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Legal Governance of Plant Genetic Resources: Biodiversity Conservation, Biotechnology, and Emerging Policy Challenges

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ABSTRACT
Plant genetic resources (PGRs) are fundamental to global food security, agricultural sustainability, biodiversity conservation, and climate resilience. Rapid advances in biotechnology, genome editing, and digital genetic information have expanded their utilization while creating significant legal and ethical challenges related to access, ownership, intellectual property rights, and benefit-sharing. This review examines the evolution of international and national legal frameworks governing PGRs, highlighting major agreements such as the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the Nagoya Protocol, the Cartagena Protocol on Biosafety, the TRIPS Agreement, and the International Union for the Protection of New Varieties of Plants (UPOV). It also evaluates India's legal framework, including the Biological Diversity Act, the Protection of Plant Varieties and Farmers' Rights Act, and biosafety regulations. Furthermore, the review discusses emerging challenges involving climate change, CRISPR-based genome editing, digital sequence information, synthetic biology, and biopiracy. It emphasizes integrated governance approaches that promote conservation, sustainable utilization, equitable benefit-sharing, and responsible biotechnological innovation.
Keywords: *Plant genetic resources, biodiversity, legal governance, biotechnology, biosafety, intellectual property rights, farmers' rights, access and benefit-sharing.*

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INTRODUCTION

Plant genetic resources (PGRs) represent one of the most valuable components of global biological diversity and serve as the foundation for agriculture, forestry, horticulture, pharmaceutical development, ecological restoration, and climate resilience. They comprise the hereditary material found in cultivated crops, crop wild relatives, medicinal plants, forest species, forage crops, ornamental plants, and microorganisms associated with plant ecosystems (1,2). The conservation and sustainable utilization of these genetic resources are fundamental for ensuring food security, nutritional diversity, ecosystem stability, and agricultural innovation (1).

Over the past century, rapid industrialization, agricultural intensification, urban expansion, habitat fragmentation, invasive species, and climate change have accelerated the erosion of plant genetic diversity (3). The Food and Agriculture Organization has estimated that a substantial proportion of traditional crop varieties has disappeared from agricultural systems during the last century, increasing dependence on a limited number of genetically uniform cultivars (3). Such genetic erosion reduces the adaptive capacity of crops to emerging pests, diseases, and environmental stresses, thereby threatening global food systems and sustainable agricultural development (2,3).

Simultaneously, remarkable advances in plant biotechnology—including molecular breeding, tissue culture, marker-assisted selection, transgenic technology, genome editing, and synthetic biology—have transformed crop improvement and conservation strategies (4). These technologies enable rapid development of improved crop varieties with enhanced yield potential, disease resistance, abiotic stress tolerance, and nutritional quality (4). However, technological progress has also generated complex legal and ethical questions concerning ownership of genetic resources, patentability of biological materials, farmers' rights, access to genetic resources, benefit-sharing mechanisms, and protection of traditional knowledge (5).

Historically, plant genetic resources were widely regarded as the common heritage of humankind and exchanged freely among nations (2). The emergence of biotechnology and commercial plant breeding,

however, shifted international policy toward recognizing the sovereign rights of states over their biological resources (6). This transition culminated in the adoption of several international legal instruments that collectively regulate conservation, utilization, access, and intellectual property associated with plant genetic resources. The Convention on Biological Diversity (CBD), adopted in 1992, marked a significant turning point by recognizing national sovereignty over biological resources while promoting conservation, sustainable use, and equitable sharing of benefits arising from genetic resources (6). Subsequent agreements, including the Nagoya Protocol (2010), the International Treaty on Plant Genetic Resources for Food and Agriculture (2001), the Cartagena Protocol on Biosafety (2000), the TRIPS Agreement, and the UPOV Convention, have further shaped the global governance framework for plant genetic resources (5,8).
At the national level, countries have developed legislative systems tailored to their biological wealth, agricultural priorities, and socio-economic conditions (1). India, recognized as one of the world's megadiverse countries, has enacted comprehensive legislation including the Biological Diversity Act, 2002; the Protection of Plant Varieties and Farmers' Rights Act, 2001; the Seeds Act, 1966; and biosafety regulations governing genetically modified organisms. These legal frameworks aim to balance biodiversity conservation, scientific research, agricultural development, and the protection of indigenous knowledge while complying with international obligations (2,5).
Despite these legal advancements, significant governance challenges remain. Climate change is altering species distributions and increasing the urgency of conserving diverse genetic resources (3). Emerging technologies such as CRISPR-based genome editing, synthetic biology, and digital sequence information challenge existing legal definitions and regulatory systems (4). Moreover, concerns regarding biopiracy, unequal benefit-sharing, inadequate recognition of indigenous communities, and inconsistencies between international agreements continue to complicate effective governance (5,9)
This review synthesizes current scientific and legal literature on the governance of plant genetic resources by examining international treaties, national legislative frameworks, intellectual property systems, access and benefit-sharing mechanisms, biosafety regulations, and emerging technological developments. It also identifies existing policy gaps and future priorities for developing a coherent legal framework capable of balancing biodiversity conservation, agricultural innovation, and equitable socio-economic development in the twenty-first century (2,4).

PLANT GENETIC RESOURCES: DEFINITION, CLASSIFICATION, IMPORTANCE, AND GLOBAL STATUS

Plant genetic resources (PGRs) comprise all genetic material of plant origin that possesses actual or potential value for food, agriculture, forestry, medicine, industry, and environmental sustainability. According to the Food and Agriculture Organization (FAO), PGRs include cultivated crop varieties, traditional landraces, crop wild relatives, medicinal and aromatic plants, forest tree species, forage crops, ornamental plants, and other wild plant species that contribute to biodiversity and agricultural development (1). These genetic resources constitute the foundation of plant breeding and crop improvement by providing genes for desirable traits such as disease resistance, pest tolerance, enhanced nutritional quality, drought tolerance, and adaptation to changing climatic conditions (10). The conservation and sustainable utilization of PGRs are therefore essential for ensuring global food security, environmental resilience, and sustainable agricultural production (3).
Plant genetic resources can be broadly classified into six major categories: cultivated crop varieties, traditional landraces, crop wild relatives (CWRs), medicinal and aromatic plants, forest genetic resources, and wild plant species (11). Cultivated varieties include modern commercial cultivars developed through conventional and molecular breeding techniques. Traditional landraces are locally adapted populations that have evolved through farmer selection over generations and possess high genetic variability. Crop wild relatives are naturally occurring species closely related to cultivated crops and serve as valuable sources of genes for resistance to biotic and abiotic stresses (12). Medicinal plants provide bioactive compounds for pharmaceutical industries, while forest genetic resources contribute to timber production, carbon sequestration, watershed protection, and ecosystem stability. Wild plant species further support ecological functions such as pollination, nutrient cycling, and habitat conservation.
The importance of plant genetic resources extends far beyond agriculture. Genetic diversity enables plant breeders to develop improved crop varieties capable of withstanding emerging diseases, insect pests, drought, salinity, flooding, and extreme temperatures associated with climate change (3). Diverse germplasm also supports sustainable agriculture by reducing dependence on chemical inputs and enhancing crop resilience. In addition, medicinal and aromatic plants provide raw materials for modern pharmaceuticals and traditional healthcare systems, while forest genetic resources contribute significantly to biodiversity conservation, climate-change mitigation, and rural livelihoods (10). Consequently, PGRs play a central role in achieving the United Nations Sustainable Development Goals (SDGs), particularly those related to food security, biodiversity conservation, climate action, and sustainable development.

Despite their immense importance, plant genetic resources are experiencing rapid genetic erosion. Habitat destruction, agricultural intensification, urbanization, deforestation, invasive species, pollution, and climate change have substantially reduced plant diversity worldwide (3). The replacement of traditional crop varieties with genetically uniform, high-yielding cultivars has narrowed the genetic base of major crops, increasing vulnerability to pests, diseases, and environmental stresses (11). According to FAO (2019), nearly 75% of crop genetic diversity has been lost during the last century due to the widespread adoption of modern varieties. In response, international initiatives such as the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and global conservation programs promote both in situ and ex situ conservation strategies, including protected areas, seed banks, botanical gardens, tissue culture repositories, and cryopreservation (7,8). Strengthening these conservation efforts is essential to safeguard plant genetic diversity and ensure sustainable agricultural development for future generations.

Evolution of International Legal Frameworks Governing Plant Genetic Resources- The governance of plant genetic resources (PGRs) has undergone a profound transformation over the past five decades, evolving from a system based on the principle of the common heritage of humankind to one emphasizing national sovereignty, access and benefit-sharing (ABS), and intellectual property rights (IPRs). This evolution reflects growing concerns over biodiversity conservation, food security, technological innovation, and the equitable distribution of benefits arising from the utilization of genetic resources (2).

During the 1960s and 1970s, plant genetic resources were generally regarded as freely accessible resources that could be exchanged internationally for agricultural research and crop improvement. This open-access approach facilitated the development of improved crop varieties through international breeding programs coordinated by organizations such as the Consultative Group on International Agricultural Research (CGIAR) and the Food and Agriculture Organization (FAO) (10). However, increasing commercialization of biotechnology and plant breeding raised concerns about the unequal exploitation of biodiversity-rich developing countries and the lack of recognition of farmers' contributions to conserving genetic diversity.

A major turning point occurred in 1983 with the adoption of the International Undertaking on Plant Genetic Resources (IUPGR) by the FAO. The Undertaking promoted unrestricted access to plant genetic resources based on the principle that these resources constituted the common heritage of humanity (13). Although legally non-binding, it established the first international framework for cooperation in the conservation and exchange of plant genetic resources. Nevertheless, disagreements between developed and developing countries regarding ownership of genetic resources and plant breeders' rights limited its effectiveness (2).

The most significant milestone in international biodiversity governance was the adoption of the Convention on Biological Diversity (CBD) at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. The CBD fundamentally changed international legal thinking by recognizing the sovereign rights of states over their biological resources rather than treating them as common property (7). The Convention established three primary objectives: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the utilization of genetic resources. It also emphasized prior informed consent (PIC) and mutually agreed terms (MAT) as prerequisites for accessing genetic resources.

To address the specific needs of agriculture, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was adopted in 2001 and entered into force in 2004. The Treaty established a Multilateral System (MLS) for facilitated access and benefit-sharing covering key food and forage crops, while simultaneously recognizing farmers' rights to conserve, use, exchange, and participate in decision-making concerning plant genetic resources (8). Subsequently, the Nagoya Protocol on Access and Benefit-sharing, adopted in 2010, strengthened the implementation of the CBD by providing legally binding procedures for access to genetic resources, compliance mechanisms, and equitable benefit-sharing (9).

More recently, rapid advances in genome editing, digital sequence information (DSI), synthetic biology, and artificial intelligence-assisted breeding have exposed limitations within existing international legal frameworks. Current international negotiations seek to modernize governance systems capable of addressing emerging technologies while maintaining biodiversity conservation, promoting agricultural innovation, and ensuring equitable sharing of benefits among countries, researchers, indigenous communities, and farmers (14,15). These developments demonstrate that international legal frameworks governing plant genetic resources continue to evolve in response to scientific progress, global environmental challenges, and changing socio-economic priorities.

INTERNATIONAL AGREEMENTS GOVERNING PLANT GENETIC RESOURCES

The governance of plant genetic resources (PGRs) is supported by a network of international agreements designed to promote biodiversity conservation, sustainable use, equitable benefit-sharing, and food security. The Convention on Biological Diversity (CBD), adopted in 1992, established the principle that

states have sovereign rights over their biological resources and introduced the concepts of prior informed consent (PIC) and fair and equitable access and benefit-sharing (7). To strengthen the implementation of these principles, the Nagoya Protocol (2010) created a legally binding framework for regulating access to genetic resources and ensuring that benefits derived from their utilization are shared fairly with provider countries and indigenous communities (9).

Recognizing the unique role of crop diversity in agriculture, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) established a Multilateral System (MLS) that facilitates access to essential crop germplasm while recognizing farmers' rights and supporting global food security (8). In parallel, the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and the International Convention for the Protection of New Varieties of Plants (UPOV) provide legal mechanisms for protecting plant breeders' rights and intellectual property, thereby encouraging innovation in plant breeding (5,16). Collectively, these agreements form the foundation of international governance for plant genetic resources by balancing conservation, innovation, and equitable access in an era of rapid biotechnological advancement (2,14).

NATIONAL POLICIES AND LEGAL FRAMEWORKS GOVERNING PLANT GENETIC RESOURCES

National policies and legal frameworks play a critical role in conserving plant genetic resources (PGRs), ensuring their sustainable utilization, and regulating access while balancing biodiversity conservation, agricultural development, and intellectual property protection. Although international agreements establish broad principles for the governance of genetic resources, their implementation depends largely on national legislation tailored to each country's biological wealth, socio-economic priorities, and institutional capacity (14). Effective national policies are therefore essential for fulfilling obligations under international treaties such as the Convention on Biological Diversity (CBD), the Nagoya Protocol, and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

India possesses nearly 8% of the world's recorded biodiversity and is recognized as one of the world's megadiverse countries, making the conservation of plant genetic resources a national priority (National Biodiversity Authority [NBA], 2023). The Biological Diversity Act, 2002, amended through the Biological Diversity (Amendment) Act, 2023, serves as the principal legislation governing the conservation, sustainable use, and equitable sharing of benefits arising from biological resources. The Act established the National Biodiversity Authority (NBA), State Biodiversity Boards, and Biodiversity Management Committees to regulate access to biological resources, protect traditional knowledge, and facilitate benefit-sharing with local communities (19). The amendment further seeks to streamline research approvals while strengthening India's bioeconomy and compliance with international biodiversity commitments.

The Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001 represents a distinctive legal framework that balances plant breeders' rights with farmers' rights. Unlike many intellectual property systems, it recognizes farmers as cultivators, conservers, and breeders by granting them rights to save, use, exchange, and sell farm-saved seeds while encouraging the registration of new plant varieties (17). This legislation aligns with Article 9 of the ITPGRFA and supports the conservation of agro-biodiversity through participatory plant breeding and recognition of traditional knowledge (8).

Additional legislation contributes to the governance of plant genetic resources in India. The Seeds Act, 1966, and the proposed Seeds Bill regulate seed quality, certification, and distribution, ensuring the availability of high-quality planting material. The Environment (Protection) Act, 1986, together with the Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells (1989), provides the legal basis for biosafety regulation of genetically modified organisms (GMOs). Regulatory bodies such as the Genetic Engineering Appraisal Committee (GEAC) evaluate environmental and biosafety risks before approving the release of genetically modified crops (Ministry of Environment, Forest and Climate Change [MoEFCC], 2022).

Globally, countries have adopted diverse legal approaches according to their agricultural priorities and innovation systems. The European Union maintains stringent biosafety and traceability regulations for genetically modified crops, while the United States emphasizes science-based risk assessment through coordinated oversight by federal agencies. Countries such as Brazil, China, and Australia have also strengthened national legislation on biodiversity conservation, plant variety protection, and access and benefit-sharing to comply with international agreements while promoting agricultural innovation (20). Despite these advancements, challenges remain in harmonizing national legislation with rapidly evolving technologies such as genome editing, digital sequence information, and synthetic biology. Strengthening institutional coordination, enhancing farmers' participation, and integrating biodiversity conservation with sustainable agricultural policies will be essential for ensuring effective governance of plant genetic resources in the future.

BIOTECHNOLOGY AND BIOSAFETY

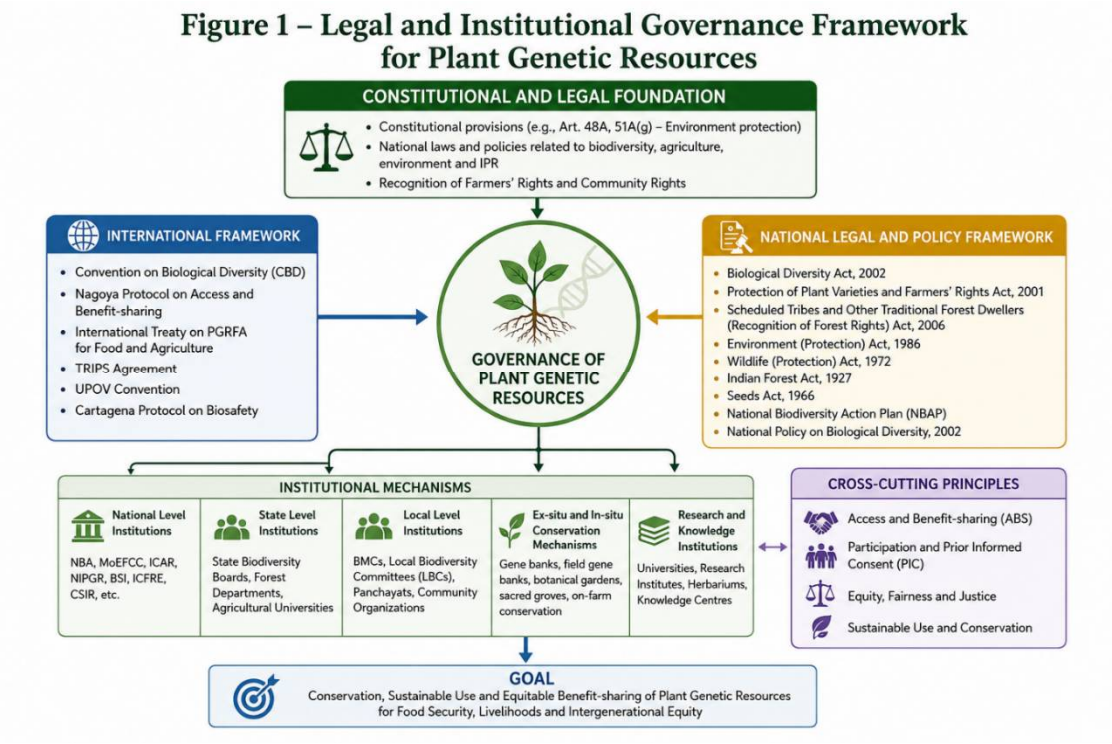
Biotechnology has emerged as one of the most influential tools for the conservation, characterization, and utilization of plant genetic resources (PGRs). Modern biotechnological approaches, including tissue culture, molecular marker-assisted selection, genetic transformation, genome sequencing, CRISPR-Cas genome editing, and synthetic biology, have significantly accelerated crop improvement and enhanced agricultural productivity. These technologies enable the development of crop varieties with improved yield, nutritional quality, resistance to pests and diseases, and tolerance to abiotic stresses such as drought, salinity, and extreme temperatures, thereby contributing to global food security under changing climatic conditions (14,21). Furthermore, biotechnology supports the conservation of endangered and economically important plant species through in vitro propagation, cryopreservation, and DNA banking, complementing conventional in situ and ex situ conservation strategies (22).

Among recent innovations, **CRISPR-Cas genome editing** has revolutionized plant breeding by enabling precise modifications of target genes without introducing foreign DNA in many applications. Compared with conventional breeding and transgenic approaches, genome editing offers greater precision, shorter breeding cycles, and lower development costs, making it an attractive strategy for developing climate-resilient and disease-resistant crops (23). Similarly, advances in genomic sequencing, high-throughput phenotyping, and bioinformatics have enhanced the identification and utilization of valuable alleles present in crop wild relatives and landraces, thereby expanding the genetic base available for breeding programs (24). Synthetic biology further provides opportunities for engineering novel metabolic pathways to improve crop productivity, nutritional value, and resistance to environmental stresses.

Despite these benefits, the application of biotechnology raises significant biosafety, environmental, ethical, and socio-economic concerns. The intentional release of genetically modified organisms (GMOs) may lead to unintended ecological consequences, including gene flow to wild relatives, the evolution of resistant pests and weeds, effects on non-target organisms, and potential impacts on ecosystem functioning (25). In addition, concerns regarding food safety, allergenicity, biodiversity loss, and long-term environmental effects continue to influence public perception and regulatory decision-making (26). Consequently, robust biosafety frameworks are required to ensure that biotechnological innovations are developed and deployed responsibly.

At the international level, the Cartagena Protocol on Biosafety under the Convention on Biological Diversity (CBD) provides the principal legal framework governing the transboundary movement, handling, and use of living modified organisms (LMOs). The Protocol emphasizes the precautionary approach, risk assessment, advance informed agreement (AIA), and information exchange through the Biosafety Clearing-House to protect biodiversity and human health (27). Complementary international guidance is provided by the Codex Alimentarius Commission, which establishes science-based principles for assessing the food safety of genetically modified foods (28).

At the national level, countries have established biosafety regulations according to their legal and institutional systems. In India, the Environment (Protection) Act, 1986, together with the Rules for the Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells (1989), provides the legal basis for regulating genetically engineered organisms. Oversight is provided by the Genetic Engineering Appraisal Committee (GEAC), which evaluates environmental and health risks before approving confined field trials or commercial release of genetically modified crops [23]. As biotechnology continues to evolve, regulatory frameworks must adapt to address emerging technologies such as genome editing, synthetic biology, and digital sequence information while balancing innovation, biosafety, biodiversity conservation, and public confidence. Strengthening international cooperation, science-based risk assessment, and transparent regulatory governance will be essential for ensuring that biotechnology contributes to sustainable agriculture without compromising ecological integrity or human well-being (Figure-1).

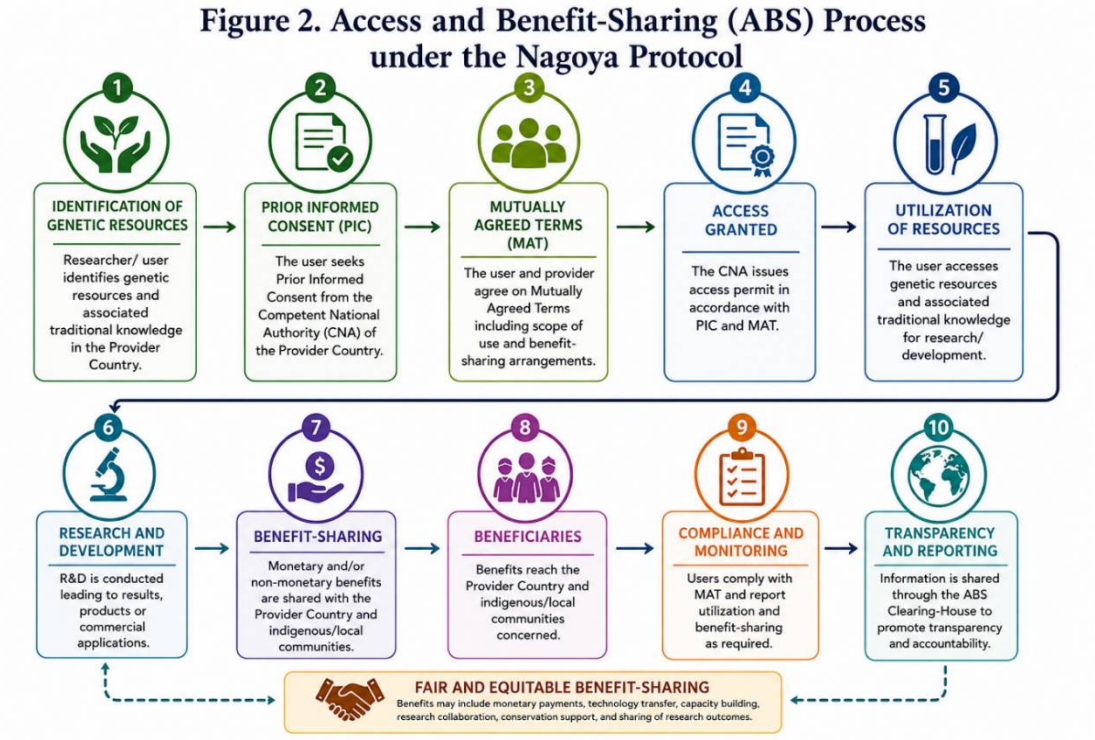


Intellectual Property Rights and Farmers' Rights- Intellectual property rights (IPRs) play a crucial role in promoting innovation in plant breeding by providing legal protection for new plant varieties and biotechnological inventions. International agreements such as the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and the International Convention for the Protection of New Varieties of Plants (UPOV**)** establish minimum standards for protecting plant breeders' rights while encouraging investment in agricultural research and the development of improved crop varieties (World Trade Organization [WTO]. However, the expansion of IPRs has raised concerns regarding farmers' access to seeds, traditional knowledge, and equitable sharing of benefits derived from plant genetic resources (5).
To address these concerns, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) recognizes Farmers' Rights, including the protection of traditional knowledge, equitable participation in benefit-sharing, and involvement in decision-making related to plant genetic resources (8). India has adopted a balanced approach through the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001, which grants plant breeders exclusive rights while allowing farmers to save, use, exchange, and sell farm-saved seeds, subject to legal provisions (17). This unique framework seeks to balance innovation with biodiversity conservation, food security, and the livelihoods of farming communities. Strengthening legal mechanisms for benefit-sharing and recognizing indigenous knowledge remain essential for achieving equitable and sustainable governance of plant genetic resources (2).

EMERGING CHALLENGES

The governance of plant genetic resources (PGRs) is facing unprecedented challenges due to rapid technological advances, climate change, and evolving global policy demands. Climate change has accelerated genetic erosion by altering species distribution, increasing the frequency of extreme weather events, and threatening the survival of crop wild relatives and traditional landraces that are essential for future crop improvement (14). Simultaneously, emerging technologies such as CRISPR-Cas genome editing, synthetic biology, and artificial intelligence (AI)-assisted breeding have created regulatory uncertainties regarding biosafety, intellectual property rights, and ethical oversight (20,23). Another major challenge is the governance of Digital Sequence Information (DSI), where genetic data are shared electronically without the physical transfer of biological materials, complicating existing access and benefit-sharing (ABS) mechanisms established under the Convention on Biological Diversity and the Nagoya Protocol (31) (Figure-2). In addition, concerns regarding biopiracy, inadequate recognition of indigenous and local communities, inequitable benefit-sharing, and inconsistencies among national legal frameworks continue to hinder effective implementation of international agreements (2). Addressing these challenges requires harmonized international regulations, strengthened institutional capacity, transparent governance, and

greater collaboration among governments, researchers, farmers, and indigenous communities to ensure the sustainable conservation and equitable utilization of plant genetic resources in the face of global environmental and technological change (14,20).



FUTURE PERSPECTIVES

The sustainable governance of plant genetic resources (PGRs) will require integrated legal, scientific, and policy approaches to address emerging global challenges. As climate change, biodiversity loss, and increasing food demand continue to threaten agricultural systems, strengthening the conservation and sustainable utilization of plant genetic resources must remain a global priority (14). Future governance frameworks should promote stronger coordination among international agreements, including the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and the Nagoya Protocol, to reduce regulatory inconsistencies and enhance the implementation of access and benefit-sharing (ABS) mechanisms (33).

Rapid advances in biotechnology, particularly genome editing, synthetic biology, artificial intelligence (AI)-assisted breeding, and digital sequence information (DSI), necessitate the development of adaptive and science-based regulatory frameworks. Policymakers must establish clear guidelines that encourage innovation while ensuring biosafety, environmental protection, and equitable access to genetic resources (23). International cooperation will also be essential to develop transparent governance mechanisms for DSI, ensuring that benefits arising from the use of genetic information are shared fairly among provider countries, researchers, and indigenous communities (31).

Future policies should place greater emphasis on strengthening in situ and ex situ conservation strategies, expanding national and international gene banks, and improving digital documentation of plant genetic resources through modern genomic and bioinformatics tools (14). Increased investment in public research institutions, capacity building, and technology transfer will enable developing countries to participate more effectively in plant breeding and biodiversity conservation initiatives.

Furthermore, recognizing the contributions of farmers and indigenous communities should remain central to future governance. Strengthening Farmers' Rights, protecting traditional knowledge, promoting participatory plant breeding, and ensuring equitable benefit-sharing will support both biodiversity conservation and rural livelihoods (2). Finally, closer collaboration among governments, research organizations, the private sector, and international agencies is essential to develop harmonized legal frameworks that balance agricultural innovation, biodiversity conservation, and food security. Such an integrated and inclusive governance approach will be critical for safeguarding plant genetic resources and achieving the United Nations Sustainable Development Goals (SDGs) in an era of rapid.

CONCLUSION

Plant genetic resources (PGRs) are indispensable for ensuring global food security, agricultural sustainability, biodiversity conservation, and climate resilience. As the primary source of genetic diversity for crop improvement, these resources enable the development of high-yielding, nutritious, and stress-tolerant crop varieties capable of meeting future food demands. Over the past few decades, international agreements such as the Convention on Biological Diversity (CBD), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the Nagoya Protocol, and the Cartagena Protocol on Biosafety have established a comprehensive legal framework for the conservation, sustainable use, and equitable sharing of benefits arising from plant genetic resources (9,14).

Despite significant progress, challenges including climate change, genetic erosion, biopiracy, digital sequence information (DSI), genome editing, and unequal access to genetic resources continue to test existing governance systems (31). Addressing these issues requires harmonized international policies, adaptive national legislation, science-based biosafety regulations, and stronger recognition of farmers' rights and traditional knowledge. Future governance should promote innovation while ensuring biodiversity conservation, equitable benefit-sharing, and sustainable agricultural development. Strengthened international collaboration, investment in conservation programs, and inclusive policy frameworks will be essential to safeguard plant genetic resources for present and future generations and to support the achievement of global food security and the United Nations Sustainable Development Goals (SDGs).

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