversity innovation platforms connecting farming communities, community seed banks, ICAR institutions, State Agricultural Universities, national and international genebanks, private enterprises, civil society and local governments. Such platforms could systematically:

- **Map diversity and threats** – identify crop diversity, crop wild relatives, traditional knowledge and areas experiencing rapid genetic erosion.
- **Secure priority diversity** – strengthen complementary ex situ, in situ and on-farm conservation.
- **Characterize value** – combine genomics, phenotyping, nutritional profiling and traditional knowledge to identify useful traits.
- **Evaluate under real conditions** – deploy TRICOT, citizen science and decentralized trials across diverse environments.
- **Connect diversity with breeding** – facilitate pre-breeding and use of landraces and crop wild relatives for climate-resilient crop improvement.
- **Strengthen diverse seed systems** – establish community seed banks, decentralized seed production and farmer-led seed enterprises.
- **Create market incentives** – support value addition, branding, processing, geographical differentiation and market development.
- **Integrate diversity into food systems** – connect traditional crops with nutrition programmes, institutional procurement and local diets.

Modern genomics, high-throughput phenotyping, environmental characterization, digital agriculture and artificial intelligence can substantially accelerate these processes. But technology should complement rather than replace the accumulated knowledge of farming communities. The most powerful innovation is likely to emerge from combining genomic intelligence, environmental information and farmers' experiential knowledge.

Redefining Success in PGR Management: Historically, the success of PGR conservation has often been measured through numbers of accessions collected, characterized and safely conserved. These remain essential indicators. However, the next generation of PGR programmes should also measure **how effectively diversity generates societal benefits**.

We should increasingly ask:

How many conserved accessions have returned to farmers' fields? How many have contributed useful traits to climate-resilient varieties? How many nutritionally superior landraces have

entered food systems? How many community seed enterprises are sustainably maintaining diversity? How many farmers obtain greater income because genetic diversity has acquired market value? And how much threatened diversity has become secure because farmers once again have a reason to cultivate it?

Such questions shift the emphasis from simply conserving diversity to conserving diversity through sustainable use and value creation. This transformation will require closer collaboration among genebanks, breeders, geneticists, ecologists, nutritionists, economists, seed-system specialists, market actors, policymakers and most importantly the farming communities that have maintained this diversity over generations.

Conclusion

Plant genetic resources constitute biological insurance for an increasingly uncertain agricultural future. Yet this insurance has value only when genetic diversity is conserved, understood, accessible and capable of responding to changing environments and human needs. The challenge before the PGR community is therefore to transform collections of genetic material into dynamic portfolios of adaptive options for farmers, breeders, communities and food systems. Experience of the Alliance of Bioversity International and CIAT and its partners demonstrates that this transformation is possible when conservation is connected with participatory evaluation, citizen science, community seed systems, nutritional characterization, crop improvement, value-chain development and enabling policies.

For Peninsular India, the opportunity is particularly significant. Its extraordinary crop diversity, associated traditional knowledge, strong scientific institutions and emerging markets provide the foundations for moving decisively from a biodiversity hotspot to a sustainable bioresource hub. The future of crop diversity will ultimately depend not only on how much diversity we conserve, but also on how intelligently we use it, how equitably we share its benefits and how successfully we create incentives for farmers and future generations to continue maintaining it.

Adaptive management of crop diversity therefore provides a pathway in which conservation and development cease to be competing objectives. Instead, crop diversity becomes the connecting thread between genetic-resource conservation, climate-resilient agriculture, nutritious food systems, viable rural livelihoods and sustainable management of India's biological heritage.

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Biosecurity and PGR: Safeguarding against Emerging Threats

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Introduction

International exchange of seeds and other planting material carries an inadvertent risk of introduction of exotic pests viz., insects, fungi, bacteria, viruses, nematodes, weeds etc. or their new virulent races/strains/biotypes into new areas. History has witnessed several examples of dangerous pests introduced along with seeds and other planting material that have led to economic yield losses and plant quarantine assumes special importance in pest-free trade/exchange of plant genetic resources (PGR). International exchange of PGR is important to broaden the genetic base of crops in order to develop improved crop varieties. The Government of India has legislated the Plant Quarantine (Regulation of Import into India) Order 2003, [hereafter referred to as PQ Order] under the Destructive Insects and Pests Act 1914 to regulate the import of plant material. As per the PQ Order, >1200 pests are regulated pests which are of quarantine significance for India. The PQ Order requires *Additional Declarations* to be included in the Phytosanitary Certificate for seeds and other planting material as free from pests. Also, the PQ Order stipulates post-entry quarantine growing of plant propagative materials of specific commodities for a specific period in a confined area to prevent entry of exotic pests. Under the PQ Order, ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR) has been delegated powers to issue Import Permit and to carry out quarantine processing of imported PGR including transgenics and for issue of Phytosanitary Certificate for PGR meant for export.

ICAR-NBPGR, New Delhi is well equipped with *state-of-the-art* facilities including a Containment Facility for quarantine of transgenic germplasm. ICAR-NBPGR also has a well-equipped quarantine station at Hyderabad, which mainly deals with the quarantine of PGR meant for Southern India including State Agricultural Universities, ICAR institutes, private industry and international institutes viz., International Crop Research Institute for Semi-arid Tropics (ICRISAT) and World Vegetable Centre.

The Division of Plant Quarantine at ICAR-NBPGR, New Delhi has developed an efficient and systematic methodology for quarantine processing for pest diagnosis, interception and salvaging of infected/ infested PGR to ensure biosecurity during exchange of PGR. Stringent quarantine examination including systematic step-wise strategy is being followed for testing of each of the imported samples for presence of any exotic pests.

Over the years, during quarantine processing, a large number of pests have been intercepted in imported germplasm. The intercepted pests can be categorized as: Pests not known to occur in India; Pests with different races/ biotypes/ strains not known to occur in India; Pests intercepted on a new host or are from a country from where they have never been reported before; New pest species hitherto unreported in science and Pests reported to be present in India. A total of 100 exotic pests including insects/ mites (26), fungi (7), bacteria (1), viruses (25), nematodes (9) and weeds (32) that are not yet reported from India have been intercepted so far. The samples found infested/ infected with pests were salvaged using suitable methods and if they could not be salvaged, they were rejected and destroyed by following Standard Operating Procedure. If any of these exotic pests had not been intercepted and had escaped, they could have entered and established in India and subsequently caused devastation to Indian agriculture.

Under the PQ order, a pest risk analysis (PRA) has been made mandatory for all material being imported into the country other than those present in Schedules V and VI. In case of germplasm, a large number of species of cultivated crops and their wild relatives with useful traits are imported. Such wild relatives are not mentioned in the PQ Order, which hampers their import. However, in 2007 the legislation has been amended whereby ICAR-NBPGR is empowered to undertake PRA for germplasm of crops/ country not mentioned in the PQ Order. In order to facilitate PRA, ICAR-NBPGR has brought out edited books on potential quarantine pests for India in cereals, grain legumes, edible oilseeds, cucurbitaceous and solanaceous vegetable crops, tropical and sub-tropical fruit crops, temperate fruit crops and root, bulb and tuberous vegetable crops including information on global distribution, host range and other aspects related to biology, survival and spread of these pests which are essential components of risk analysis to meet international regulations.

The technical issues include issues pertaining to quarantine processing i.e. methodology for detection and salvaging of pests are enumerated follows:

- The amount/ size of the germplasm sample is very crucial from quarantine processing point of view, as sampling procedures meant for bulk material cannot be adopted. Also, the technique applied should enable detection of miniscule amounts of pest in the samples drawn and also be non-destructive. The sample size may not be enough for direct testing of seed and post-entry quarantine testing and release from virus-free plants after testing may take one crop season.
- The reference material/ positive controls for exotic pests are often not available. A repository of reference material needs to be established as one has to deal with exotic pests in quarantine.

Development of sensitive molecular diagnostic protocols kits for prognostic detection of exotic pests and their variants is important.

- Expertise is also required in the field of taxonomy and biosystematics as there is a continuous need to identify unknown/ new pathogens or strains. Also, there is a need for development of digitized biosystematic keys for pest identification.
- Strengthening research on the development of eco-friendly non-chemical techniques as effective mitigation treatment as alternatives to methyl bromide fumigation.

India need to establish a strong network of interconnected accredited laboratories to quickly diagnose new pests/pathotypes/biotypes/strains and enhance surveillance capacity to identify new pests. This makes it imperative that India should put in place a “National Plant Pests Diagnostic Network” to enhance preparedness. By closely monitoring which pests are most frequently reported from which countries, and what plant material tend to be infested/infected, it may be possible to predict high-risk pests and crops. Also, genomics would help in continuous surveillance, rapid diagnosis and real-time tracking of global movement of pathogens and insect pests. Machine learning and AI algorithms can be leveraged to analyse large-scale genomic data sets and predict disease outbreaks based on environmental and epidemiological factors. The importance of quarantine has increased manifold in the WTO regime and adopting not only the appropriate technique but also the right strategy for pest detection and diagnosis would go a long way in ensuring pest-free exchange of PGR and is considered the best strategy for managing transboundary movement of pests.

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Farmers' Rights and Community Participation in PGR Governance in Biodiversity Hotspots

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Introduction

Any discussion on farmers' rights in plant genetic resources (PGR) governance must begin with two questions: Who qualifies as a farmer? and What constitutes a farmers' variety?

The Protection of Plant Varieties and Farmers' Rights Act, 2001 (PPVFR Act) defines a farmer as one who cultivates land personally or through supervision, or conserves wild species and traditional varieties. A farmers' variety is one traditionally cultivated and evolved by farmers, or a wild relative/landrace known to them. The Biological Diversity Act (Amendment), 2023 complements this framework by separately defining cultivars, folk varieties, landraces, and farmers' varieties, while retaining the PPVFR Act's definition for the latter. (Sahai, 2003).

These definitions recognize a wide spectrum of farmers, from tribal communities conserving crop wild relatives in the Western Ghats to commercial farmers selecting varieties for yield and market demand. Farmers as conservers extend to wild species of food, medicine, and cultural value. The Botanical Survey of India has described over 44,500 plant species from India, including 22,108 angiosperms, 1,319 pteridophytes, 2,819 bryophytes, 3,044 lichens, 15,701 fungi, and 9,035 algae, making India one of the world's richest centres of plant diversity (Botanical Survey of India, 2022)

Wild PGRs and Farmers' Rights

India's genetic wealth of food, nutrition and health value extends beyond cultivated crops to over 320 crop wild relatives (CWRs) documented by the National Bureau of Plant Genetic Resources (NBPGR), with many concentrated in biodiversity hotspots like the Western Ghats (Pradheep et al., 2022). About 6,560 species are recognized as medicinal plants, widely used by tribal households.

The Indian gene centre comprises 166 native cultivated plants and their wild relatives, reservoirs of traits for yield, nutrition, and resilience. In the Western Ghats, families such as *Fabaceae*, *Poaceae*, *Cucurbitaceae*, and *Zingiberaceae* dominate. Tribal farmers conserve wild rice, pepper, cardamom, bananas, and yams across generations. Laws such as the PPVFR Act



(2001), Forest Rights Act (2006), and Biological Diversity Act (2002) secure farmers' rights as cultivators and conservers.

Crop Wild Relatives and Tribal Custodianship in Kerala

Kerala's Western Ghats, especially Wayanad, are rich in crop wild relatives and wild foods. A study on wild foods of Wayanad documented over 300 wild edible species, many of which are crop wild relatives of cultivated staples (Ratheesh *et al.*, 2011). Forest dwellers thus qualify as farmers under law, sustaining biodiversity through conservation and seasonal use.

Tribal communities conserve wild rice in wetlands, maintain pepper vines in sacred groves, protect cardamom in forest patches, and preserve bananas, yams, cucurbits, ginger, and turmeric for food, rituals, and medicine. These practices highlight that custodianship of wild relatives is integral to biodiversity governance.

Gender and Farmers' Rights

India's biodiversity laws recognize farmers as cultivators and conservers. The Kunming–Montreal Global Biodiversity Framework (KMGBF) strengthens this mandate. Target 22 demands equitable participation of indigenous peoples, while Target 23 emphasizes gender-responsiveness and protection of traditional knowledge.

Women, often primary custodians of seed diversity, wild foods, and medicinal plants, must be central to governance. Several studies show in biodiversity hotspots like the Western Ghats, tribal women play a central role in conserving wild yams, leafy greens, and medicinal rhizomes (Narayanan & Kumar, 2007). Recognizing this gap, the Kerala State Biodiversity Board (KSBB) has taken pioneering steps in gender mainstreaming within biodiversity governance (She-Bio Report KSBB, 2025) through:

- 50% representation of women in Biodiversity Management Committees (BMCs).
- Annual awards for women conservers of biodiversity.
- “She Bio” programme, ensuring equitable access to justice, information, and decision-making.

Aligning national laws with KMGBF ensures inclusive governance that empowers women farmers as equal custodians of genetic resources.

Way Forward

1. Strengthening Documentation and Custodianship

The Biological Diversity Act mandates documentation of traditional knowledge through People's Biodiversity Registers (PBRs). These must be community-specific and resource-specific, not generic. Registers should include:

- **Farmers' Varieties Registers** for cultivated and wild relatives.
- **Medicinal Plant Registers** linked to traditional healers.
- **Community-specific registers** for forest dwellers, fisher groups, pastoralists, and tribal farmers.

Such tailored documentation embeds governance at the grassroots, makes custodianship visible, and ensures benefit-sharing provisions are enforceable.

2. Strengthening Benefit-Sharing Mechanisms

Registers must link directly to benefit-sharing under the PPVFR Act, Biological Diversity Act, and National Gene Fund. Breeders accessing documented diversity for crop improvement trigger benefit-sharing obligations. Communities conserving genetic material are entitled to rewards—monetary, infrastructural, or developmental. This approach recognizes custodians as co-creators of agricultural innovation, while breeders gain access to diverse genetic resources.

Conclusion

The PPVFR Act's recognition of farmers as cultivators and conservers expands the scope of farmers' varieties to include crop wild relatives, medicinal plants, and culturally significant species. Linking documentation mandates under the BD Act with KMGBF's inclusive targets ensures that custodianship, gender-responsive participation, and benefit-sharing are practically realized. This integration makes biodiversity governance in hotspots like the Western Ghats inclusive, just, and equitable, empowering tribal and women farmers as equal rights-holders and custodians of genetic resources.

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Harnessing Plant Genetic Resources of Peninsular India

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Introduction

Peninsular India, comprising the Western Ghats, the Eastern Ghats, the Deccan Plateau, the coastal plains, and the adjoining island systems, is among the most botanically diverse tracts in the country. This landmass is not a uniform block of forest and farmland; it is a mosaic of climates, soils, and altitudes that has, over millions of years, given rise to an extraordinary range of plant life. Within this larger canvas, the Western Ghats stand out in particular. Recognised by UNESCO as a World Heritage Site and counted among the world's biodiversity hotspots, the range alone is home to approximately 5,000 species of vascular plants, a striking proportion of which occur nowhere else on Earth.

This region deserves special attention because it has such a wide variety of valuable resources. Peninsular India is agriculturally and horticulturally rich in spices, plantation crops, medicinal and aromatic plants, fruits, vegetables, tuber crops, millets, pulses, oilseeds, and a wide array of wild relatives of cultivated species. Many of these plants are not merely present in the region; they are found in forms and combinations unique to it, shaped by centuries of local cultivation practices alongside natural evolutionary pressures. Such diversity underpins food security, nutrition, and rural livelihoods across southern India, and it also carries considerable, still largely untapped, commercial and pharmaceutical value.

At the same time, this genetic wealth is under mounting pressure. Habitat degradation, climate change, unchecked urbanisation, overexploitation of wild populations, and the gradual erosion of traditional knowledge systems are together eating into the resource base faster than it can be documented, let alone conserved. Compounding the problem are gaps in the systems meant to safeguard this diversity: exploration of many areas remains incomplete, genetic characterisation lags behind collection, and policy frameworks across states are not always in harmony with one another.

Understanding Diversity for Sustainable Use

Scientific work on plant genetic resources cannot proceed responsibly without a clear legal and ethical framework to guide it, and this is the concern this theme addresses. In India, this framework rests substantially on the Protection of Plant Varieties and Farmers' Rights Act



(PPV&FRA) and the Biological Diversity Act, both of which set out how genetic resources may be accessed, used, and exchanged, while also defining the rights of the farmers and communities who have preserved this diversity over generations. Alongside these laws, biosafety and quarantine regulations play a preventive role, ensuring that the movement of plant material, whether within the country or across borders, does not introduce pests, diseases, or unintended ecological risks. Just as important is the protection of traditional knowledge, the accumulated understanding that farming and indigenous communities hold about local plants, which is often overlooked despite being central to how these resources were identified and conserved in the first place. Tying all of this together is the principle of benefit-sharing: when a genetic resource leads to a commercial product, whether a new crop variety or a pharmaceutical compound, the communities who conserved and shared that resource should receive a fair share of the resulting benefits, and ethical bioprospecting practices exist to see that this happens in practice rather than merely in principle.

In this progression is where conserved and well-understood genetic diversity is translated into tangible economic and social value. This happens partly through value addition, processing raw plant material into finished products, and branding them effectively, which is especially visible in the growing market for nutraceuticals and herbal formulations derived from traditional medicinal plants. Start-up incubation support and public–private partnerships play a significant role here as well, since converting a promising plant-based idea into a viable product usually requires funding, technical guidance, and market access that individual researchers or farmers rarely have on their own. Equally important is the deliberate promotion of traditional and underutilised crops, plants that have long been part of local diets and farming systems but have been overshadowed by a handful of mainstream commercial crops, for niche and specialty markets where their unique qualities can command a premium. Taken together, these efforts show how biodiversity, when supported by the right institutional and market mechanisms, can directly improve rural livelihoods rather than remaining a purely scientific or conservation concern.

Why Biodiversity Matters for Sustainable Development

Biodiversity is the foundation of food security, health, and economic stability. The genetic diversity found in crops, wild relatives, and traditional varieties helps agriculture adapt to challenges such as changing rainfall and new pests and diseases. Greater diversity improves nutrition, supports communities during climate change, and protects traditional knowledge and livelihoods passed down through generations. This is why the Sustainable Development Goals emphasize conserving genetic resources. Biodiversity provides the basis for climate-resilient crops, plant-based medicines, and the ecological balance needed for agriculture. Losing it through habitat destruction or replacing traditional varieties with a few commercial crops would reduce the choices available to both present and future generations. India's status as one of the world's twelve mega gene centres means its agricultural landscape carries genetic wealth far

beyond what most people assume. This diversity shapes how resilient the country's food system is to climate stress, pests, and shifting demands. The sections below look at how this diversity is conserved, how it is applied through natural farming, how research turns it into usable crop improvements, and how it connects to the law that keeps food safe.

Plant Genetic Resources Research Helps in Agriculture

PGR research becomes valuable when conserved plant diversity is used to improve crops. A good example is the development of flood-tolerant rice. The rice landrace FR13A from Odisha was found to survive complete submergence for up to two weeks, while most high-yielding varieties would die within a few days. Researchers found that this tolerance comes from the SUB1A gene, which slows the plant's growth underwater and helps it save energy until the floodwater goes down. Using marker-assisted backcrossing, breeders transferred SUB1A from FR13A into popular rice varieties while keeping their other useful traits. This led to flood-tolerant varieties such as Swarna-Sub1, which had two to four times higher survival than ordinary Swarna after 12–17 days underwater. This example shows why NBPGR's work is important. Conserving traditional landraces preserves valuable genetic traits that can later be used to solve specific farming problems caused by climate change. A study in the Western Himalaya recorded a decline of 42 to 92 percent in the area under traditional crops such as finger millet and buckwheat, as farmers shifted to high-yielding varieties, while a Western Ghats survey in Karnataka found that landraces mainly survive where they still suit local conditions or hold cultural value.

Role of The Biological Diversity Act, 2002 in Conserving Biodiversity and Genetic Resources

Along with food safety laws, the Biological Diversity Act, 2002 also plays an important role as to how India's plant genetic resources (PGR) can be studied and used. Section 3 is especially important because it requires foreign individuals, non-resident Indians, and companies with foreign participation to get approval from the National Biodiversity Authority (NBA) before accessing Indian biological resources for research, commercial use, or bio-survey. This means that a foreign university or company cannot simply collect plant samples or traditional seed varieties from places such as the Western Ghats or local farming communities without permission. The law therefore helps protect valuable PGR, including landraces, medicinal plants, and wild relatives of crops, which are important biological resources of Peninsular India.

Section 6 becomes important after research has produced useful results. It states that no one can apply for a patent or Intellectual property right in India or abroad based on research or information obtained from an Indian biological resource without prior approval from the National Biodiversity Authority (NBA). The NBA can also require benefit-sharing fees, royalties, or other conditions so that part of the financial benefits from commercial use goes back to India and to local communities whose resources or knowledge helped in the discovery. This is important for PGR because landraces and traditional plant knowledge may have future commercial or medicinal value.



Together, Sections 3 and 6 act as regulatory system. Section 3 regulates who can access India's biological resources, while Section 6 regulates how the results of that access can be commercially used. This helps ensure that India's genetic resources are not only conserved and researched but also protected from exploitation without fair benefits.

Food Safety and Food Security India

Harnessing plant genetic resources is only half the job; the other half is making sure that what finally reaches someone's plate is actually safe to eat. This is where food law steps in, and in India that mostly means the Food Safety and Standards Act, 2006. The courts have made it clear that this is not just a technical regulation but a constitutional issue: in *People's Union for Civil Liberties v. Union of India*, the Supreme Court said the right to food comes from the right to live with dignity under Article 21, and in *Centre for Public Interest Litigation v. Union of India*, the Court told FSSAI to keep a closer watch on pesticide residues in food and drinks. So, the same crop diversity that PGR work tries to conserve and improve is, in the end, meant to serve this constitutional promise of safe, adequate food. The National Food Security Act, 2013 adds another layer by giving eligible citizens a legal right to subsidised foodgrain, which means food security in India is not just a goal but something the law guarantees on paper.

Since food adulteration is on the Concurrent List, both the central and state governments get the power in regulating it: FSSAI decides the national standards, and the state Commissioner of Food Safety handles the actual licensing and inspections on the ground. FSSAI cancelled the licences of 111 spice manufacturers and cases like this bring the whole PGR conversation into a full circle. Resilient crops are important, but Indian law makes it equally clear that the food coming from those crops have to pass safety standards too, and every business, big or small, are to be held accountable.

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GIs as a Tool for Biodiversity Valorisation in India

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Introduction

“Geographical Indication” in relation to goods means an indication which identifies such goods as agricultural goods, natural goods or manufactured goods as originating in the territory of a country, region or locality, where a given quality, reputation or other characteristics is essentially attributable to its geographical origin; for manufactured goods, at least one activity of production, processing, or preparation must take place in that territory. Goods include agricultural, natural, manufactured goods, or any goods of handicrafts, or of industry, and includes foodstuff.

In an era defined by climate change and competitive global market systems, IP protection of bioresources especially through their registration as Geographical Indications (GIs), have emerged as a powerful tool for biodiversity valorisation. Protection of bioresources not only help to adapt to and mitigate climate impacts, but also drive market growth by adding enhanced value to unique goods rooted in nature of specific regions and culture of specific communities. Protection of unique goods as GIs preserves cultural heritage and their market promotion empowers local economies. In India, GIs are emerging as a powerful tool for biodiversity valorisation — converting goods from unique plant varieties, landraces, animal breeds, art and craft items and traditional foods linked to specific ecologies and communities into market-valued, income-generating GI assets for local communities. GIs can protect and preserve IP related to biological diversity, traditional cultures and knowledge and production methods.

International protection of unique goods is facilitated by multilateral treaties like the Paris Convention (1883), Madrid Agreement (1891), Lisbon Agreement (1958), and the TRIPS Agreement of 15 April 1994. TRIPS is the first multilateral treaty dealing with Geographical Indications. India, as a member of WTO and signatory to TRIPS, enacted the Geographical Indications of Goods (Registration and Protection) Act 1999 and GI Rules 2002. The Act is administered by the Controller General of Patents, Designs and Trademarks, who is also the Registrar of GIs. It came into force on 15th September 2003 and the Geographical Indications Registry was established at Chennai with all-India jurisdiction.

GIs directly link biodiversity to market value. GI registration preserves community knowledge on biodiversity. Protection of traditional knowledge on bio resources contributes to the wider objective of concerning the environment, biodiversity and sustainable agricultural



practises. By protecting traditional products that depend on local germplasm, and traditional knowledge, GIs achieve conservation of Agro-biodiversity by encouraging cultivation of native crop varieties, landraces, and breeds instead of replacing them with HYVs and hybrids. GIs grant IP right to community and not to individual right holders. This ensures flow back of benefits to all conservers of biodiversity of a specific region. More over enhancement of market recognition and premium prices of goods coming from local bioresources create income in rural areas, making conservation economically viable. Thus, GIs transform biodiversity from a "free resource" into a branded, value-added asset. GI tag signals authenticity and quality, allowing producers to command higher prices in national and international markets. More over GI registration prevents unauthorized parties from using the GI tag. GI products become cultural ambassadors, promoting eco-tourism and food and farm tourism.

Any association of persons, producers, or organization representing producers can apply for GI registration. Once registered Registered Proprietor (The association/authority that holds the GI on behalf of the community) can take legal action against infringement. Registered Authorized Users(registered individual producers)get the right to use the GI tag. They can independently sue infringers and are key to maintaining quality and consistency.

At present, a total of 822 goods is registered under the GI Act and many more are awaiting registration. Examples of GIs from bioresources include Coorge orange, Mysore betel leaf, Nanjanagud banana and Coorge green cardamom from Karnataka; Pokkali rice and Chengalikodan nendran banana from Kerala; Tezpur litchi from Assam, Gundur sannam chilli from AP, Thooyamalli rice from TN and Goa kaju apple from Goa.

Darjeeling tea was the first product registered as a GI in India in 2004. Darjeeling tea is a tea (*Camellia sinensis*) cultivated grown, produced, processed and manufactured in 87 tea gardens of Darjeeling district in the state of West Bengal. The tea gardens are located at elevations of over 2000m above the sea level. In order to ensure the supply of genuine Darjeeling tea, a compulsory system of certifying the authenticity of exported Darjeeling tea was incorporated into the 1953 Tea Act in February 2000. The system makes it compulsory for all the dealers of Darjeeling tea to enter into a licence agreement with tea board of India on payment of an annual fee.

GIs are more than just IP tools. In the Indian context, they offer a mechanism for biodiversity valorization. By linking product, place, and people with market, GIs ensure that conservation of native biodiversity, traditional knowledge, and local ecosystems is profitable. This creates a sustainable model where conserving nature and its genetic resources directly translates into prosperity for rural communities.

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Conservation, Characterization, and Commercialization of Farmers' Varieties

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Introduction

Conservation, characterization, and commercialization of local germplasm developed by farming communities besides grassroots innovators who have developed farmer own varieties, pose several challenges. Studies have shown that soil health, crop health, animal health, and human health are linked (Gupta, 2009; Bishnoi et al., 2026) and therefore, germplasm/landraces and farmers' varieties help in reaching these goals (Banerjee & van der Heijden, 2023). These have to be identified, amplified, and leveraged for meeting food, nutrition, and health needs of people, their ecosystems, and agroecosystems (Gupta, 2003, 2007). For over twenty years, the Honey Bee Network has been arguing that the descriptors of various crops and horticultural species must be modified to include information about their unique nutritional and agroecological adaptability to abiotic and biotic stresses, as well as their suitability for food processing related to the health and wellness sector. Several directors of NBPGR were contacted in this regard, and a substantial change is yet to take place. Even the descriptors used by the FAO have not been broad enough to include farmers' indigenous knowledge, women's culinary criteria in their choices, and other community knowledge about adaptability to different stresses, specific mineral uptake efficiencies, food processing, and other functional food potential.

In an international project, NBPGR and ICRISAT tried to close some of the gaps in the case of Fonio millet (*Digitaria exilis*) by looking at characteristics of nutrition and adaptability to biotic and abiotic stresses. It is well known that when income increases in any society, the share of processed food also increases. If we do not document and characterize the suitability of our landraces for food processing, health, medicinal, and wellness sectors, the incentives for conserving these varieties decline because of lower yields and prices. In this paper, we argue that there is a huge potential for increasing farmers' income by characterizing the germplasm, particularly the landraces, on various criteria that the market has begun to appreciate. It is true that not all characteristics may be known in scientific terms to the local communities. Flaxseed (*Linum usitatissimum*), which was fed to horses in olden times and sold for one hundred rupees a quintal, now sells for one hundred rupees per one hundred grams. Such income enhancement took place largely through characterization, as scientists found it to have a very high content of omega-3 fatty acids (Goyal et al., 2014). Since the vegetarian population often lacks this nutrient, flaxseed is now found on the table of most people.



Even more useful is *Perilla* (*Perilla frutescens*), grown in Nagaland and a few other places, which has double the omega-3 and omega-6 fatty acid content (Asif, 2011). The future superfood is waiting to transform the lives of local communities in the far northeastern corner of India. In part one, we discussed various criteria on which the germplasm can be characterized and recommended a massive national mission for conservation, characterization, and commercialization of local varieties, to provide incentive for conservation of agrobiodiversity in different agroecological contexts and at the same time improve the health and wellness of consumers. We also suggest that postgraduate departments of biochemistry, microbiology, and food science should also be involved in creating a distributed program for characterization in a time-bound manner. The same species growing on different kinds of soils and in different agro-climatic conditions may show valuable nutrients and other adaptive properties (Soares *et al.*, 2019).

a. Functional Food Uses

There are many crops and varieties which mobilize specific nutrients more effectively or in higher amounts than other crops. Within a crop, such as maize (*Zea mays*), local varieties have been reported to mobilize more boron than the hybrid ones. This helps in reducing the incidence of arthritis (Newnham, 1991). It is well known that one adverse health episode wipes away four–five years of savings of small farmers with low income. Hence, the case for meeting health goals with functional food is important. Bitra *et al.* (2023) discovered that the role of boron in the gut microbiota played an important role in dealing with Complex Regional Pain Syndrome, and boron compounds could offer a new therapeutic role. Germplasm rich in the ability to uptake boron needs special attention from conservation and characterization perspectives.

b. Medicinal Uses of Local Germplasm

Scientists have found that low glycemic index in crops such as rice or plant parts of other crops has medicinal uses (Tiozon *et al.*, 2025). Corn silk has a very high content of antioxidants and is known to be useful for UTI in women and prostate in men. There are many other plants and landraces which are particularly useful for medicinal purposes. Gurej pea was analyzed, courtesy of NBPGR and Biodiversity International, and it was found to have about 25 percent protein but very low phytates, making it more digestible for children and adults alike (Dey *et al.*, 2025).

c. Mineral Mobilization by the Crops

A lot of work has been done on iron and zinc mobilizing ability of crops. In a study of villages with high versus low incidence of chronic diseases, we have studied the health of soil, crop, animal, and human with the help of volunteer scientists from Anand Agricultural University and SRISTI. Medical doctors from public hospitals were also involved after ethics committee clearance. It was found that copper was one element that could be traced all the way from soil to human blood, correlating with lower arthritis incidence in the samples (Shinde, 2026; Bishnoi

et al., 2026). The point here is that different kinds of mineral-mobilizing abilities will have to be studied so that in future, doctors would not recommend only tablets but also specific crops or varieties grown in regions where their ability to mobilize bioavailable mineral forms is much higher. In a DBT-sponsored project, Dey et al. (2024) found that among 30 kidney bean varieties in Kiphire, Nagaland, six had higher iron content than most pulses, thanks to the pro bono analysis done by TIGS, Bengaluru.

d. Cultural, Culinary, and Other End Uses

Gupta and Dey (2017, Dey, Singh and Gupta, 2017) reported that *Oryza rufipogon*, a special wild rice variety, is a climate-resilient crop and a collective survival resource; its wild traits foster community-driven food security among marginalized farmers. Similarly, other rice varieties or crops are suitable for puffing, roasting, flour making, and other cultural as well as religious uses. For example, *Echinochloa colona* (jungle rice) is consumed during fasting periods in different parts of the country and though it grows as a weed in many places, it has been conserved. A study also found that one of the rice pests on this plant does not complete its life cycle, and thus it helps in plant protection. It grows in highly stressful and depleted soil environments while stabilizing fields along the irrigation channels (Chauhan & Johnson, 2010).

e. By-product Characterization and Uses

It is well known that in many drought-prone regions, three out of five years face severe or moderate drought. The anchor for survival then becomes livestock instead of crop. Most traditional varieties in these places serve a dual purpose and are selected for palatable fodder. There are very few studies in which, in early generations of breeding programs, populations were screened for fodder palatability (Rao & Hall, 2003). Decline in the livestock population in many regions could partly be explained by the lack of quality fodder. Similarly, roots, peel, tassel, silk, and other parts of the plants may have more functional value than has been appreciated in the literature so far. Wild strawberry (*Fragaria vesca*) root tea has been used for urinary tract infections, skin problems, hemorrhoids, and cough symptoms (Dias et al., 2015); jackfruit peel has healing properties on cuts and wounds (Gupta et al., 2009); dry scales of onion (*Allium cepa*) have antimicrobial properties when soaked or boiled in water, creating a non-chemical sanitizer (Kim et al., 2011). Dried and powdered mango peel can be used as a supplement to the flour for Mid-Day Meal Scheme. This is an area where there is little research. So, we do not know from which region or which variety of a crop, a peel has higher antimicrobial properties. In this regard, a DBT-sponsored project was conducted by GIAN, which focused on abundant resources from Himalayan regions to develop valuable products (Dey et al., 2024).

f. Companion Plants / Weeds with Significant Nutritional and Other Benefits

Various crops harbor some specific weeds or companion plants which may have functional properties. For example, *Chenopodium album* is often found as a weed in wheat fields and other

cultivated crop fields. This weed has carminative, digestive, appetizer, and invigorating effects according to Ayurvedic texts (Poonia & Upadhayay, 2015). Similarly, dandelion (*Taraxacum officinale*[/I]) roots make very useful tea and are a natural diuretic; it helps in strengthening liver health (Napoli & Zucchetti, 2021). Similarly, stinging nettle (*Urtica dioica*[/I]) has multiple uses; apart from fiber, iron, and protein, it also heals cuts, wounds, and second-degree burn wounds (Akbari *et al.*, 2015). So, it could be used as a substitute for silver sulfadiazine and Vaseline in resource-constrained environments for burn wound healing.

g. Mycorrhiza and Other Microbial Associations Helping in Resilience

Traditional crop varieties are known to have more effective mycorrhizal and microbial associations than modern hybrid varieties. In sorghum (*Sorghum bicolor*) and some other traditional rice varieties, intense surge in mycorrhizal activity has been observed during dry spells, an important contribution to climate resilience. Besides uptake of water and nutrients, traditional wheat varieties are also reported to have efficient arbuscular mycorrhizal networks (Mardukhi *et al.*, 2011). Dhami *et al.* (2025) found that certain landraces have symbiotic mycorrhizal associations helping in coping with drought and suggested, “Their drought-inducible mycorrhizal symbiosis offers a sustainable strategy for climate-resilient rice production, emphasizing soil–genotype interactions in agroecological adaptation.”

h. Food for Farmers, Emergency, and Survival

Literature shows considerable work on famine or stress foods. Once in a hundred years, the El Niño effect has created long dry spells in many parts of India. We need to give much more attention to crops and varieties that can take advantage of late rains or can survive in minimal rainfall conditions. Studies can be done on either a sole crop or a mixture of different kinds of crops as stress foods and fibers. For example, *Ipomoea carnea*[/I] is an invasive shrub; its biomass has been explored for biofuel (Kumari & Pramanik, 2013). In Mali (a country in West Africa), a study was done on *Oryza longistaminata*. It was noticed that there were migrants from Timbuktu who collected grass seeds for their consumption from the swampy areas and also knew several features of the shattering wild rice (Gupta, 2004). For farmers, it was a weed, but for these migrant laborers, it was precious food. The Xa21 gene from this wild rice was cloned by Pamela Ronald at UC Davis (Gupta, 2004), and it was found that it was responsible for conferring stress resistance to this variety (Song *et al.*, 1995) and resistance to leaf blight and blast could be transferred through insertion of the Xa21 gene into other paddy varieties (Ronald, 1997). These migrants had songs and folklore which highlighted the strength of this wild rice, but they did not get sufficient credit so that its functional properties got noticed. Wild yam, Ensete, and many other plants have also been known as stress foods. There is a need to look at such germplasm that has high-density nutrition, shows fewer side effects, and is suitable for growing under stress conditions. They are the stress foods which can deal with future climatic exigencies. There are crop varieties we have noticed in Bangladesh; they have high satiety value and are easily digested.

The pangs of hunger are more painful than hunger itself. Therefore, some of the rice varieties which swell and give a sense of fullness even with less quantity provide temporary relief from pangs of hunger. However, the starch intake has to be reduced, and frequent consumption needs to be avoided.

i. Gendered Uses and Characterization of Germplasm

Women have conserved germplasm from time immemorial and often helped decide which seed could be grown in a certain place. In addition, they knew about stability of grains, particularly long-duration stability. They knew techniques for safe storage of grains long back. In a conversation with Dr. Mangesha, then the in-charge of the genebank at ICRISAT, I asked whether they had paid attention to the stability of sorghum grains in their descriptors, and the reply was that it had not been done so far. A traditional variety of sorghum, Irumbu cholam, in South India is red in color due to high iron content and can be stored for a long period (see Elangovan & Prabhakar, 2023; Sanjeev, Patil, & Govindraj, 2023). Due to the near absence of data on community knowledge, particularly women's knowledge, in the descriptors, we have not only ignored but also negated the knowledge of women in breeding crops. Building upon this knowledge can help in creating markets for such landraces. Drawing mainly upon women's knowledge about so-called abundantly growing weeds in Baramulla and Sikkim, in a DBT-supported project, Dey et al. (2025) not only developed a herbal product, Paindel, but also put the names of knowledge providers on the product label, apart from pursuing other benefit-sharing arrangements (also see Dey, Singh and Gupta, 2018, Dey & Gupta, 2024).

Summary

There is an attribution and acknowledgement gap in research. Several plant germplasm collections have been characterized with the help of PPVFRA, but the knowledge and contributions of farmers and local communities have not received adequate attention. NBPGR and other bodies concerned with ex situ and in situ conservation need to pay attention to a large-scale program of in situ conservation and characterization of germplasm blending local knowledge and modern science. We hope that these ideas will be debated and built upon by incorporating the precious knowledge of communities and individual grassroots innovative farmers for different crops and their varieties. If Kalidas Banerjee could develop a mango variety in which mangoes do not fall even during storms, then we should accept that there is a contribution that farmer-breeders can make together with institutional scientists. We hope that a mission-mode program will be designed in which the Honey Bee Network and GIAN are willing to play an active role in cementing the bridge between people's knowledge and people's research goals. In 1984, the study of match or mismatch between farmers' breeding goals and scientists' objectives was initiated for the same purpose (Gupta, 1989). We do not have to wait another fifty years to build momentum for such work. The question is not only why we need to expand the scope of germplasm conservation and characterization, but also how to leverage scientific and community knowledge to address contemporary problems in health, nutrition, and wellness.



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Reengineering India's Apple Sector Through High-Density Cultivation

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Introduction

India's apple sector spans ~3.04 lakh hectares across the temperate northern hill states. This places us 2nd largest apple-growing area globally, yet national productivity remains stagnant at ~10 tonnes/hectare (T/Ha), far below international benchmarks. This yield gap drives a demand-supply shortfall in fruit exceeding 600,000 MT annually; and this gap is currently filled through imports from New Zealand, the United States, and South Africa. However, these economies are far higher farm labor costs but superior yield efficiency, giving them a competitive edge in the Indian market.

Problem Analysis & Structural Bottlenecks

The core driver of stagnation is legacy orchard architecture: standard seedling rootstocks planted at low density (150–250 trees/ha), taking 6–8 years to bear commercially, with dense shading canopies and inferior fruit quality. Globally, leading producers have shifted to High/Modern-Density Planting (HDP/MDP) using dwarf or semi-dwarf clonal rootstocks, reaching up to 100 T/Ha internationally; India's ICAR-CITH confirms 50–60 T/Ha is achievable domestically with modern HDP canopy design. Despite HDP being introduced in India roughly 10 years ago, adoption remains at just 7,000 hectares nationwide (>80% in Kashmir, balance in Himachal Pradesh), and this is due to:

- i. **Genetics Scarcity:** modern, climate-resilient clonal rootstocks and proprietary cultivars, clean planting material suited to local conditions etc which are largely inaccessible in domestic nurseries, directly hurting higher HDP establishment success and pack-out ratio on fruits (marketable fruit per hectare).
- ii. **Extension Deficit:** limited specialized agricultural extension services, technical training, canopy management expertise, and automated fertigation know-how needed to manage HDP systems.
- iii. **Post-Harvest & Market Constraints:** even where HDP orchards are established, growers face limited storage, sale, and marketing avenues, undercutting income and long-term sustainability.



3. Seven Star Fruits Intervention & Strategic Vision

Seven Star Fruits Pvt. Ltd. (SSFPL), an integrated fresh produce company and subsidiary of the Mahyco Group - launched a comprehensive apple initiative in 2015–16 to modernize India's apple supply chain (alongside cherry, kiwi, and blueberry for temperate regions), aiming to create positive impact across growers, fruit handling agencies, and consumers. As a member of the Associated International Group of Nurseries, Inc. (AIGN), and with a strong emphasis on IP protection, SSFPL holds exclusive propagation licenses for Geneva® rootstocks (apple, Cornell University) and Gisela® rootstocks (cherry, University of Giessen, Germany), plus exclusive propagation/commercialization rights for club varieties including Pink Lady® sports (APAL) and Cosmic Crisp®/WA 38 (Proprietary Variety Management LLC, bred by Washington State University), among other globally recognized varieties. Geneva-rootstock HDP have the potential to lift yields from a current baseline of ~15 T/Ha to over 50 T/Ha. SSFPL's own tissue culture labs and nurseries supply this improved genetic material, and it facilitates end-to-end market linkages via appointed fruit handling agencies for sorting, grading, and packing to global brand standards.

4. Over a 10-year horizon, SSFPL's strategic vision targets three national outcomes:

- i. Smallholder Empowerment: raise yield per hectare and net farm incomes for small/marginal orchardists.
- ii. Import Substitution: expand domestic HDP volume to cut reliance on ~600,000+ MT of annual fresh apple imports.
- iii. Export Competitiveness: build an India-focused IP licensing model for premium cultivars, positioning India as a global horticulture exporter.

5. Progress to date by SSFPL:

- i. 3.5 lakh trees established on ground,
- ii. Targeting 1 million trees by 2028;
- iii. ~100 MT of club-variety fruit placed under SSFPL licensed brands last season, with a positive consumer response which is an early proof point for the commercialization strategy.

6. Immediate Action Plan & Next Steps Immediate Impact

- i. Around **3.5–4.0 lakh growers** are engaged in apple cultivation in India, of which **approximately 80% are small and marginal growers**.
- ii. Adoption of **High-Density Planting (HDP)** with **club varieties** and **improved genetics** can significantly enhance orchard productivity and grower income.

- iii. Improved genetics clubbed with HDP cultivation practices can increase the **orchard productivity by 5 to 8 times** in comparison to traditional orchard farming.
- iv. Additionally such improved genetics require **lower input usage** and offer **better resistance to prevailing diseases**, resulting in reduced expenditure on chemical sprays and improved profitability of growers.

Action Plan

- i. Improve the availability and accessibility of improved genetics for small and marginal growers to accelerate the adoption of High-Density Planting (HDP) by establishing clean plant nurseries supported with true-to-type plants from tissue culture.
- ii. Train the growers on improved cultivation practices of such new genetics for better adaption and production of quality fruit.
- iii. Creating market place through fruit handling agencies for the better price realisation and enhance growers' income.

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Tropical and Subtropical Fruit Genetic Resources of Western Ghats

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The world is facing three major crises, namely climate change, food and nutritional insecurity, and biodiversity loss. Biodiversity meets the majority of human needs, and agrobiodiversity provides all the five Fs of life—Food, Fodder, Fuel, Fertilizer, and Fiber. Due to large-scale anthropogenic activities, many habitats and ecosystems are being disturbed and are gradually disappearing. Monocropping over large areas has resulted in the loss of indigenous biodiversity, including landraces, crop wild relatives (CWRs), and other valuable genetic resources. Consequently, the global food basket is shrinking. Today, only three cereal crops, two vegetable crops, and five meat sources provide food for more than 90% of the world's population. The end result is widespread undernutrition, malnutrition, and micronutrient deficiencies. The only sustainable solution is to conserve ecosystems along with the diversity of all life forms for the welfare of humankind and the planet. The notified biodiversity hotspots of the world require immediate attention, particularly the biodiversity-rich regions of the Asian subcontinent. India, home to an enormous diversity of flora and fauna, possesses two globally recognized biodiversity hotspots: the North-Eastern Region and the Western Ghats.

About the Western Ghats

- The Western Ghats are a mountain range that runs parallel to the western coast of India. They extend from near the Maharashtra–Gujarat border through Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu, ending at Kanyakumari.
- The Western Ghats are one of the world's most important biodiversity hotspots.
- These hills cover approximately 160,000 sq. km and form the catchment for complex river drainage systems that support nearly 40% of India's rainfall.
- The average elevation is about 1,200 m (3,900 ft).
- In 2012, 39 sites in the Western Ghats were declared UNESCO World Heritage Sites.

Some Facts about the Biodiversity of the Western Ghats

- Older than the Himalayan mountain chain, the Western Ghats are a geomorphic feature of immense global significance.
- They are home to over 5,000 species of flowering plants.

- They support 139 species of mammals.
- They harbour 508 species of birds, including 22 endemic species.
- They contain 225 species of reptiles.
- They are home to 179 species of amphibians.
- The region supports at least 325 globally threatened species of plants, mammals, birds, amphibians, reptiles, and fishes.
- Nearly 10% of the native plant species, including many medicinal plants, are believed to fall under one or another threatened category.
- Since the early 1900s, the Western Ghats have lost nearly 50% of their forest cover, and the trend continues because of fragmentation and encroachments.

Why Fruit Diversity Matters

Fruits constitute the second largest component of agrobiodiversity, next only to vegetables, and contribute significantly to human nutrition and health. They are widely distributed and easily accessible to a large section of the population, particularly tribal communities and the rural poor, because of their nutrient-dense nature. Fruits are among the cheapest and most unadulterated sources of vitamins, minerals, antioxidants, and other health-promoting compounds. They are generally consumed fresh, ensuring maximum retention of nutrients.

Fruit crops are well suited to diverse farming systems, particularly those of small and marginal farmers. Their wider adaptability makes them climate-resilient, ensuring family nutrition, livelihood security, and sustainable income generation. In addition, they offer immense opportunities for value addition and agro-processing. Wild edible fruits served as important food sources for humankind long before the advent of civilization. Tribal communities living in forest ecosystems have traditionally depended on these fruits and have passed on valuable knowledge regarding their uses from one generation to the next. Nearly 30,000 edible plant species are known to humankind, of which about 7,000 species have historically been used as food. However, only about 150 plant species are cultivated commercially, and merely 103 species contribute more than 90% of the world's calorie intake. Hundreds of nutritionally valuable fruit species remain underutilized and deserve greater scientific attention.

Why They Are Important Now

- They are rich sources of nutrients and health-promoting bioactive compounds.
- They can help address increasing food and nutritional insecurity.
- They possess excellent climate resilience.
- They exhibit resistance to both biotic and abiotic stresses.
- They are rich in nutraceutical and medicinal properties.



- They serve as valuable donors of genes for crop improvement.
- They cater to the growing ageing population and increasing health consciousness.
- Diversification of the global food basket has become an urgent necessity.

Our Work

The fruit species diversity of the Western Ghats constitutes a major component of the region's biodiversity and includes shrubs, climbers, and trees. Exploration and collection of NUS fruit crops has been completed covering 36 districts of nine states. 77 custodian farmers, 38 nurseries and 37 institutions have been visited for the study and collection of the material (Table 1). The targeted fruit species were mainly collected from wild and semi areas of forest, marginal forest lands, homestead gardens, orchards and from farmer's field. The selection is carried out based on genetic diversity, information on available genetic traits and stability. Most species in the collection have come from custodian farmers directly or indirectly.

Important species such as jackfruit, jamun, wood apple, mango, banana, custard apple, bullock's heart, karonda, eight species of *Garcinia*, gooseberry, *Gardenia*, breadfruit, and rose apple occur abundantly in the forests of the Western Ghats.

The Biodiversity Centre, Bengaluru, established in 2014, has carried out extensive surveys throughout the Western Ghats in Peninsular India and has established a Genetic Diversity Park of underutilized fruit species comprising 33 families, 56 genera, 103 species, and 223 varieties. All collected accessions have been studied for their geographical distribution, ecological requirements, morphological characteristics, nutritional composition, and medicinal importance wherever applicable. Propagation protocols and nursery production techniques have also been standardized for the multiplication and distribution of quality planting material. Genetic variability has been collected and evaluated in six promising fruit crops—jackfruit, jamun, custard apple, ber, karonda, and tamarind—for detailed investigation. Elite genotypes have been identified for mainstream cultivation and commercialization. Furthermore, value-added products have been developed from all these fruit species to ensure their year-round availability, enhance farmers' income, and promote their wider utilization.

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Pulse Genetic Resources for Peninsular India

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Introduction

India stands as the world's largest producer, consumer, processor and importer of pulses. It accounts for about 25 per cent of the global production with more than 12 pulse crops grown regularly in different agro-ecological regions. Within its vast agricultural landscape, Peninsular India—comprising the Deccan Plateau, the Eastern and Western Ghats, and the Malabar coast—serves as a critical primary centre of diversity for major pulse crops. The Western Ghats especially is a UNESCO World Heritage site and a recognized global biodiversity hotspot. This region serves as a vital reservoir of genetic resources for pulse crops, including pigeonpea (*Cajanus cajan*), horsegram (*Macrotyloma uniflorum*), and several wild and cultivated species of the genus *Vigna*, such as mungbean, urdbean, and cowpea.

The strategic importance of Peninsular India has increased in recent decades due to a significant spatial shift in pulse cultivation. Following the Green Revolution, pulse acreage in Northern India drastically declined as most of the fertile, irrigated lands were diverted to wheat and rice. Consequently, the "pulse heartland" moved southward to states like Madhya Pradesh, Maharashtra, Andhra Pradesh, Telangana and Karnataka. Consequently, today the Peninsular states are the primary drivers of India's pulse production, yet they face the dual challenges of rainfed agriculture and climate-induced heat stress. Harnessing the Plant Genetic Resources (PGR) of this region is therefore not merely a scientific endeavour but a necessity for transforming Peninsular India from a biodiversity hotspot into a sustainable bioresource hub of pulses.

Assessing Genetic Diversity and Allelic Richness

Peninsular India exhibits a rich and unique genetic profile, especially for pigeonpea and wild legumes. Earlier researches deploying morphological diversity data and molecular studies using BAC-end sequence-derived simple sequence repeat (BES-SSR) markers indicate that Peninsular region of India harbours higher genetic diversity as compared to the North-western and Northern plains. Furthermore, the Eastern Peninsular region and the Deccan are identified as major diversity zones for cowpea, horsegram, pigeonpea, mungbean, and ricebean. The Western Peninsular region, including the Western Ghats and Malabar, is similarly rich in cowpea, horsegram, and urdbean. Systematic explorations in the Western Ghats upto the Nilgiri Mountains, have led to the collection of rare wild *Vigna* species, which are essential for



broadening the narrow genetic base of cultivated pulses. Many such explorations have been conducted jointly by ICAR-NBPGR and ICAR-IIPR and a wide genetic diversity of *Vigna* and *Rhynchosia* was collected.

Genetic Diversity of Major Legumes

The Deccan Plateau and Eastern Ghats transition zones harbor immense landrace diversity of pigeonpea. Peninsular India is also rich in the ‘Crop Wild Relatives’ (CWRs) and the Western and Eastern Ghats host important wild progenitors and related species. Traditional varieties of pigeonpea preserved by tribal communities exhibit variable seed and pod size, maturity durations, multi-pick harvestability, and distinct seed coat colors. Likewise, the wild relatives include *Cajanus albicans*, *C. lineatus*, *C. scarabaeoides*, and *C. trinervius* which harbour high protein content, cyst nematode resistance, and pod borer resistance. Chickpea (*Cicer arietinum*) is historically adapted to post-monsoon residual moisture in the Deccan black soils; local *Desi* landraces display deep root structures and tolerance to terminal drought.

Blackgram (*Vigna mungo*) & Greengram (*Vigna radiata*) are cultivated extensively in rice fallows and coastal zones of Andhra Pradesh, Tamil Nadu, and Karnataka. The thriving landraces show adaptability to soil salinity and moisture stress. Similarly, cowpea (*V. unguiculata*) is broadly cultivated across drylands and vegetable gardens of Keralam and Karnataka, possessing significant variation in pod length, and shade and drought tolerance. Similarly, ricebean (*V. umbellata*) and mothbean (*V. aconitifolia*) are cultivated in niche micro-climates across tribal belts, offering very high level of resistance to heat and foliar diseases besides *Vigna vexillata*, *V. bourneae*, and *V. hainian*, the wild relatives which contain genes for biotic stress resistance and waterlogging tolerance). Among the minor and underutilized pulses, Horsegram (*Macrotyloma uniflorum*), a hardy, drought-tolerant pulse, widely grown in dry rainfed tracts of Karnataka, Tamil Nadu, and Andhra Pradesh, thrives well in poor soils with minimal inputs, supplying protein and medicinal antioxidants.

Mapping Key Traits for Climate Resilience and Bio-Economy

Local landraces and wild pulse wild relatives found in Peninsular India have evolved under natural selection pressures, accumulating wider genetic adaptations. The following table elaborates key traits which can be introgressed from these genetic resources into the cultivated backgrounds of pulses:

Crop Species	Genetic Resource Type	Target Traits / Eco-Adaptations
Pigeonpea	Wild <i>Cajanus</i> spp. (<i>C. scarabaeoides</i>)	High seed protein (>28%), cytoplasmic male sterility (CMS) sources, pod borer tolerance
Chickpea	Deccan landraces	Heat tolerance during flowering, early maturity, deep taproot architectures

Crop Species	Genetic Resource Type	Target Traits / Eco-Adaptations
Blackgram/ Greengram	Rice-fallow landraces	Salinity tolerance, pre-harvest sprouting resistance, MYMV (Mungbean Yellow Mosaic Virus) resistance
Horsegram	Local ecotypes	Extreme drought avoidance, high nitrogen-fixation under low pH, anti-lithic bio-actives
Cowpea	Dual-purpose landraces	Heat tolerance, canopy shade tolerance, multi-cut forage potential

Making Peninsular India a Sustainable Bioresource Hub

To convert the rich pulse biodiversity of Peninsular India into a bioresource hub, a multi-pronged scientific and policy approach is required. The 1st step would be a comprehensive exploration and digital gene mapping of the region encompassing a systematic, geo-referenced mapping of pulse CWRs across micro-habitats using GIS and satellite imagery and establishing digital pulse trait databases integrated with high-throughput phenotyping platforms. This should be followed by development of *ex situ* and *in situ* integrated conservation banks facilitating expanding cryo-banks and medium/long-term conservation facilities and empowering farming communities through ‘Community Seed Banks’. This will also boost participatory plant breeding. To maximize genetic gains and climate resilience in pulse-based cropping systems, an integration of pre-breeding and genomic utilization must be deployed alongside bio-economy and value chain strategies. Likewise, harnessing marker-assisted selection (MAS) and pangenomics to introgress critical traits for biotic and abiotic stress resistance into elite, high-yielding cultivated backgrounds without incurring linkage drag will accelerate the rapid development of short-duration, heat-tolerant, and disease-resistant pulse varieties for non-traditional cropping windows, including summer pulse niches and post-rice fallows. Characterizing underutilized pulses like horsegram and cowpea for their high-value functional food properties, bioactive peptides, and nutraceutical applications will create a strong market pull. The research outcomes will directly empower farming communities, ensure premium market returns, and drive sustainable pulse production systems.

Conclusion

Peninsular India’s pulse genetic diversity is a strategic national asset. As climate variability threatens agricultural productivity, these native landraces and wild relatives provide genetic solutions required to breed drought-tolerant, disease-resistant, and nutrient-rich crops. By linking exploration, modern genomics, participatory conservation, and equitable policy frameworks, Peninsular India can transform its pulse agrobiodiversity hotspot into a sustainable, innovation-

driven bioresource hub for national food and nutritional security. Nonetheless, effective management of pulse genetic resources requires strict alignment with national and international legal frameworks, including the Biological Diversity Act (2002), the Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA, 2001), and the ITPGRFA. By systematically integrating Peninsular India's rich pulse genetic diversity into modern breeding and conservation frameworks while remaining aligned with national and international laws, the country can secure a climate-resilient, nutritionally rich, and ecologically sustainable future for its pulses landscape.

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Decoding Diversity for Sustainable Use

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Introduction

Plant Genetic Resources (PGR) are essentially required for global food security and environmental sustainability. It is the diversity existing in their genetic material and its manifestation in terms of their effect on function and expression that makes PGR an invaluable resource for future readiness. Global-level efforts are undertaken to identify, characterize, store, conserve and evaluate these underlying variations and make them available for their applications and effective utilization. Thus, genetic diversity existing in these germplasms needs to be decoded as a preliminary step in their effective utilization. Genomics, as a field of study, offer technical solutions to capture the existing diversity at the nucleic acid level, and other ‘omic’ technologies capture this at other biomolecular levels and at vast ranges. It is an integration of molecular techniques at the “whole-level”, availability and ease-of-use of computational techniques and resources and the power of statistics to capture the potential variability and narrow the gap between phenotype and genotype. Owing to its vast scope, genomics has become the choice of study in research areas to dig into these sequence-based resources and uncover meaningful information.

Development of Genomic Resources

Genomics has seen its days starting from analyzing multiple genes in parallel to multiple genomes in parallel today. The outputs from these genomic techniques can be summarized as whole-genome sequences, molecular markers, omics datasets like transcriptome, proteome, etc, bioinformatics resources and databases or other repositories of this information, which are continually increasing today. These resources are further employed to assess the genetic diversity in different germplasm panels, assist in the development of representative germplasm sets like molecular cores for trait mapping and gene discovery and tap the variation to uncover the genes/alleles contributing to the trait through genotyping and association studies. Repositories of the generated resources are thus an easy-to-access hub for future applications by the research community.

In this aspect, 36 hypervariable SSR markers distributed across the 12 rice chromosomes were identified by Singh et al. (2013) that could dissect the genetic diversity of over 350 rice varieties, working equally well with a set of 36 SNP markers. These have since then been used by various researchers to dissect the genetic polymorphism and have proven to be a valuable genomic resource for the staple crop rice. Such genome-level markers like SSRs have been developed for multiple crops through genomic as well as transcriptomic approaches like *Andrographis*



(Kumar *et al.*, 2020; Singh *et al.*, 2023), *Tinospora* through transcriptome and enriched libraries from genome approach (Singh *et al.*, 2016; Paliwal *et al.*, 2016), Novel Genome level SSRs in *Amaranthus* (Vats *et al.*, 2023), *Bunium* (Bansal *et al.*, 2022), *Psidium* (Kumar *et al.*, 2020, Pramanik *et al.*, 2025), Mango (Srivastav *et al.*, 2021). Candidate gene-based markers have been developed for Wheat (Singh *et al.*, 2018), indel-based markers differentiating basmati from non-basmati varieties (Yadav *et al.*, 2017), SNP-derived KASP markers in Lentil (Singh *et al.*, 2026), Wheat (Bashir *et al.*, 2024), and gene start codon-targeted markers (Singh *et al.*, 2014). Apart from these low-throughput markers, high-throughput genome-wide single-nucleotide polymorphism (SNP) markers have also been developed in *Amaranthus* (Singh *et al.*, 2025).

Whole-genome sequences as a major genomic resource for *Bunium* (Bansal *et al.*, 2022), *Trigonella* (Gaikwad *et al.*, 2025) have been developed, and comparative genome analyses have yielded the identification of genome-wide SSR markers in *Amaranthus* (Singh *et al.*, 2023). These have been utilized to characterize the genetic diversity of Giloe or *Tinospora* (Paliwal *et al.*, 2022), *Amaranthus* (Vats *et al.*, 2023), *Bacopa* (Choudhury *et al.*, 2025), *Bunium* (Bansal *et al.*, 2026), rice (Choudhury *et al.*, 2023; Mahendran *et al.*, 2023; Singh *et al.*, 2026), guava (Mishra *et al.*, 2026)

The application of developed markers has been a core development in rice, where unlinked SNPs distributed across all 12 rice chromosomes have been employed to develop a core set of germplasm consisting of 6,984 rice accessions, originating from the NE and 2990 accessions originating from east coastal areas of India. A core set of 701 accessions obtained from the NE collection accounted for approximately 10% of the total collection (Roy Choudhury *et al.*, 2014). Similarly, for coastal collections, utilisation of a diverse set of 2,242 rice accessions led to delineation of a core set of 300 accessions (247 as core and 30 as mini-core set) to capture the maximal diversity (Roy Choudhury *et al.*, 2021). A composite core collection of sesame has been developed using RAD-seq technology that captures maximal genotypic as well as phenotypic diversity in the crop and is another useful genomic resource developed for future studies (Ruperao *et al.*, 2025).

The developed SSR markers have been used to map QTLs for quality trait-aroma (Singh *et al.*, 2007; Amravati *et al.*, 2008) and yield-contributing trait grain length (Singh *et al.*, 2012) using Recombinant Inbred Lines (RILs). Further, candidate genes responsible for aroma have been identified using a combined approach of QTL mapping with transcriptome profiling using these markers (Pachauri *et al.*, 2014). Genome-wide association studies (GWAS) have been used to identify candidate genes related to quality traits in rice such as aroma, length, width, and length-width ratio (Choudhury *et al.*, 2024). Significant Marker-trait associations have identified 5 candidate genes/QTLs for aroma, seven each for head rice recovery and chalkiness percentage (Sachdeva *et al.*, 2024a). Over 200 significant QTNs have been found associated with nine grain biochemical traits: glycemic index, total dietary fibre, oil%, protein, amylose, moisture%, phytate, phenol, and starch content in rice (Sachdeva *et al.*, 2025). 73 QTNs

and 75 candidate genes contributing to plant height, days to flowering and yield in rice have been identified (Sachdeva *et al.*, 2024b). GWAS have identified QTNs and underlying genomic resources for traits like stem and leaf rust in wheat (Deo *et al.*, 2026; Yadav *et al.*, 2025), heat stress in wheat (Kumar *et al.*, 2026), grain quality in wheat (Bashir *et al.*, 2025), seed size in Lentil (Singh *et al.*, 2026), and seed weight in moth bean (Yadav *et al.*, 2025). Besides, candidate genes have been validated for their functional roles, such as the NAC Transcription Factor from *Andrographis paniculata* for its role in Andrographolide Production (Kumar *et al.*, 2024); WRKY transcription factors for their role in salinity and drought tolerance have also been reported (Singh *et al.*, 2025).

Technology platforms and data repositories like those for *Amaranth* (Singh *et al.*, 2023), *Bunium* BpGDB (Singh *et al.*, 2025), *Tinospora* TinoTranscriptDB (Singh *et al.*, 2022), ApTransDB for *Andrographis* (Singh *et al.*, 2023), and FHBMarkerDb (Mohapatra *et al.*, 2026) have been made available for public use. Other technological solutions for future studies include the development of high-density genotyping arrays, such as a 64K SNP array for *Amaranthus hypochondriacus*. It is a ready-to-use technological platform as a useful resource for genotyping and association studies to be taken further in this nutritional crop (Singh *et al.*, 2025). Speed breeding protocol for rapid generation advancements in rice has been another development in this field (Kabade *et al.*, 2023).

These genomic resources and their associated outputs, such as molecular core collections of germplasm, discovered QTNs, MTAs and genes, and association mapping outputs, are currently available high-quality resources for plant breeders to maximize their utilization for sustainable ends.

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Horticultural Genetic Resources in India: Conservation and Utilisation

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Introduction

The horticulture sector, contributing nearly 33% to agricultural GVA, has become a major driver of growth in India's agricultural economy. Horticultural production increased substantially from 280.70 million tonnes in 2013–14 to an estimated 367.72 million tonnes in 2024–25. During 2024–25, horticulture output was estimated at 362.08 million tonnes, exceeding the projected food grain production of 329.68 million tonnes. India is a leading global producer of horticultural commodities, ranking globally first in dry onion production and second in the production of vegetables, fruits and potatoes, contributing approximately 12–13% of global production. These achievements highlight the growing importance of Indian horticulture in global food supply and its considerable potential for expanding high-value crop production.

Horticultural genetic resources (HGR) comprise the entire spectrum of heritable genetic diversity present in cultivated horticultural crops and their related taxa. These resources include traditional landraces, obsolete and modern cultivars, breeding lines, elite germplasm, wild relatives, indigenous and underutilized species, mutants, rootstocks, and genetic stocks conserved for research, breeding, and commercial utilization. The scope of horticultural genetic resources extends beyond the conservation of crop diversity to encompass their systematic exploration, collection, characterization, evaluation, documentation, conservation, exchange, and utilization. Conservation strategies include both in situ approaches, such as the protection of wild populations and on-farm maintenance of traditional cultivars, and ex situ methods including field gene banks, seed banks, in vitro repositories, cryopreservation, pollen storage, and DNA banks. Advances in genomics, transcriptomics, metabolomics, phenomics, bioinformatics, and artificial intelligence have significantly enhanced the characterization and utilization of horticultural crops germplasm. Modern breeding approaches, including marker-assisted selection, genomic selection, mutation breeding, genome editing, and speed breeding, increasingly rely on diverse genetic resources to develop cultivars with improved yield, nutritional quality, postharvest life, resistance to pests and diseases, and tolerance to environmental stresses. Horticultural genetic resources also support the floriculture, landscaping, pharmaceutical, nutraceutical, essential oil, cosmetic, and food-processing industries.



Horticultural genetic resources play a pivotal role in global agricultural sustainability, biodiversity conservation, and rural livelihoods. They provide income generation and employment opportunities for millions of smallholder farmers, nursery operators, seed producers, floriculture enterprises, and value-chain stakeholders worldwide. The remarkable diversity within horticultural species enables continuous genetic improvement to address emerging challenges such as climate change, evolving pests and pathogens, water scarcity, and changing consumer preferences. Conserving this diversity safeguards unique alleles that may confer resistance to diseases, tolerance to heat, drought, salinity, and flooding, or improved quality traits.

Diversity of Horticultural Genetic Resources

Horticultural genetic resources in India

India is recognized as one of the world's 17 megadiverse countries and harbours nearly 7% of global biodiversity. Its diverse agro-climatic conditions support approximately 45,000 plant species, including nearly 15,000 species with medicinal properties. Approximately 1,000 wild edible species have been documented, encompassing roots and tubers, leafy vegetables, bulbs and flowers, fruits, seeds and nuts. In addition, nearly 9,500 plant species have recognized ethnobotanical uses, of which about 8000 are associated with traditional medicinal practices and 3,900 are utilized as food by indigenous communities. Among the 583 cultivated plant species reported in India, 417 are horticultural crops, representing important diversity in fruits and nuts, vegetables, plantation and tuber crops, spices and condiments. Wild relatives further constitute an important genetic resource, particularly in fruits and nuts, vegetables, plantation and tuber crops, and spices and condiments (Dhillon *et al.*, 2005). Horticultural genetic diversity of India is very vast and scattered across 19 different regions namely Western Himalayan Region, Eastern Himalayan Region, Brahmaputra Valley Region, Malwa Plateau Region, Bundelkhand Region, Garo, Khasi and Jaintia Hills, North-eastern Hills, Arid Western Region and Semi-arid Kathiawar Peninsula, Upper Gangetic Plains, Middle Gangetic Plains, Lower Gangetic Plain or Delta Region, Chhotanagpur Plateau, Bastar Region, Koraput Region, South Eastern Ghats, Kaveri Region, North-western Deccan Plateau, Konkan Region and Malabar Region. India possesses approximately 117 cultivated fruit and nut species and 175 wild relatives, highlighting its importance as a reservoir of fruit genetic resources (Sankaran and Dinesh, 2020). Major crops such as mango, banana, citrus, jackfruit, papaya, guava, sapota, annona and grape exhibit substantial variation in fruit characteristics, productivity, maturity and quality. Mango, in particular, possesses extensive cultivar diversity resulting from long-term domestication, selection and vegetative propagation (Mukherjee, 1951; Mukherjee and Litz, 2009), while banana and citrus represent important centres of diversity with considerable variation among cultivated forms and wild relatives (Heslop-Harrison and Schwarzacher, 2007; Wu *et al.*, 2018).

Vegetable crops constitute one of the most diverse components of horticultural genetic resources including cultivated varieties, indigenous cultivars, landraces, breeding materials,

introduced or exotic germplasm, wild relatives and underutilized vegetables. This diversity is distributed both within species, among populations and among related species, and has been influenced by domestication, selection (both natural and farmer-mediated), migration, geographical isolation and adaptation to diverse agro-ecological conditions. Collectively, these resources provide the genetic variation required for improving productivity, nutritional security, and resistance to biotic and abiotic stresses (Ebert, 2020). Exotic and introduced vegetables are non-native plant species brought in from other regions or countries, valued for their unique tastes, distinct textures, and high market demand in modern culinary and health food sectors. The genetic resources of the following crops such as tomato, potato, capsicum, sweet pepper, cabbage, cauliflower, broccoli, carrot, beetroot, lettuce, turnip, radish, French bean, zucchini, celery, leek, brussels sprouts, kale, asparagus, artichoke and parsley are collected and established in India. Apart from that, indigenous vegetables are native or traditional plant species shaped by regional ecosystems and local human selection, whereas landraces are dynamic, locally adapted traditional crop varieties developed by farmers through generations of open pollination and selection. Regional and tribal farming communities have played a major role in maintaining this diversity through seed selection, exchange and on-farm cultivation.

Furthermore, the Indian subcontinent harbours a rich diversity of ornamental trees, shrubs, climbers, herbs and succulents. Numerous indigenous species, including *Nelumbo nucifera*, *Saraca indica*, *Cassia fistula*, *Lagerstroemia indica*, *Magnolia champaca* and *Butea monosperma*, have considerable ornamental value and are widely utilized in landscape gardening and garden beautification. The distribution of genetic diversity of various ornamental plants are presented in Table 1. The natural distribution of medicinal and aromatic plants (MAPs) is concentrated largely in ecologically diverse regions, with nearly 70% occurring in the tropical forests of the Western and Eastern Ghats, Vindhyan and Chhota Nagpur plateaus, Aravalli ranges, and the Himalayan region.

Table 1. Region wise ornamental crops diversity in India

Sl. No.	Agroecological region	Crop/Species
1.	Humid Western Himalayan Region	Aconitum, Acorus, Anemone, Arisaema, Arundinaria, Arundodonax, Barleria, Delphinium, Hedychium spp, Impatiens spp., Iris, Jasminum, orchids, Primula, Potemilla, Rhododendron, Ranunculus, Solidago, Rosa spp. Viola spp.
2.	Humid Bengal / Assam Basin	Acacia, Aglaonema, Barleria, Bauhinia, Clerodendron, Cordylis, Crinum, Hiptage, Ixora, Jasminum spp., Magnolia, Muassaenda, Solidago, Kadamba, neem, pride of India

3.	Humid Eastern Himalayan Region and Bay Lands	Aconitum, Acorus, Anemone, Arisaema, Barleria, Hiptage, Impatiens spp., Jasminum spp., Ligllstrum, Lilium spp., Litsea. Magllolia, Meconopsis, Michelia, Murraya, Mussaenda, Rododendmm, Solidago, Rosa spp., orchids, primula
4.	Sub humid Sutlej Ganga Alluvial Plains	Acacia, Barleria, Impatiem spp., Ipomoea, Jasminum spp.
5.	Humid Eastern and South-eastern Uplands	Acacia, Barleria, Impatiens spp., Ipomoea, !xora, Jasmillum spp. Neem
6.	Arid Western Plains	Acaia, Delonix, Impatiens, Jasminum spp., Terminalia, neem
7.	Semiarid Lava plateau and Central Highlands	Acacia, Bauhinia, Erythrina, Impatiens spp., Ixora, Terminalia, Jasminum spp., neem, pride of India
8.	Humid to semi-arid Western Ghats and Karnataka plateau	Acacia, Acalypha, Kadamba, Clerodendron, Crinum, Erythrina, Hiptage, Impatiens spp., !xora, Michelia, Mllrraya, Pongamia, Jasminum spp. bamboo, neem, orchids, pride of India

Source: Rajasekharan and Ramanatha Rao (2019)

The Western Ghats is part of a globally recognized biodiversity hotspot represents an important centre of diversification for ornamental genera such as *Impatiens*, *Strobilanthes*, *Begonia*, *Sonerila*, *Ceropegia*, *Hoya*, *Curcuma*, *Kaempferia*, *Smithia* and *Exacum*. The Eastern Ghats contribute flowering trees, shrubs, climbers and geophytes such as *Gloriosa*, *Crinum*, *Barleria*, *Clerodendrum*, *Wrightia* and *Bauhinia*. The Deccan Plateau supports drought- and heat-adapted species with considerable potential for low-input and water-efficient landscapes. Forest understoreys harbour shade-adapted *Begonia*, *Sonerila*, orchids and ferns. Freshwater wetlands support aquatic ornamentals such as *Nelumbo*, *Nymphaea* and *Monochoria*, while coastal ecosystems contain species adapted to salinity, strong winds and sandy substrates. Lateritic and rocky plateaus additionally support distinctive seasonal flora including *Ceropegia*, *Smithia* and *Eriocaulon*.

ICAR–Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru has undertaken efforts towards the exploration, collection, conservation, evaluation and domestication of indigenous ornamental plant resources for landscape gardening, particularly from the Western Ghats and adjoining regions (Sumangala, 2019a). A Native Conservatory at ICAR-IIHR was subsequently developed as a living platform for ex situ conservation, evaluation, demonstration and awareness creation regarding indigenous ornamental flora. Exploration of biodiversity-rich

landscapes, including the Biligiriranga Hills, further documented the ornamental potential of regional flora. A promising germplasm accession of native ornamental *Jasminum malabaricum* was registered with ICAR-NBPGR for high concrete recovery (0.375%) and a high proportion of volatile esters (17%) in the flowers.

National Status of Horticultural Genetic Resources

India has a well-established institutional framework for the exploration, collection, conservation, characterization, evaluation and utilization of plant genetic resources. The ICAR- National Bureau of Plant Genetic Resources (NBPGR) serves as the nodal organization for plant genetic resource management, including germplasm exploration, introduction, exchange, quarantine, conservation and characterization. National Active Germplasm Sites (NAGS) maintained by ICAR institutes and State Agricultural Universities conserve crop-specific germplasm and facilitate its evaluation and utilization in breeding programmes. State Agricultural Universities (SAUs) contribute through regional collection, characterization, conservation and utilization of locally adapted genetic resources. NAGS is the decentralized framework for medium-term germplasm conservation, regeneration, and distribution of genetic resources. The Botanical Survey of India (BSI) plays an important role in documenting and conserving the country's vast plant diversity, particularly through botanical exploration and herbarium-based resources. It involved on taxonomical research and identification of new species, in situ conservation through botanical gardens, data management and publication. The Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) supports the recognition and protection of plant varieties and farmers' varieties through the framework of plant variety protection and associated benefit-sharing mechanisms and maintenance breeding through filed gene bank. Collectively, these institutions form an integrated national system for safeguarding India's plant genetic wealth and promoting its sustainable utilization in crop improvement.

ICAR currently reports 9,240 fruit accessions within its horticultural genetic resources, with molecular characterization undertaken in crops including mango, banana and citrus. Crop-specific ICAR field genebanks are maintained at specialized institutes for arid fruits, banana, citrus, grape, litchi, mango, guava, bael, aonla, jackfruit and temperate fruits, while ICAR-IIHR maintains collections of tropical and subtropical fruit crops. The ICAR-NBPGR base collection currently contains 30,689 vegetable crops accessions, with chilli, brinjal, okra, tomato and onion combining account 62.1% total germplasm collection. India harbours substantial genetic diversity in several major spice crops, particularly black pepper, cardamom, ginger, turmeric and cinnamon. However, limited genetic diversity in vanilla, nutmeg, clove and several seed spices constrain the crop improvement and development of superior cultivars in India. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, has played a key role in enriching India's spice germplasm through the introduction of exotic accessions from diverse geographic regions. More than 1000 accessions of spices and condiments have been introduced,



including materials possessing desirable traits such as superior rhizome quality, high dry recovery, low fibre content, heat tolerance, extended crop duration, and other agronomically important characteristics. These introductions have contributed to crop improvement and breeding programmes.

India possesses substantial genetic resources of plantation crops, particularly oil palm, coconut, arecanut, cashew, cocoa, tea, coffee and rubber. These resources include indigenous diversity, introduced germplasm, farmer selections, elite clones, breeding lines and exotic accessions maintained in field gene banks and national research institutions. ICAR- Central Plantation Crops Research Institute, Kerala maintains the world's largest germplasm collection of coconut (comprising 401 accessions 269 indigenous and 132 exotic). The exotic collections represent 28 countries of South Asia, South-East Asia, Africa, Caribbean Islands, Indian Ocean Islands and Pacific Ocean Islands. Similarly, in arecanut, 164 germplasm collections of which 23 exotic and 141 indigenous and in cocoa, 321 germplasm collections including 281 exotic and 40 indigenous clones are being conserved under field gene bank. Oil palm germplasm collection of 79 accessions is maintained in the field gene bank of ICAR-Indian Institute of oil palm research, Pedavegi, Andhra Pradesh. The collected and evaluated germplasm represented Nigerian, Papua New Guinea and Zaire, Tanzania, Zambia, and Guinea Bissau origins and these lines contributed in identification of superior palms for hybrid seed production. Tea, Coffee and rubber are of other important plantation crops. Tea genetic resources belong to China type (*Camellia chinensis*), Assam type (*Camellia assamica*) and Cambodian hybrid type (*Camellia assamica ssp lasiocalyx*) were being maintained by Uniters Planters Association of Southern India (UPASI) and Tea experiment station, Assam.

India also possesses rich and diverse genetic resources of flower and ornamental crops, comprising indigenous species, traditional cultivars, farmer selections, introduced germplasm, breeding lines, hybrids and wild relatives. The indigenous diversity included approximately 43 species of Rhododendron, 1,234 orchids, 43 Primula, 23 Lonicera, 14 Aster, 64 Begonia, 241 Impatiens, 73 Iris, 43 Jasminum, 24 Hedychium, 7 Pandanus, 37 Ixora, 14 Gardenia, 12 Crinum, 11 Lilium, 26 Barleria, 37 Ipomoea, 14 Tabernaemontana, 10 Thunbergia and 37 Bauhinia species (Khoshoo, 1968). Major flower crops with significant genetic resources in India include rose, chrysanthemum, jasmine, tuberose, marigold, gladiolus, carnation, gerbera, dahlia, bougainvillea, orchids, anthurium, lilium, crossandra, barleria, gomphrena, celosia, heliconia, bird of paradise and other speciality flowers. More than 1,293 accessions representing diverse ornamental crops were acquired over the three-decade period from 1982 to 2016. The majority of these accessions were introduced from the USA (55%), followed by the UK (9%), Slovenia (6%), and the Netherlands (5%). In addition, ICAR-NBPGR registered 38 accessions belonging to ornamental crops such as rose, gerbera, jasmine, anthurium, carnation, China aster, gladiolus, orchids, chrysanthemum, and crossandra (Pedapati et al., 2018). Notably, ICAR-IIHR, Bengaluru maintains the following genetic resources of rose (63), marigold (9), tuberose (45), gladiolus (5), chrysanthemum (50)

China aster (28), gerbera (14 in polyhouse and 12 in open field), crossandra (16), barleria (25), dahlia (40), carnation (50), annual chrysanthemum (17), lotus (74) and Jasmine (45) in the field gene bank. Apart from ICAR institutions (IIHR, Bengaluru, IARI, New Delhi and DFR, Pune State agricultural universities and CSIR institutes NBRI, Lucknow and IHBT, Palampur also maintain the genetic resources of ornamental crops. Orchids are another important group of ornamental crops has commercial value in the national and international market. India alone hosts over 1,200 orchid species, with hotspots in the North-East Himalayas and Western Ghats with large and economically important genera include *Dendrobium*, *Bulbophyllum*, *Cymbidium*, and *Vanda*. ICAR-National Research Centre for Orchids, collected and conserved 3150 accessions of 352 native species of orchids. In addition to that Tippi Orchid Research Centre, Arunachal Pradesh also conserves considerable number of orchid species native to India and 1000 exotic orchid hybrids of *Paphiopedilum*, *Dendrobium*, *Cattleya* and *Vanda* groups.

Medicinal and aromatic plants (MAPs) with diverse phytochemicals have long been utilized in traditional medicine for the management of various health conditions and for promoting general well-being. Aromatic plants are particularly valued for their essential oils and other volatile compounds, which have applications in flavouring, fragrance and therapeutic products. The growing demand for plant-based and natural products has further increased the importance of MAPs, creating opportunities for their conservation, sustainable utilization, cultivation and genetic improvement. ICAR-Directorate of Medicinal and Aromatic plants, Ananad, Gujarat and ICAR-IIHR together conserving 1398 germplasm of various species of medicinal & aromatic plants in the field gene bank. Apart from that CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow is conserving and maintaining more than 2500 germplasm resources of Medicinal and aromatic plants.

Conservation Strategies

Ex situ conservation: Ex situ conservation refers to the preservation of germplasm outside its natural habitat, primarily through gene banks and other specialized conservation facilities. The National Genebank (NGB) comprises four major components: the seed genebank, field genebank, cryobank, and *in vitro* genebank. Field genebanks are the principal conservation method for perennial and clonally propagated fruit crops. ICAR has designated crop-specific institutions, including ICAR-CISH for mango, guava, bael, aonla and jackfruit; ICAR-NRCB for banana; ICAR-CCRI for citrus; ICAR-NRCG for grape; ICAR-NRCL for litchi; ICAR-NRCP for pomegranate; ICAR-CIAH for arid fruits; and ICAR-IIHR for tropical fruits. Their principal limitations are the substantial land, irrigation and maintenance requirements and vulnerability of perennial collections to diseases, pests and climatic events. In vitro conservation is particularly useful for vegetatively propagated fruit crops, especially banana, for which ICAR-NRCB maintains an in vitro germplasm conservation facility. Cryopreservation provides a long-term conservation option for fruit germplasm that is difficult to maintain through seed



storage or continuous field maintenance. A documented Indian example is banana, in which ICAR-NBPGR cryopreserved in-vitro-derived shoot meristems at -196°C in liquid nitrogen; approximately 40% of the meristems regenerated successfully, and the recovered plants were established in the field and produced fruit. Embryo and ovule conservation is relevant to fruit crops in which conventional seed storage is unsuitable because of recalcitrant or intermediate seeds. It provides an alternative route for conserving material from crops where whole seeds rapidly lose viability. ICAR includes embryo and ovule conservation among the approaches applicable to horticultural genetic resources. The main limitation is the requirement for crop-specific protocols for excision, culture, cryoprotection and regeneration. PPV&FRA field gene banks provide an additional conservation mechanism for authenticated registered varieties of HGR. PPV&FRA approved guidelines for establishment and management of field gene banks in 2024, and a banana field gene bank was launched at ICAR-NRCB, Tiruchirappalli, in April 2026 and initiated at ICAR-IIHR, Bengaluru for conservation of registered Horticulture crop varieties and farmers' varieties. NBPGR has maintained vegetables (30689), fruits and nuts (310), Medicinal & Aromatic plants (9866), ornamental (774) and Spices, Condiments and Flavour (3799) accessions in seed Genebank (-18°C). Similarly in the *In vitro* genebank (-196°C), a total of 2076 accessions of horticulture genetic resources are conserved.

In situ conservation: The conservation of germplasm in its natural habitat or under natural environmental conditions is referred to as in situ conservation especially in natural parks, biosphere reserves, or gene sanctuaries. India has substantial opportunities for in situ conservation of fruit genetic resources because many indigenous fruit species and their wild relatives occur naturally in the country's biodiversity-rich regions, particularly the Western Ghats, Northeast India, Eastern Himalaya, Andaman and Nicobar Islands and central Indian forests. In situ conservation is particularly relevant to wild and semi-domesticated relatives of citrus, banana, mango, Artocarpus, Garcinia, Syzygium, Annona and other indigenous fruit taxa. In India, the NBPGR has facilitated the establishment of gene sanctuaries in the Meghalaya and other North-Eastern regions for the conservation of important genetic resources, including Citrus, Musa, and other crops.

On-farm conservation: On-farm conservation of fruit genetic resources in India is documented through farmer-maintained traditional and locally selected types of banana, mango, jackfruit, tamarind, guava and other fruit crops. The Plant Genome Saviour Community Awards have recognized farmer communities and individual farmers conserving traditional fruit diversity. For example, the Chengalikodan Banana Growers Association, Thrissur, Kerala, has been recognized for conserving Chengalikodan Nendran banana through traditional practices, along with other crops including mango and jackfruit. Individual farmers in Kerala, Karnataka, Goa and Chhattisgarh have also been recognized for maintaining traditional banana, mango, jackfruit, tamarind and guava types on their farms (PPV&FRA, 2016). A particularly well-documented example is the farmer-led conservation of jackfruit diversity in Tumakuru, Karnataka. Farmers

S. S. Paramesh and Shankariah conserved the distinct jackfruit selections later named Siddu and Shankara on their farms for more than two decades. ICAR-IIHR surveyed and evaluated farmer-selected jackfruit genotypes during 2014–2018, and both Siddu and Shankara were subsequently registered under PPV&FRA in 2023. The documented Siddu and Shankara jackfruit case also illustrate how farmer conservation can be linked with institutional evaluation, PPV&FRA registration and subsequent wider dissemination (PPV&FRA, 2023; ICAR-IIHR, 2026). ICAR-IIHR has identified on-farm conservation as an important component of fruit genetic-resource management, while ICAR-NBPGR has emphasized the identification of gene sanctuaries for fruit crops and greater attention to minor fruits with rich genetic diversity. This programme specifically recognizes the importance of fruit genetic resources maintained outside formal institutional collections (ICAR, 2021). The available evidence indicates that on-farm conservation is particularly significant for traditional banana, mango and jackfruit selections and farmer-maintained indigenous fruit types.

Characterization and evaluation

HGR genetic diversity encompasses morphological, agronomic, biochemical, and molecular variation across cultivated and wild species, assessed through phenotypic characterization, molecular markers, and genome-wide analyses. Human selection, hybridization, and local adaptation over hundreds of years have generated wide variation in fruit size, shape, colour, taste, and seed characteristics across species. Molecular markers provide complementary resolution to phenotypic evaluation for assessing genetic relationships. Extensive molecular characterization of fruits, vegetable and flower crops yielded substantial diversity. To mention few, comprehensive evaluation of 256 apple germplasm resources across 26 phenotypic traits revealed substantial phenotypic variation; across 12 morphological traits, the average coefficient of variation was 66.39%, ranging from 21.10% to 201.5% (Tian et al., 2024). Jackfruit accessions yielded 23,795 high-quality biallelic SNPs with an average gene diversity of 0.28 and a transition/transversion ratio of 1.34, consistent with patterns in other outcrossing tree species (Amin et al., 2026). Avocado germplasm analyzed with 4,706 SNPs revealed three distinct populations corresponding to Guatemalan, West Indian, and Mexican ecotypes (Li et al., 2024). Similarly, in flower crops Tang et al. (2013) assessed the genetic diversity and population structure of 72 tulip accessions using 121 informative SNP markers, selected from 236 polymorphic SNPs, and reported an overall heterozygosity of 0.35, ranging from 0.22 in *Tulipa fosteriana* to 0.43 in *T. gesneriana*–*T. fosteriana* hybrids.

Digital Phenotyping of Horticultural Genetic Resources

Digital phenotyping uses imaging, spectral, thermal, three-dimensional, physiological and environmental sensors to record plant traits repeatedly and at higher throughput than manual scoring. It does not eliminate conventional phenotyping: sensor outputs require biological definitions, calibration and ground-truth validation. Horticultural collections are particularly



suitable because colour, geometry, ripening, canopy architecture, disease lesions and postharvest change are often image- or spectrum-responsive. They are also challenging because plants may be trained, grafted, perennial, spatially complex, grown under protected structures or harvested repeatedly. High-throughput phenotyping of horticultural germplasm relies on a range of imaging and sensor technologies to accurately measure plant architecture, growth, stress responses, yield, and quality traits. RGB imaging is widely used for low-cost assessment of fruit and flower segmentation, fruit count, canopy cover, flowering, ripening, disease severity, and leaf area, although its performance is influenced by lighting conditions and occlusion. Multispectral imaging captures reflectance in selected wavelength bands to estimate vegetation indices, canopy vigour, pigment content, water status, disease hotspots, and crop maturity, while hyperspectral imaging provides detailed spectral signatures for early stress detection, fruit quality assessment, leaf biochemical analysis, and disease diagnosis, despite its higher cost and data complexity. Thermal infrared imaging measures canopy and fruit temperature to evaluate drought tolerance, heat stress, irrigation response, transpiration, and postharvest cooling. Chlorophyll fluorescence detects changes in photosystem II activity before visible symptoms appear, enabling early diagnosis of heat, chilling, salinity, and disease stress. Structural sensing technologies such as LiDAR, structured light, and photogrammetry generate three-dimensional measurements of plant height, canopy density, branch angle, biomass, pruning response, and fruit or flower geometry. In addition, X-ray, CT, MRI, and near-infrared (NIR) imaging enable non-destructive evaluation of internal fruit, seed, tuber, and root characteristics, including dry matter, seed fill, internal defects, and quality, whereas electronic nose (e-nose) sensor arrays characterize volatile compounds for monitoring ripening, aroma, spice chemotypes, disease detection, storage quality, and off-odours. Together, these complementary sensing technologies support precise, rapid, and non-destructive phenotyping for horticultural crop improvement and breeding.

Utilization of Horticultural Genetic Resources

Horticulture genetic resources are utilized in crop improvement primarily for fruit quality, productivity, biotic- and abiotic-stress tolerance, rootstock traits, nutritional quality and adaptation. Systematic evaluation of fruit germplasm at IARI demonstrated this utilization potential: 1,529 accessions representing 25 fruit crops were evaluated, of which 88 accessions were utilized as commercial cultivars, rootstocks or breeding material (Pandey and Singh, 2004). Trait-specific exploration has also identified valuable diversity for fruit weight, TSS, flavour, yield and stress tolerance. More recently, the national assessment of fruit genetic resources has documented the contribution of both indigenous and introduced germplasm to Indian fruit improvement programmes, including the use of exotic material for developing more than 100 fruit varieties in India and the utilization of Indian germplasm internationally, particularly in mango, citrus and banana (Ranjan et al., 2022). The utilization strategy is increasingly moving from conventional selection and hybridization towards trait-specific, molecular and genomic

approaches. ICAR-NBPGR has emphasized the identification and supply of trait-specific germplasm for crop improvement, while molecular characterization and genomic resources are increasingly being integrated with conventional evaluation (Tyagi et al., 2021; Ranjan et al., 2022). This provides opportunities to deploy genetic resources for disease resistance, drought and salinity tolerance, fruit quality, nutritional traits, shelf life and climate adaptation, including through wild relatives, landraces, traditional cultivars and rootstocks. The present Indian priority is therefore not only conservation of fruit germplasm but its systematic identification, evaluation and deployment of useful alleles and trait-specific accessions in breeding programmes (Ranjan et al., 2022; Srivastava et al., 2024). The ornamental horticulture industry represents a multibillion-dollar global market, with substantial scope for further expansion through the introduction and cultivation of new ornamental species as loose flowers, cut flowers, potted plants, and landscape plants.

Crop Wild Relatives as Genetic Resources for Fruit, Vegetable, and Flower Crop Improvement

Crop wild relatives (CWRs) are invaluable reservoirs of genetic diversity and have contributed significantly to the improvement of fruit, vegetable, and flower crops by providing genes for resistance to biotic and abiotic stresses, quality enhancement, and adaptation. In fruit crops, wild *Mangifera* species such as *M. sylvatica*, *M. laurina*, *M. odorata*, and *M. foetida* have been utilized to broaden the genetic base of mango by contributing disease resistance, improved tree architecture, environmental adaptation, and fruit quality traits (Dinesh et al., 2011). Similarly, wild relatives of citrus, including *Poncirus trifoliata*, *Citrus ichangensis*, and *C. micrantha*, serve as important sources of tolerance to citrus tristeza virus, *Phytophthora*, salinity, drought, and cold, as well as superior rootstock characteristics (Nageswara Rao et al., 2011). Wild grape species such as *Vitis rupestris*, *V. riparia*, *V. berlandieri*, and *V. labrusca* provide resistance to phylloxera, downy mildew, powdery mildew, nematodes, and environmental stresses (Soneji and Nageswara-Rao, 2011), while wild diploid *Musa* species are important breeding resources for broadening the genetic base and introducing useful resistance traits in banana (Ortiz, 2011). Likewise, wild apple species including *Malus sieversii*, *M. sylvestris*, and *M. floribunda* have been extensively exploited for resistance to apple scab, fire blight, powdery mildew, and adaptation to adverse environments (Ignatov and Bodishevskaya, 2011). In vegetable crops, crop wild relatives have been widely exploited for resistance breeding and quality improvement. Wild tomato species such as *Solanum peruvianum*, *S. chilense*, *S. pennellii*, and *S. habrochaites* possess resistance to tomato mosaic virus, tomato leaf curl virus, bacterial spot, root-knot nematodes, drought, salinity, chilling stress, and also contribute enhanced fruit quality traits such as high sugar and lycopene content. In chilli, species including *Capsicum chinense*, *C. baccatum*, *C. chacoense*, *C. pubescens*, and *C. frutescens* provide resistance to powdery mildew, bacterial wilt, bacterial leaf spot, and root-knot nematodes. Wild eggplant relatives such as *Solanum torvum*, *S. incanum*, *S. viarum*, and *S. aethiopicum* are important sources of resistance

to bacterial wilt, shoot and fruit borer, thrips, and root-knot nematodes, whereas wild *Allium* species contribute resistance to onion leaf blight, downy mildew, pink root, and cytoplasmic male sterility. In cucurbits, species such as *Cucumis metuliferus* and *C. anguria* provide resistance to viral diseases and root-knot nematodes, while wild carrot subspecies are valuable sources of cytoplasmic male sterility for hybrid breeding. Similarly, in ornamental crops, wild relatives of chrysanthemum (*Chrysanthemum indicum*, *C. zawadskii*, *C. vestitum*), rose (*Rosa brunonii*, *R. multiflora*, *R. rugosa*), and tulip (*Tulipa stellata*) contribute vigor, stress tolerance, disease resistance, fragrance, early flowering, and weather tolerance, highlighting the broad utility of CWRs in sustainable horticultural breeding.

Genomics and Modern Technologies for utilization of germplasm

GWAS has identified loci underlying fruit quality traits across multiple fruit species. In avocado, 12 markers within 11 genomic regions were significantly associated with fruit color, shape, taste, and skin texture, explaining 14.84% to 43.96% of phenotypic variance (Li *et al.*, 2024). A European-centered strawberry diversity panel identified 71 GWAS associations with 11 quality traits, with major QTL for firmness, glossiness, skin resistance, and bruising susceptibility co-localizing within a low-diversity region of chromosome 3D (Prohaska *et al.*, 2024). Apple association mapping identified 71 novel marker-trait associations for 10 fruit quality traits, including 15 for fruit length and 6 for anthocyanin content (Poonam *et al.*, 2023). Fig whole-genome resequencing of 286 genotypes identified 481 significant SNPs linked to 11 fruit traits and productive type, with candidate genes associated with fruit weight, firmness, sugar content, and acidity (Castellacci *et al.*, 2026). Peach genomic analysis of 480 wild and cultivated accessions provided evidence that distinct domestication and improvement phases increased fruit size and taste, with selection for large fruits causing loss of genetic diversity in several fruit weight QTLs (Li *et al.*, 2019). A *Malus* pan-genome of 13 accessions identified 20,220 CNVs and 317,393 SVs, with a 209-bp insertion in the MMK2 gene generating noncoding RNA that regulates fruit coloration; nine structural variants shared between disease-resistant and color-related groups suggest potential trade-offs between fruit quality and immunity in apple (Wang *et al.*, 2023).

The development of crop-specific genomic databases has significantly advanced genomics-assisted breeding, gene discovery, and functional genomics in vegetable crops germplasm by providing access to genome assemblies, gene annotations, molecular markers, genetic maps, transcriptomic datasets, and comparative genomics tools to explore in germplasm for novel alleles. The Sol Genomics Network (SGN) (<https://solgenomics.net/>) is the primary resource for tomato and several Solanaceae crops, including chilli/pepper, brinjal (eggplant), and potato. Chilli researchers can also access the Pepper Genomics Database (<https://ted.bti.cornell.edu/cgi-bin/pepper/index>), while brinjal genomic information is available through the Eggplant Database (<https://eggplant.kazusa.or.jp/>). Potato genomic resources are provided

by the Potato Genome Sequencing Consortium (<https://www.potatogenome.net/>), and sweet potato genomic information is available through the Sweetpotato Genomics Resource (<https://sweetpotato.uga.edu/>) and Sweetpotato Garden (<https://sweetpotato-garden.kazusa.or.jp/>). Similarly, comprehensive genomic resources have been established for several other vegetable crops. The Cucurbit Genomics Database (CuGenDB) (<https://cucurbitgenomics.org/>) provides genomic information for cucumber, watermelon, muskmelon, and pumpkin, whereas the Brassica Database (<https://www.brassica.info/tools/databases.html>) serves cabbage, cauliflower, broccoli, and turnip. Dedicated databases are also available for radish through the Radish Genome Database (<http://radish-genome.org/>), beetroot through Beta vulgaris Genome Resources (<https://bvseq.boku.ac.at/>), carrot through CarrotDB (<http://carrotdb.cn/>), lettuce through LettuceGDB (<https://lettucegdb.com/>), onion through the Onion Genome Sequencing Project (<https://www.oniongenome.wur.nl/>), legumes including pea, beans, and cowpea through the Legume Information System (LIS) (<https://www.legumeinfo.org/>), and asparagus through Asparagus Genome Resources (<https://asparagus.uga.edu/>). Multi-crop platforms such as the Vegetable Information Resource (TVIR) (<https://www.tvir.cn/>) and VegSNPDB (<http://www.vegsnpdb.cn/>) integrate genomic and SNP datasets across diverse vegetable species, facilitating comparative genomics, genetic diversity analysis, and genomics-assisted crop improvement.

Pan-genome resources have revolutionized vegetable crop genomics by capturing the complete spectrum of genetic diversity that cannot be represented by a single reference genome. Unlike conventional reference genomes, pan-genomes integrate multiple cultivated varieties, landraces, and wild relatives, enabling the identification of non-reference genes, structural variants, presence–absence variations (PAVs), and copy number variations (CNVs) (Liu et al., 2023). Recent advances include the tomato pan-genome comprising 725 accessions and a graph pangenome cataloguing more than 19 million variants from 838 tomato genomes (Gao et al., 2019; Zhou et al., 2022). A section-wide tomato super-pangenome based on 13 wild and cultivated genomes has further expanded analysis of structural variation across the tomato clade (Li et al., 2023). Similarly, the pepper pan-genome developed from 383 accessions has revealed extensive genomic presence-absence variation relevant to cultivated pepper diversity (Ou et al., 2018). These pan-genome resources are publicly accessible through databases such as the Solanaceae Genomics Network (SGN), PepperDB/PepperPan, SpudDB, CuGenDB, BRAD, Lettuce Portal, LIS, PulseDB, and NCBI Genome, providing researchers with graph genomes, genome browsers, comparative genomics tools, and functional annotations for precision breeding. Although comprehensive pan-genomes are now available for several economically important vegetable crops, many species including onion, garlic, okra, carrot, radish, squash, and other minor vegetables still lack mature, publicly available graph-based pan-genomes, highlighting important opportunities for future genomic research. The continued development of long-read sequencing, telomere-to-telomere (T2T) assemblies, and graph-based pan-genomes will further accelerate the identification of novel alleles from crop wild relatives and improve the efficiency of breeding.

The Genomic Database of Fruits (TGDF) is the first comprehensive, open-access genomic database integrating genome information from 44 fruit crops, including apple (*Malus domestica*), grape (*Vitis vinifera*), citrus (*Citrus* spp.), pear (*Pyrus* spp.), peach (*Prunus persica*), kiwifruit (*Actinidia* spp.), pineapple (*Ananas comosus*), blueberry (*Vaccinium* spp.), persimmon (*Diospyros kaki*), strawberry (*Fragaria* spp.), bayberry (*Myrica rubra*), and several cucurbit and Rosaceae fruit species. TGDF integrates genome assemblies, gene annotations, transcriptomic datasets, homologous genes, gene duplication analyses, and more than 1.43 million CRISPR guide sequences. It also provides functional information on genes associated with flowering, anthocyanin biosynthesis, auxin and ABA signaling, cell division, starch synthesis, fruit size, and sugar transport, along with integrated bioinformatics tools such as BLAST, JBrowse, Sequence Fetch, and Synteny. By bringing together genomic resources from diverse fruit crops into a single platform, TGDF serves as a valuable resource for comparative genomics, functional gene discovery, genome editing, and molecular breeding of fruit crops (Liu et al., 2024).

In flower crops, pangenome analysis identified 1,801,537 structural variants, revealing genetic factors underlying continuous flowering, petal number, and discoloration. Notably, a *CCD4* homolog was identified as a major regulator of petal discoloration. Rose genome assembly was generated using doubled haploid rose line ('HapOB') from *Rosa chinensis* which anchored to seven pseudo-chromosomes (512 Mb with N50 of 3.4 Mb and 564 contigs). Combining genetic and genomic approaches, potential genetic for prickly density and the number of flower petals were identified. A rose *APETALA2/TOE* homologue was found to be the major regulator of petal number in rose. A total of 451 tree peony accessions was evaluated for 27 flowering and floral traits, and GBS generated 107,050 genome-wide SNPs, enabling association mapping that identified 1,047 candidate genes. GWAS analyses of rose identified nine significantly associated single nucleotide polymorphisms (SNPs) and genomic regions contributing to various root primordia and adventitious root formation traits. The recently developed FlowerBase provides the first comprehensive multi-omics platform dedicated to ornamental flowering plants. It integrates 62 high-quality genome assemblies representing 58 ornamental species, along with 44 transcriptome datasets, over 2.58 million annotated genes, and 8,754 metabolites. The database includes major ornamental genera such as *Rosa*, *Chrysanthemum*, *Lilium*, *Orchidaceae*, *Paeonia*, *Prunus*, *Rhododendron*, *Bougainvillea*, *Nelumbo*, *Nymphaea*, and *Osmanthus*. FlowerBase also incorporates analytical tools including JBrowse genome browser, BLAST, GO/KEGG enrichment, gene expression analysis, GWAS, genomic selection, SSR marker identification, primer design, CRISPR guide RNA design, and AI-based phenotyping, thereby supporting genomics-assisted breeding and functional genomics research (Wang et al., 2026).

Future Prospects of HGRs

Future management of horticultural genetic resources should focus on expanding systematic exploration, comprehensive characterization, and digital documentation of germplasm through

integrated phenotypic, molecular, and genomic approaches. Development of core collections, pan-genomes, graph-based genomes, high-throughput phenotyping platforms, and AI-assisted data analysis will accelerate the discovery of novel alleles from landraces, indigenous germplasm, and crop wild relatives. Wider application of marker-assisted breeding, genomic selection, genome editing, mutation breeding, and pre-breeding will enhance the efficient transfer of desirable traits for climate resilience, pest and disease resistance, nutritional quality, post-harvest life, and consumer-preferred characteristics. Strengthening national and international germplasm exchange, improving conservation infrastructure, expanding cryopreservation and in vitro repositories, and promoting the domestication and commercialization of underutilized and native horticultural species will broaden the genetic base of breeding programmes and contribute to sustainable horticultural production under changing climatic conditions.

Conclusion

Horticultural genetic resources represent one of the most valuable biological assets for ensuring future food, nutritional, environmental, and economic security. Their conservation and effective utilization provide the genetic diversity required to develop superior cultivars capable of withstanding emerging biotic and abiotic stresses while meeting evolving market and consumer demands. The integration of conventional germplasm conservation with advanced genomic technologies, digital phenotyping, bioinformatics, and precision breeding has transformed the utilization of genetic resources from simple conservation to targeted trait improvement. Strengthening collaboration among national and international institutions, enhancing conservation strategies, promoting on-farm conservation and crop wild relative utilization, and expanding genomic resource development will be essential for safeguarding horticultural biodiversity and accelerating the development of climate-resilient, high-yielding, and nutritionally enriched horticultural crops for future generations.

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Leveraging Genomics and Digital Tools for PGR Characterization and Utilization

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Introduction

Feeding a growing global population under a changing climate is one of the greatest challenges confronting modern agriculture. Dryland regions, which support nearly one-third of the world's population, are particularly vulnerable due to recurrent droughts, erratic rainfall, poor soil fertility and increasing incidences of biotic and abiotic stresses (Hultgren et al., 2025). These challenges are further compounded by land degradation, urbanization, shrinking natural resources and evolving market demands, collectively threatening agricultural productivity and the livelihoods of millions of smallholder farmers. Developing resilient, climate-smart crop varieties has therefore become a global priority for ensuring food and nutritional security.

Crop improvement has historically relied on harnessing genetic variation through conventional breeding and, more recently, genomics-assisted approaches. However, many breeding programmes continue to utilize a relatively narrow pool of elite germplasm, limiting the genetic gains that can be achieved for complex traits such as drought resilience, disease resistance, nutritional quality and productivity. Expanding the genetic base of breeding populations has become increasingly important to address emerging production challenges and sustain long-term genetic improvement (Bohra et al., 2022).

Genebanks represent the world's largest repositories of genetic diversity, conserving landraces, wild relatives and traditional cultivars that collectively capture centuries of natural evolution and farmer selection (Halewood et al., 2020). These collections harbor novel alleles and adaptive haplotypes that are often absent from modern breeding materials, providing an invaluable resource for developing future-ready crop varieties (Varshney et al 2021). Yet, despite their immense potential, much of this diversity remains underutilized because of limited genomic characterization and an incomplete understanding of its functional value.

The future of crop improvement, therefore, depends not only on generating new genetic variation but also on unlocking the vast diversity already conserved in genebanks. Recent advances in genomics, digital technologies and artificial intelligence are enabling this transformation, allowing genebanks to evolve from repositories of conserved germplasm into predictive biological knowledge systems that accelerate discovery, breeding and varietal development.



Global status of Plant Genetic Resources

According to FAO's Third Report on the State of the World's Plant Genetic Resources for Food and Agriculture, more than 5.9 million accessions are conserved *ex situ* under medium- and long-term storage conditions across 852 national genebanks in 116 countries, four regional genebanks and 13 international genebanks. These collections represent about 7,300 genera and 51,500 species from 394 botanical families. Food crops constitute the largest share of conserved germplasm, accounting for 73% of global holdings and including cereals, pulses, vegetables, fruits, oilseed crops, roots and tubers, herbs and spices, pseudo-cereals, sugar crops and nuts. Most accessions are conserved as seed, while the remaining materials are maintained through field collections and *in vitro* conservation. The CGIAR genebanks conserve over 0.74 million accessions of cereals, grain legumes, forages, tree species, root and tuber crops and banana, underscoring their central role in safeguarding globally important crop diversity (FAO 2025).

The ICRISAT genebank is one of the world's largest repositories of genetic resources for dryland food crops, including legumes, and cereals and serves as a global public good for agricultural research and crop improvement. Conserving more than 132,000 accessions (Figure 1) of 11 crops collected from 144 countries, it safeguards an exceptional breadth of genetic diversity encompassing landraces, breeding lines, improved cultivars and crop wild relatives (<https://genebank.icrisat.org/>). Over the past five decades, this invaluable resource has supported global agriculture by distributing more than 1.72 million seed samples to researchers and breeding programmes across 151 countries, while repatriating over 56,000 accessions to 12 countries to strengthen national conservation efforts. To ensure long-term security, 96% of the collection has been safety duplicated in the Svalbard Global Seed Vault, protecting this irreplaceable genetic heritage for future generations.

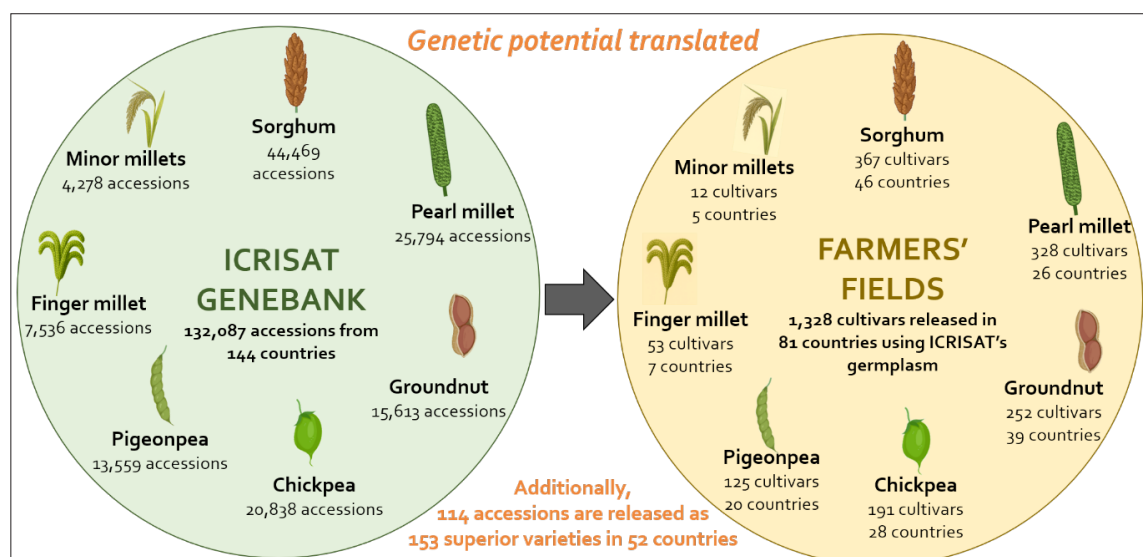


Figure 1. Genetic diversity from ICRISAT Genebank translated to Genomics research, Breeding pipelines and Farmer's fields across the globe

From Conservation to Genomic Curation

A primary responsibility of the genebank curator is to maintain the genetic integrity of each conserved accession, while preserving its inherent variability and diversity, including rare allelic variants. Changes in the genetic composition of germplasm accessions and the subsequent loss of alleles during conservation are mainly associated with inadequate sample sizes and unintended outcrossing during regeneration. Therefore, understanding of genetic diversity within and among landraces is critical for effective genebank management. Studies assessing within-accession diversity and sample size requirements in sorghum, pearl millet, and pigeonpea have revealed low, moderate, and high levels of within-accession diversity, respectively. The estimated effective sample sizes required to capture the maximum genetic variation and retain rare alleles during regeneration ranged from 47 to 101 plants in sorghum, 155 to 203 plants in pearl millet, and 77 to 89 plants in pigeonpea accessions (Allan et al. 2020). Similar studies in other crops are critical for the scientific curation of germplasm.

For decades, genebanks have measured their value by the number of accessions conserved. However, advances in genome-wide characterization have revealed that accession numbers do not necessarily reflect the extent of unique genetic diversity (Sahu et al., 2022). Repeated germplasm collection from the same geographical regions, exchange of materials among genebanks and inconsistent naming or documentation have resulted in considerable redundancy within and across collections. Beyond increasing the cost of long-term conservation, such redundancy can bias diversity panels, reduce the efficiency of germplasm utilization and limit the discovery of novel alleles in genomic studies.

These findings have catalyzed a paradigm shift from conservation to genomic curation, where the objective is not merely to preserve accessions but to accurately define and validate their genetic identity. At ICRISAT, genome-wide SNP profiling has enabled systematic detection of duplicate accessions, assessment of genetic purity and characterization of within- and among-accession diversity (Allan et al., 2020). Studies in groundnut and pulse crops have revealed varying levels of redundancy among landraces. In a study, a total of 1143 accessions of *Ae. Tauschii* from Wheat Genetic Resources Centre (WGRC, Kansas State University), 187 from Punjab Agricultural University (PAU, India), and 388 from CIMMYT were assessed to understand the extent of germplasm duplicates within and among genebanks (Singh et al. 2019). The results indicated that the number of duplicated accessions was ~26% in WGRC, 43% in CIMMYT and 54% in PAU (54.01%), with 50% duplicates combined across all genebanks were putatively duplicated.

Towards Genebank Genomics-informed Dynamic Diversity Panels

The effective utilization of genebank diversity depends not only on conserving genetically unique accessions but also on identifying representative germplasm for research and breeding.



Traditionally, diversity panels at the ICRISAT genebank, including core and mini core collections, were developed using passport information, geographical origin and morpho-agronomic descriptors. These strategies substantially improved the management and utilization of large collections. Integrating genotyping data together with morphology-based diversity while developing diversity subsets could further capture genome-wide allelic variation, particularly for complex traits governed by numerous small-effect loci.

Over the past decade, ICRISAT has established an extensive suite of genomic resources across its mandate crops, including high-quality reference genomes, pangenomes, large-scale whole-genome resequencing datasets and high-, medium- and low-density genotyping platforms (Varshney *et al.*, 2017; Bohra *et al.*, 2020; Pandey *et al.*, 2020; Roorkiwal *et al.*, 2020). These foundational resources have transformed the characterization of conserved germplasm, enabling comprehensive assessment of genome-wide variation, population structure, domestication history and haplotype diversity. Rather than relying solely on phenotypic similarity or geographic origin, diversity can now be quantified directly at the genomic level, providing a much more accurate representation of functional variation within collections.

These advances are redefining the concept of diversity panels. Instead of static collections assembled primarily from passport and morphological information, next-generation panels are becoming dynamic, genomics-informed resources that integrate genome-wide variation, functional haplotypes and breeding objectives. Such panels can be tailored to specific traits, environments or breeding targets, enabling more efficient genome-wide association studies, genomic prediction, donor selection and pre-breeding (Abbai *et al.*, 2026). By shifting from phenotype-guided sampling to genome-guided representation of diversity, predictive genebanks maximize the probability of capturing rare and beneficial alleles, thereby accelerating the discovery and deployment of superior genetic variation for crop improvement.

Integrating Digital Technologies for Genebank Characterization

The growing scale of genebank collections has made conventional approaches to germplasm characterization increasingly labour-intensive and time-consuming. While genomics provides a comprehensive understanding of genetic variation, its full potential can only be realized when complemented by accurate, high-throughput phenotypic and operational data. Recognizing this need, ICRISAT has integrated digital technologies across the germplasm characterization pipeline, enabling rapid, standardized and data-driven evaluation of conserved genetic resources. Rather than functioning as independent technologies, genomics and digital platforms are being combined to generate integrated genome–phenome datasets that support both biological discovery and breeding applications.

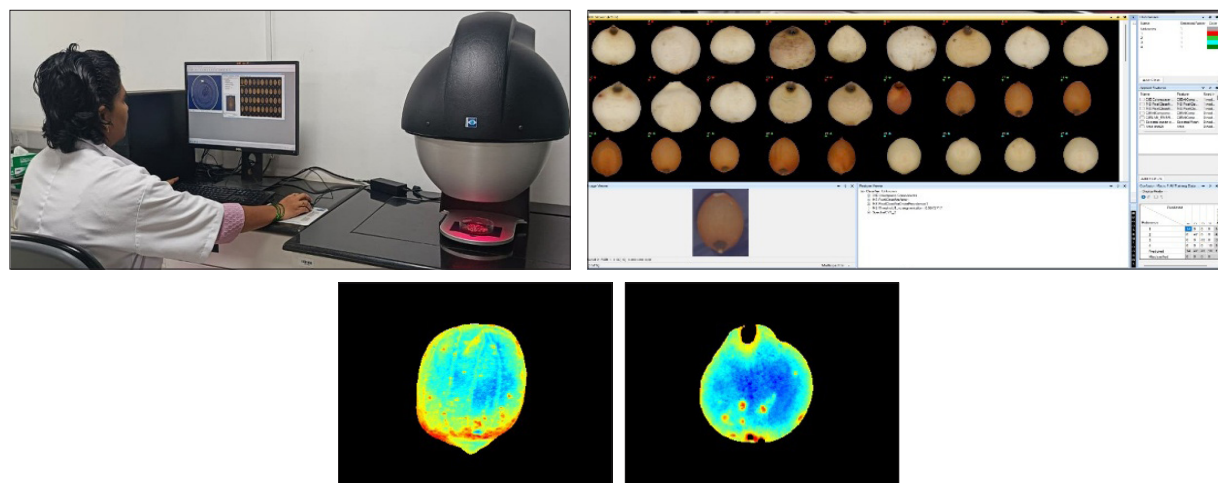


Figure 2. Digital seed characterization and viability prediction

Digital innovations have been deployed across multiple stages of germplasm management and characterization. Barcode-based field labelling and digital data capture systems facilitate accurate sample tracking and real-time recording of phenotypic observations, minimizing transcription errors while improving data quality and traceability. Seed characterization is a fundamental component of germplasm conservation, seed quality assessment, and crop improvement programs. Traditional characterization methods are often labour-intensive, subjective, and limited in their ability to capture the complex physical and physiological attributes of seeds. Imaging technologies, including the Videometer platform, provide rapid and non-destructive assessment of seed quality, purity and physical characteristics, enhancing quality assurance during regeneration and seed distribution. In this context, the VideometerLab multispectral imaging system provides a powerful platform for digital seed characterization by integrating spectral imaging with image analysis. The system captures seed information across 19 spectral bands (365-960 nm) and generates more than 150 quantitative descriptors, including morphological traits (size, shape, area, perimeter), colorimetric attributes (color intensity and distribution), textural properties, and detailed spectral reflectance features for individual seeds. These multidimensional datasets facilitate seed characterization, identification of varietal differences, detection of seed quality variations, and development of predictive models for important seed attributes. Furthermore, integrating multispectral imaging with machine learning approaches offers significant potential for non-destructive seed viability assessment. Accordingly, seed viability prediction models for sorghum and groundnut are currently under development in ICRISAT genebank using VideometerLab-derived data, providing a promising pathway toward automated and accurate seed quality evaluation for germplasm management and seed system applications.

AI-assisted image analysis and emerging high-throughput phenotyping platforms, for example, LeasyScan, further enable objective measurement of complex plant traits that are

difficult to quantify through conventional approaches, thereby increasing both the speed and reproducibility of germplasm evaluation.

The true power of these technologies lies in their integration with genomic information. By linking genome-wide variation with precise phenotypic measurements, digital characterization generates rich genome–phenome datasets that improve the resolution of trait mapping, facilitate functional validation of candidate genes and enhance predictive breeding models. As artificial intelligence and machine learning continue to advance, such integrated datasets will become increasingly valuable for identifying superior germplasm, predicting trait performance and supporting evidence-based decision making. Consequently, digital technologies are no longer simply tools for efficient data collection—they are fundamental enablers of next-generation, predictive genebanks that connect conserved diversity with accelerated crop improvement.

Translating Diversity into Discovery

The ultimate value of a genebank lies not only in the diversity it conserves, but in its ability to translate that diversity into biological knowledge and breeding solutions. The integration of genomics with curated germplasm collections has transformed genebanks from repositories of genetic resources into discovery platforms for identifying genes, quantitative trait loci (QTLs), superior haplotypes and genomic regions underlying agriculturally important traits. By combining genome-wide variation with high-quality phenotypic data, researchers can systematically dissect the genetic architecture of complex traits and identify elite donor accessions for crop improvement.

At ICRISAT, this discovery pipeline spans multiple mandate crops and diverse trait categories, including resistance to major diseases, tolerance to abiotic stresses, nutritional enhancement, seed quality, flowering behaviour, maturity, root architecture and other agronomically important characteristics. Genome-wide association studies, haplotype-based analyses and genomic prediction have enabled the identification of functional alleles and superior haplotypes that provide greater precision in donor selection than conventional phenotype-based approaches (Abbai *et al.*, 2019; Sinha *et al.*, 2020; Varshney *et al.*, 2021; Shah *et al.*, 2026; Rangari *et al.*, 2026). Rather than focusing on individual crops, a common genomics framework has been established, where conserved diversity is systematically characterized, trait-associated genomic regions are identified, and the resulting knowledge is translated into breeding-ready resources. This pipeline significantly shortens the path from germplasm conservation to trait discovery and genetic improvement.

A key component of this strategy is the integration of crop wild relatives through the Centre for Pre-breeding Research (CPBR), ICRISAT which bridges the gap between conserved diversity and breeding programmes. Wild species often possess valuable alleles that have been lost during domestication but remain difficult to utilize because of crossing barriers and linkage drag. Through genomics-assisted pre-breeding, superior alleles from wild relatives can be efficiently introgressed into elite backgrounds, expanding the genetic base available to breeders.

Discovery to Delivery

The true measure of success for a genebank is not the number of accessions it conserves, but the extent to which conserved diversity is translated into improved crop varieties that benefit farmers. At ICRISAT, genomics has established a seamless pathway connecting germplasm conservation with cultivar development, enabling valuable genetic variation to move efficiently from the genebank into breeding pipelines. This integrated approach combines genomic characterization, trait mapping, superior haplotype identification, genomics-assisted breeding and genomic prediction to accelerate the development of improved cultivars for dryland agriculture.

Across ICRISAT mandate crops, genomics-enabled breeding has delivered tangible outcomes. In groundnut, genomic discoveries have facilitated the development of improved cultivars with enhanced resistance to rust, late leaf spot and high oleic acid content (Varshney et al., 2014; Janila et al., 2016; Pandey et al., 2020). In pigeonpea, genomic prediction models incorporating additive and dominance effects have improved the prediction of hybrid performance and mid-parent heterosis, while advanced genomic prediction approaches are accelerating selection for complex yield and quality traits (Bhora et al., 2020; Saxena et al., 2021). Similar successes have been achieved in chickpea through marker-assisted introgression of the drought tolerance "QTL-hotspot" (Roorkiwal et al., 2020; Barmukh et al., 2022). These examples illustrate how genomic knowledge is being translated into practical breeding solutions across diverse crops and production environments.

The cumulative impact of these efforts extends far beyond individual breeding programmes. Germplasm conserved in the ICRISAT Genebank has contributed to the release of 1,328 cultivars across 81 countries (Figure 1), demonstrating the global value of conserved genetic resources. These achievements highlight a complete innovation pipeline—from conserving millions of seeds, to discovering valuable alleles and haplotypes, developing superior breeding materials, and ultimately delivering improved cultivars to farmers. This transformation from discovery to delivery exemplifies how genomics is maximizing the value of genebank collections, ensuring that conserved diversity directly contributes to resilient agricultural systems, improved livelihoods and global food and nutritional security.

Conclusion

Feeding a growing population under climate change demands a fundamental shift in how we conserve and use crop genetic resources, particularly for vulnerable dryland agriculture. While genebanks safeguard millions of accessions, their true impact depends on moving beyond conservation to genomic curation and predictive utilization. The integration of genome-wide characterization, digital phenotyping, and AI-driven analytics is enabling genebanks to evolve into dynamic platforms that accurately define genetic identity, eliminate redundancy, and identify functionally valuable diversity. The ICRISAT genebank exemplifies this transition, leveraging extensive genomic resources and digital tools to establish phenomics and genomics informed



diversity panels, accelerate trait discovery, and bridge conservation with breeding through pre-breeding and genomics-assisted selection. The delivery of over 1,328 cultivars from conserved germplasm underscores the power of this discovery-to-delivery pipeline in addressing drought, disease, and nutritional challenges in dryland crops. Going forward, maximizing the value of global genetic resources will require continued investment in genomics, phenomics, and data integration to build predictive genebanks that can rapidly translate diversity into climate-resilient varieties. By unlocking the vast allelic potential already conserved, we can ensure that genebanks not only preserve agricultural heritage but also drive the next generation of crop improvement for food and nutritional security in a changing climate.

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Millets for the Future: Unlocking Genetic Resources for Climate Resilience and Nutritional Security

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Introduction

Millets have re-emerged as strategically important crops, addressing two of the most pressing challenges confronting contemporary food systems: climate vulnerability and micronutrient insecurity. Pearl millet, sorghum, finger millet, foxtail, little, kodo, barnyard and proso millet exhibit exceptional adaptation to semi-arid and rainfed environments, where drought, heat stress, poor soil fertility and water scarcity routinely constrain the productivity of major cereals. Their low water requirement, short duration, resource-use efficiency and inherent tolerance to drought, heat and disease establish millets as natural anchors of climate-resilient cropping systems.

Beyond agronomic resilience, millets deliver substantial nutritional value—dietary fibre, protein and essential minerals including iron, zinc, calcium, magnesium and phosphorus. The magnitude of these nutritional attributes varies considerably across species, genotypes and environments, underscoring genetic diversity as the central resource underpinning all future improvement efforts.

Policy Framework Enabling Scientific Advancement

The scientific trajectory of millet improvement has been reinforced by a consequential shift in national policy recognition. In 2018, the Government of India formally designated millets as "nutri-cereals" through Gazette Notification dated 13 April 2018, affirming their nutritional significance and enabling their integration into national programmes for production, consumption, processing and value addition. This recognition was substantially reinforced when 2023 was declared the International Year of Millets, following India's initiative at the United Nations, which mobilized global and domestic research and development attention toward these crops.

A defining milestone followed on 1 February 2023, when the Union Budget 2023–24 formally designated millets as "Shree Anna," establishing their identity as nutritious, sustainable and climate-resilient food grains within national policy. The Budget further committed to strengthening the Indian Institute of Millet Research, Hyderabad, as a Centre of Excellence for the dissemination of millet-related research and technology at the international level.

Genetic Resource Conservation and Large-Scale Characterization

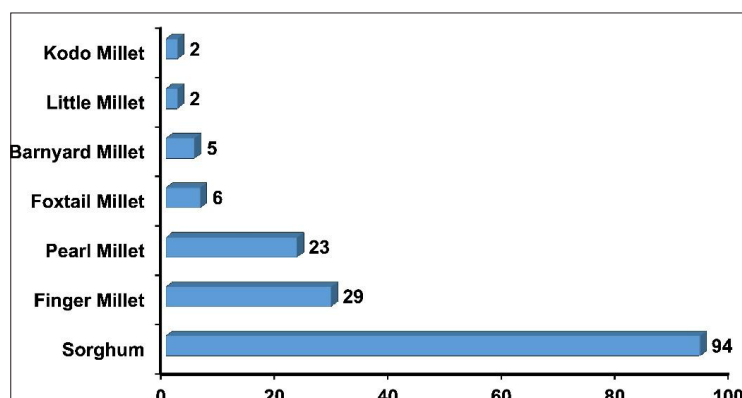
The policy transition from "nutri-cereals" to "Shree Anna" has been matched by systematic scientific effort in germplasm conservation and characterization. In collaboration with ICAR—

NBPGR, New Delhi, and NARS centres nationally, more than 50,000 millet accessions have been conserved at IIMR and the national genebank, constituting one of the most extensive repositories of millet genetic diversity globally.

This conserved diversity has been actively mobilized through coordinated national characterization initiatives. The entire sorghum germplasm collection—approximately 25,000 accessions held at the National Genebank—was subjected to large-scale characterization at ARS Washim under PDKV, Akola, during 2022–23, generating extensive phenotypic and agronomic datasets. This was followed by the characterization of approximately 12,000 finger millet accessions at TNAU, Coimbatore, during 2024–25, with particular focus on agronomic performance and calcium variability. Subsequently, approximately 4,000 foxtail millet accessions were characterized at UAS, Bengaluru, during 2025–26, enabling identification of diversity for yield, adaptation and quality traits. Collectively, these efforts constitute one of the most comprehensive multi-location germplasm characterization programmes undertaken for millets in India.

Trait Identification and Registration with ICAR–NBPGR

A critical achievement linking germplasm characterization to long-term breeding utilization has been the systematic identification, registration and conservation of trait-specific germplasm through ICAR–NBPGR. Genebanks have evolved beyond static repositories of historical diversity into active breeding infrastructure, providing characterized and traceable sources of useful alleles. Nutrient-rich accessions identified through AICRP and large-scale characterization programmes are registered with NBPGR and subsequently deployed as trait characterization programmes are registered with NBPGR and subsequently deployed as trait donors in breeding programmes.



Millet germplasm registered with ICAR-NBPGR

A total of 161 millet germplasm accessions have been registered for traits of importance. Sorghum accounts for the highest number of registrations (94), followed by finger millet (29) and pearl millet (23). Foxtail, barnyard, little and kodo millets account for 6, 5, 2 and 2 accessions respectively, indicating scope for expanded trait-focused registration efforts in the small millets.

Trait-wise analysis of these 161 registrations identifies three dominant breeding priorities: disease resistance (42 stocks; 26.1%), male sterile lines (31 stocks; 19.3%) and early flowering

(15 stocks; 9.3%). This distribution reflects concentrated national investment in biotic stress resistance, hybrid seed production systems and reduced crop duration. Traits including fodder yield, drought tolerance and nutritional richness—iron, zinc and protein content—remain comparatively underrepresented, identifying priority areas for future trait-donor development.

Genomics-Enabled Trait Discovery

Concurrent with germplasm registration, advances in genomic science are converting millet diversity into deployable breeding resources. Pan-genomics, genome-wide association studies (GWAS), genomic prediction, high-throughput phenotyping and gene editing collectively constitute this genomics-assisted breeding framework. Pan-genome analyses in foxtail and broomcorn millet have demonstrated the role of structural variants and presence–absence genes in domestication and agronomic trait expression. A newly assembled telomere-to-telomere little millet genome has established direct linkages between genomic variation and grain concentrations of iron, zinc, magnesium and phosphorus, providing a genomics-based foundation for nutritional breeding.

Across pearl millet, finger millet, foxtail millet and sorghum, GWAS and genomic selection approaches are identifying loci associated with stress tolerance and grain quality, although prediction accuracy continues to require strengthened multi-environment calibration. Gene-editing and transformation systems established in broomcorn millet further extend capacity for functional validation and targeted trait improvement. These developments collectively establish that the strategic value of millets resides not solely in their inherent resilience, but in the systematically identifiable, validatable and deployable genetic variation within and across species.

Conclusion

Future millet improvement efforts should prioritize the integration of nutrient density, climate resilience and farmer-preferred agronomic traits, supported by genomic prediction and rigorous multi-environment testing. India's millet research agenda has progressively evolved from conservation and traditional cultivation toward an integrated framework encompassing policy recognition, genetic-resource conservation, large-scale germplasm characterization, nutrient benchmarking, trait-donor development, genomics-assisted breeding, biofortification and nutritional validation.

The policy transition from "nutri-cereals" to "Shree Anna" has provided the necessary policy momentum, while AICRP programmes and the ICAR–NBPGR genebank system have supplied the scientific and genetic-resource infrastructure required to translate this vision into improved cultivars. The consolidated opportunity ahead is to systematically convert India's extensive millet genetic diversity into high-yielding, climate-resilient, nutritionally rich and locally adapted varieties and hybrids—establishing millets not as marginal or alternative cereals, but as central components of future dryland resilience and nutritional security.

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LANDSCAPE CONSERVATION AND BIORESOURCE STEWARDSHIP

Corporate Stewardship of Plant Genetic Resources

BIAL's Landscape Conservation

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A modern airport can be more than transport infrastructure: it can serve as a living repository of regional plant diversity, an ecological refuge and a public demonstration of responsible corporate stewardship.

Plant genetic resources beyond conventional gene banks

Plant genetic resources (PGR) comprise the heritable diversity contained in species, populations, landraces, cultivars and crop wild relatives. Their conservation is commonly organised through in situ protection, on-farm continuity and ex situ repositories. Large institutional landscapes can complement these systems through living collections: spatially distributed populations maintained under real climatic conditions, with records of identity, origin, establishment, survival and performance. They cannot replace seed banks or botanic gardens, but they can conserve mature genetic material, create habitat and expose large public audiences to biological diversity.

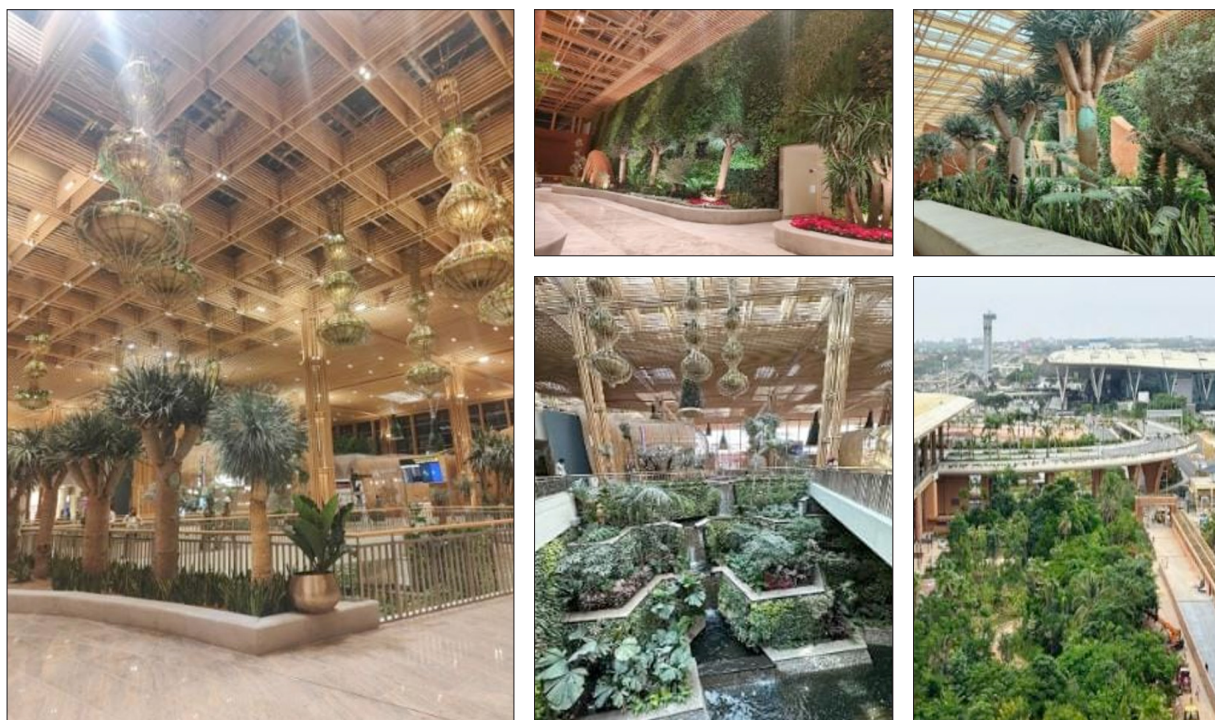
Airports present an unusually demanding test environment. Plant selection must reconcile heat, wind, reflected radiation, restricted rooting volumes, variable light, passenger safety, aviation operations, biosecurity, bird-hazard management, irrigation efficiency and intensive maintenance. Successful conservation therefore depends on more than species richness. It requires traceable accession records, risk-screened sourcing, habitat-based planting, soil-biological recovery, water budgeting, integrated pest management, phenological observation and measurable survival over time.

Why corporate landscapes matter

Large institutional campuses possess land, procurement capacity, technical teams and long management horizons. Used responsibly, these assets can retain mature trees, cultivate regionally adapted material and connect terrestrial, wetland and vertical habitats. The measurable outcomes extend beyond visual quality: canopy continuity, carbon retention, reduced surface temperature, stormwater moderation, soil protection, pollinator resources and human contact with nature.



Bangalore International Airport Limited (BIAL) illustrates this transition from ornamental horticulture to conservation infrastructure. Under the landscape leadership of Prasannamurti Desai, the design intent evolved from ‘Terminal in a Garden’ to ‘Terminal in a Biodiversity Hotspot’. The passenger sequence—from access road to terminal, forest belt, green walls and boarding piers—was treated as an ecological continuum embedded within a high-performance transport facility.



Translating ecological vision into practice

At the centre of BIAL’s landscape transformation has been the professional contribution of eminent landscape and horticulture expert Prasannamurti Desai, who served as Vice President—Landscape from 2018 to 2023. With more than two decades of experience across airports, real estate, hospitality and golf landscapes, he helped translate conservation intent into field practice—linking plant science, design management, nursery production, transplantation, irrigation, construction coordination and long-term horticultural care.

A defining contribution was the conservation of living assets during airport expansion. The initial programme covered 7,095 trees and shrubs and was supported by mechanised transplantation and scientific guidance for pre-assessment, movement and aftercare. Contemporary reporting recorded survival above 85% for the first thousand-plus transplants; species and girth determined whether mechanised or slower conventional methods were used. Later project accounts describe more than 7,700 transplanted trees and palms and over 100,000

shrubs. This is scientifically more meaningful than replacement planting because mature trees retain accumulated biomass, canopy structure, microhabitats and ecosystem function.

Mr. Desai also foregrounded edaphic conservation. The upper 6–8 inches of site topsoil were recovered and stored for reuse, retaining organic matter, propagules and part of the soil microbial community. In landscape restoration, this living layer influences aggregation, infiltration, nutrient cycling and root establishment; protecting it reduces dependence on manufactured growing media and accelerates ecological recovery.

Published project accounts report more than 3,600 plant species, approximately 620 endemic plants, over 180 rare, endangered and threatened taxa, 150 palm species and ten ecological habitat types. Around 600,000 plants were deployed across interior beds, hanging gardens and green walls, with a forest belt extending habitat structure outdoors. These totals should be read as a living-collection baseline; their enduring conservation value depends on verified taxonomy, accession-level provenance, duplicate representation, health monitoring and periodic survival audits.

From collection building to adaptive management

A dedicated two-acre pre-growing facility supported multi-year acclimatisation, uniformity assessment and installation readiness. Imported Mediterranean material underwent transport control and greenhouse acclimatisation before landscape use. For vertical systems, plant selection considered growth habit, light and water demand; plants were transferred to engineered soilless media and tested through mock-ups. This staged process—source, quarantine or inspect, acclimatise, trial, install and monitor—is central to reducing establishment failure and biosecurity risk.

Water management linked horticulture with climate resilience. Automated irrigation used evapotranspiration, soil-moisture, rainfall and level sensors to regulate delivery, while harvested rainwater supplied planted systems. Species-level hydrozoning and continuous sensor calibration are essential: automation saves water only when plant demand, emitter performance, substrate water-holding capacity and seasonal weather data are correctly matched.

The larger lesson is clear: corporate stewardship succeeds when biodiversity is treated as a long-term asset, supported by baseline inventories, traceable plant sourcing, measurable survival and diversity indicators, water-wise maintenance, biosecurity safeguards, skilled horticultural teams and transparent knowledge-sharing.

From a landmark project to a replicable movement

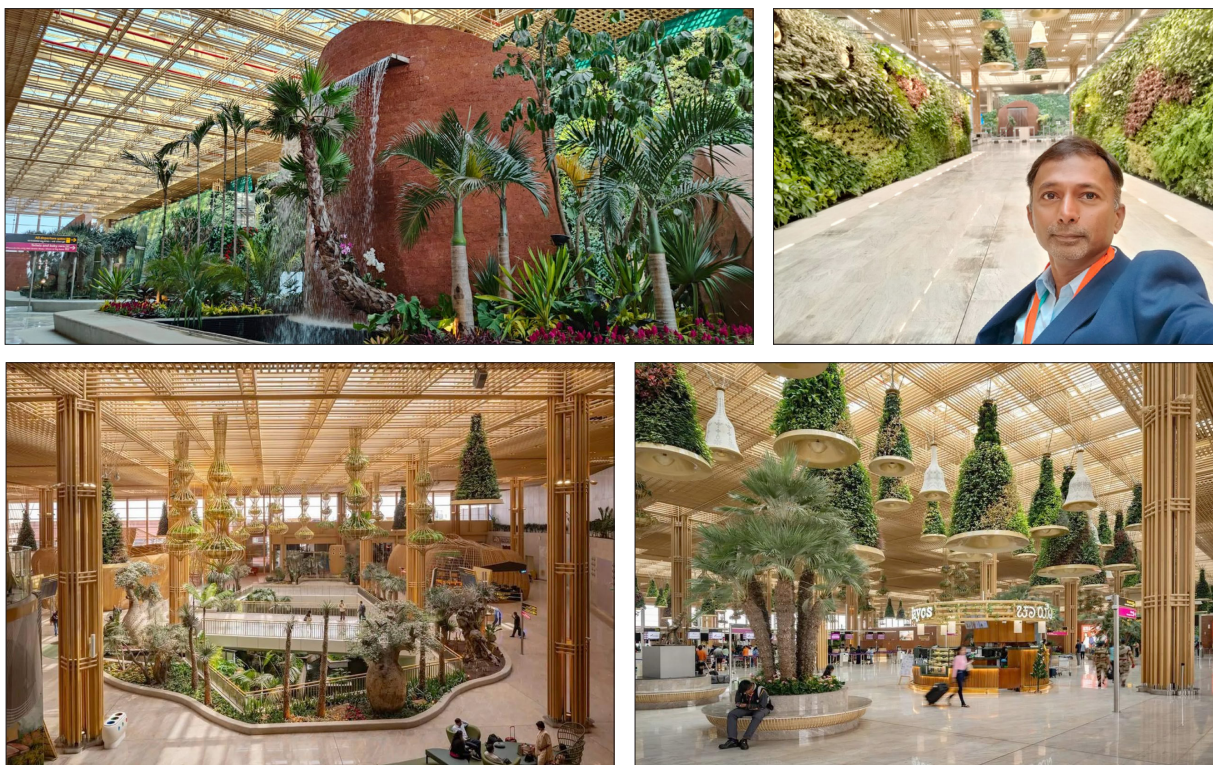
My published thinking repeatedly emphasizes local horticultural expertise, agroclimatic plant palettes, soil health, native planting, plant–fauna relationships, integrated pest management, smart irrigation, nursery systems, arboriculture, composting and maintenance planning from the



design stage. His ‘Forest of Abundance’ concept adds an ethnobotanical layer by assembling culturally significant, medicinal and threatened plants and interpreting their occurrence in Indian and world traditions.

This body of work offers a replicable framework for airports, industrial campuses, technology parks, universities and tourism destinations: map existing biological assets; conserve before clearing; safeguard topsoil; source plants traceably; pre-grow and acclimatise material; prioritise native and regionally adapted diversity; build habitat layers; use water intelligently; measure survival and ecological performance; and communicate plant knowledge to visitors and employees.

BIAL’s landscape journey demonstrates how environmental responsibility can become a visible, living and continually improving institutional practice. Through Prasannamurti Desai’s leadership and knowledge-sharing, airport horticulture was reframed as the coordinated management of genetic diversity, soil, water, habitat, technology and human experience



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Policy Frameworks and ABS: Aligning Global Commitments with Local Policy Needs in India for PGR Governance

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Introduction

Policy frameworks and Access and Benefit Sharing (ABS) for Plant Genetic Resources (PGR) governance in India focus on aligning international commitments under the Convention on Biological Diversity (CBD), Nagoya Protocol, and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) with domestic needs for conservation, sustainable use, farmers' rights, and equitable benefit sharing. India, a megadiverse country and major centre of origin/diversity for many crops, has developed a layered legal and institutional system to regulate access to biological resources (including PGR) and associated traditional knowledge.

Global Commitments

- **CBD (1992):** Sovereign rights over genetic resources; objectives of conservation, sustainable use, and fair/equitable benefit sharing. India became a party in 1993.
- **Nagoya Protocol (2010, in force 2014):** Operationalises ABS via Prior Informed Consent (PIC), Mutually Agreed Terms (MAT), and compliance measures (including Internationally Recognised Certificates of Compliance – IRCCs). India ratified it in 2012/2014 and submitted its first National Report (NR1) covering 2017–2025 in February 2026.
- **ITPGRFA:** Multilateral System (MLS) of facilitated access and benefit sharing for Annex 1 crops (food and forage). India implements this alongside CBD/Nagoya frameworks, with specific exemptions under the Biological Diversity Act for certain germplasm exchanges (e.g., via ICAR-NBPGR).
- Related instruments include the Kunming-Montreal Global Biodiversity Framework (KMGBF) targets on Indigenous Peoples and Local Communities (IPLCs) rights and Article 8(j) of the CBD on traditional knowledge.

India's Domestic Policy and Legal Framework

India's Plant Genetic Resources (PGR) governance operates via a matrix of three primary authorities, ensuring sovereign control, biosafety, and equity:



- **National Biodiversity Authority (NBA):** Regulates access to biological resources, ensures prior informed consent (PIC), executes mutually agreed terms (MAT), and oversees sovereign cross-border flows.
- **Protection of Plant Varieties and Farmers' Rights Authority (PPVFRA):** Governs plant variety protection through a *sui generis* legislation, balancing intellectual property rights for breeders with robust statutory exemptions for farmers.
- **Indian Council of Agricultural Research (ICAR):** Acts as the technical arm. The **National Bureau of Plant Genetic Resources (NBPGR)** under ICAR serves as the single window for germplasm import, quarantine, and national accessioning.

Metric / Dimension	National Biodiversity Authority (NBA)	PPV&FR Authority	ICAR-NBPGR
Statutory Mandate	Biological Diversity Act, 2002 (Amended 2023)	PPV&FR Act, 2001	Plant Quarantine Order, 2003 / Destructive Insects & Pests Act, 1914
Core Jurisdiction	Wild, domesticated PGR, and traditional knowledge	Extant, Farmers', and New plant varieties	Germplasm exchange, ex-situ banking, biosecurity screening
Mechanisms	PIC, MAT, ABS Agreements, and IRCCs	DUS Testing, Farmers' Rights, and Benefit Sharing Fund	Import Permits, Phytosanitary Certificates, In-vitro / Cryopreservation
Governance structure	NBA; SBB; BMC: 3-tiered institutional structure	Centralised functioning but testing through NARS	Centralised functioning but operated through ICAR and in compliance with the Directorate of Plant Protection, Quarantine and Storage (PPQS) is the National Plant Protection Organization (NPPO) of India under the Ministry of Agriculture and Farmers Welfare, GoI

Supplementary legislations: Geographical Indications of Goods Act, 1999: Protects region-specific PGR-linked products.

ABS mechanisms:

- Access requires PIC and MAT. Approvals cover research, bio-survey/bio-utilisation, commercial use, transfer of results, and intellectual property.
- Benefit sharing is turnover-linked (e.g., under 2025 Regulations: nil up to ₹5 crore annual turnover; 0.2–0.6% of gross ex-factory sale price for higher brackets) plus possibilities of non-monetary benefits (technology transfer, joint IP, capacity building, local production).
- Funds flow to identified beneficiaries (BMCs, communities, traditional knowledge holders, farmers) or, were unidentified, to socio-economic development/conservation in source areas. Recent NBA guidance (2026) clarifies allocation (e.g., 25–40% to institutions/repositories where relevant; remainder via SBBs to communities).

Aligning Global Commitments with Local Policy Needs

India's system emphasises sovereignty + equity + decentralisation:

- Global PIC/MAT and IRCC requirements are domesticated through NBA/SBB permitting and the three-tier structure, ensuring local communities (via BMCs and PBRs) have a voice and receive benefits.
- Farmers' rights under PPV&FRA and community documentation address local seed sovereignty and agro-biodiversity needs that pure international IP regimes might overlook.
- Exemptions and collaborative research pathways balance facilitated access (ITPGRFA/MLS, emergency research) with control over commercial/bioprospecting uses.
- Recent reforms (2023 Amendment, 2024 Rules, 2025 Regulations) aim to streamline procedures (decriminalisation of certain offences, clearer foreign/Indian distinctions, revised fees/forms, upfront payments), reduce compliance burdens for Indian researchers/industry, and strengthen benefit channelling while remaining Nagoya-compliant.

What should be the prioritised local needs:

- Conservation of on-farm and wild PGR diversity.
- Livelihood support for smallholders, tribal communities, and traditional knowledge holders.
- Prevention of misappropriation while enabling legitimate research and innovation (including classical biological control exchanges under coordinated rules).
- Integration with broader policies (National Biodiversity Action Plan/NBAP updates, sectoral policies on agriculture/forests).

Challenges and Gaps

Implementation gaps persist despite leadership in IRCCs and approvals:

- Capacity and awareness constraints at BMC/SBB levels; incomplete or uneven PBR quality.



- Overlapping jurisdictions and slow processing in some cases.
- Need for stronger user-country measures/checkpoints and clearer rules on Digital Sequence Information (DSI).
- Ensuring genuine Free, Prior and Informed Consent (beyond consultation) and effective benefit delivery to grassroots claimers.
- Harmonising BDA with PPV&FRA, quarantine rules, and collaborative research pathways for biological control agents or germplasm exchange.

It is expected that ongoing work includes NBA streamlining of ABS fund utilisation, repository guidelines, and international cooperation (e.g., ASEAN-India, GEF, UNDP BIOFIN, Indo-German projects).

Outlook for Effective PGR Governance

India's multi-layered approach demonstrates how a megadiverse developing country can translate global ABS norms into a workable national system that privileges local communities and farmers while facilitating legitimate access. However, this is work in progress and requires sustained focus at national level, e.g., capacity building for bio-diversity management committee(s), policy for DSI, improving enforcement/monitoring/technology-assisted tracking), ensuring benefits reach intended recipients, and maintaining policy coherence across agriculture, environment, and IP domains—will be essential. This alignment supports both international obligations and domestic goals of food security, livelihood resilience, and biodiversity stewardship.

* * * * *

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