



Seed Bank Strategies for Agrobiodiversity Conservation

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Agrobiodiversity is fundamental to food security, ecosystem resilience, and sustainable agriculture, yet it is increasingly threatened by climate change, habitat loss, and genetic erosion. Seed banks play a crucial role in conserving plant genetic resources by safeguarding diverse and valuable germplasm for future use. This review highlights key seed bank strategies for agrobiodiversity conservation, including advanced seed storage techniques such as cryopreservation, non-destructive viability assessment, and the application of artificial intelligence and genomic technologies. It also emphasizes dynamic conservation approaches that integrate ex situ and in situ methods, community seed banks, and participatory plant breeding. Strengthening technological innovation, farmer participation, and policy support is essential to ensure the long-term conservation and sustainable utilization of agrobiodiversity.

Agrobiodiversity Definition

The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems. Agrobiodiversity is the result of the interaction between the environment, genetic resources and management systems and practices used by culturally diverse peoples, and therefore land and water resources are used for production in different ways. Thus, agrobiodiversity encompasses the variety and variability of animals, plants and micro-organisms that are necessary for sustaining key functions of the agro-ecosystem, including its structure and processes for, and in support of, food production and food security (FAO, 1999a). Local knowledge and culture can therefore be considered as integral parts of agrobiodiversity, because it is the human activity of agriculture that shapes and conserves this biodiversity.

Need for Agrobiodiversity Conservation

Food Security: Maintains the diverse genetic base for crops and livestock, essential for stable and resilient food production.

Adaptability: Enables crops and livestock to adapt to changing environment, including climate change and disease resistance.

Nutritional Value: Diverse crops and livestock contribute to a wider range of healthier nutrient rich food options.

Ecosystem Services: Diversified farming systems offers farmers more resilient livelihoods and income streams.

Cultural Heritage: Preserves traditional knowledge, practises and varieties linked to the local food systems and cultural identity.

Climate Change Mitigation: Contributes to carbon sequestration and reduced emissions through sustainable practises like agroforestry and organic farming.

Seed Bank

A seed bank is a facility that stores seeds in order to maintain genetically pure variety for future generations. Typically, they are flood, bomb, and radiation-proof vaults that store seeds from various plant species. The seeds are usually stored in climate controlled, low humidity and frigid temperatures. This aids in the long -term preservation of the seeds, guaranteeing that they will grow at a later day. As per one estimate, there are over 1700 seed banks around the world, each with its own type, size, and concentration. The Svalbard Global Seed Vault, often known as the “doomsday vault” or “Noah’s ark of seeds,” seeks to hold a duplicate of every seed stored in other banks throughout the world. Svalbard has the capacity to store up to 4.5 million kinds of crops and 2.5 billion seeds. It contains about 1.14 million seed samples from over 6,000 distinct plant species.

Why seed banks are essential ?

The first step of growing food starts from seed. To sustain the planet and all living beings, plants are paramount. Since plants are threatened by a variety of factors, including loss of habitat, climate change, pollution, pests, and diseases, seed banks serve as an institution in building agricultural resilience in the times of crisis. It is estimated that 40% of plant species are threatened with extinction on a global scale. Plants that are rare, heritage, indigenous, wild, or locally distinctive are all at risk of extinction. Their extinction could result in the genetic deterioration of our food system. Without good genetic diversity, adapting to climate change or new pests can be challenging. Crop breeders require a diverse set of genetic resources to aid in the adaptation of our crops to changing situations. A seed bank is a type of insurance, that allows us to safeguard as many plant species as possible from extinction. Plant genetic diversity is important for a variety of reasons, and seed banks help to preserve it. These conserved seeds contain a wealth of beneficial genes that breeders might employ to build improved varieties of our most important food crops. A few specific benefits of seed banks:

- Improve plant disease and pest resistance, both existing and emerging
- Allow for drought or flood resistance
- To feed a growing global population, increase yields and improve nutrition

The Kunming Institute of Botany’s Germplasm Bank of Wild Species of China is striving to preserve the seeds of as many wild plants as possible from across China’s huge land area. Many wild plants have genes that enable them to thrive in difficult conditions and make them resistant to diseases and drought. We may need these genetic resources in the future to produce new crops that can better adapt to shifting climate.

Seed Bank Strategies for Agrobiodiversity Conservation

A. Advanced seed storage and viability assessment

1. Cryopreservation

Seeds are stored at ultra low temperatures , using liquid nitrogen at -196 degree Celsius. At these temperatures, the metabolic activities within the cells are virtually halted, preventing deterioration and preserving the genetic integrity of the stored materials. This offers the potential for long term conservation, potentially for an indefinite period.

Advantages:

- Indefinite preservation with minimal risk of genetic change
- Tiny physical footprint ; low maintenance
- Ideal for vegetatively propagated/recalcitrant germplasm
- Pathogen-free, aseptic storage environment
- Cost effective long term compared to in-vitro or field regent
- Maintains clonal integrity without repeated subculture
- Requires minimal space compared to traditional methods

Limitations

- No universal protocol: species/genotype specificity
- Cryoprotectants can be toxic: there is risk of cryoinjury
- Regeneration after thaw may be low or inconsistent
- Requires skill personnel and high tech lab infrastructure
- High upfront cost, challenging in resource limited areas

2. Non-destructive Viability Testing:

This area views emergence of advanced techniques such as Infrared thermography (IRT) and lipid thermal fingerprinting. IRT measures the heat emitted by seeds during imbibition, as metabolic activity in viable seeds causes subtle temperature changes. Other techniques involve analyzing the spectral reflectance of seeds at different wavelengths to differentiate between viable and non-viable seeds.

Advantages:

- Offer a non-invasive approach to assess seed viability unlike the traditional germination tests or tetrazolium tests that can be time consuming, labor intensive or destructive.
- Enable more efficient monitoring of seed bank accessions, minimizing resource consumption and maximize the use of valuable genetic material.
- Enhances the objectivity of viability assessments, reducing subjectivity often associated with visual inspections

Limitations

- Still under development and require further research for wider application across diverse plant species and seed types.
- Developing robust algorithms for accurate classification of viable and non-viable seeds based on spectral data or other indicators require extensive datasets for training and validation.

3. AI and Machine learning

Role in Viability Prediction & Storage Optimization: AI and machine learning algorithms can be trained on extensive datasets that encompass various factors like genetic information, environmental conditions, and phenotypic traits of seeds. This allows them to predict seed viability with high accuracy, identify optimal storage conditions (e.g., temperature and moisture levels), and assess the potential impact of climate change on specific seed collections. This enables more proactive and targeted conservation efforts, prioritizing vulnerable species and optimizing storage for long-term survival.

Advantages

- AI-powered analysis can rapidly assess and categorize seeds based on various quality parameters such as size, shape, color, and internal structures.
- This automation significantly increases efficiency, accuracy, and consistency in seed quality assessment, surpassing traditional manual methods.
- Machine learning algorithms can also assist in optimizing seed sorting and grading processes, ensuring high-quality seeds for planting.

Limitations

- The adoption of AI and machine learning in seed banks faces challenges related to data quality and availability.
- Large and diverse datasets are required to train accurate models, which may be limited for certain species or regions.
- Addressing ethical considerations, such as data privacy and algorithmic bias, is also crucial for responsible deployment of AI in conservation.

B. Dynamic Conservation approaches**1. Integrating Ex-situ and In-situ conservation synergy**

This involves the crucial integration of seed bank storage (ex situ) with on-farm conservation (in situ) where farmers actively cultivate and manage diverse crop varieties in their fields. Ex situ conservation acts as a vital safety net, preserving genetic material in controlled environments for research, restoration, and reintroduction purposes. In contrast, in situ

conservation allows for the dynamic evolution of local genetic diversity under natural conditions, preserving the crucial ecological interactions and traditional knowledge associated with the crops.

Advantages

By combining these approaches, seed banks can ensure the comprehensive conservation of agrobiodiversity, safeguarding both the raw genetic material and the evolutionary processes that allow for adaptation to changing environmental conditions, such as climate change.

2. Community Seed Banks and Farmer Empowerment:

Community seed banks, often rooted in farmer-managed seed systems, play a vital role in local seed security and the conservation of indigenous genetic diversity and associated traditional knowledge. They promote the cultivation of locally adapted varieties, which are often more resilient to local pests, diseases, and climate conditions. These community-led initiatives empower farmers by enhancing their access to diverse seeds, facilitating knowledge sharing, building capacity in seed management techniques, and promoting the exchange of valuable genetic resources.

Advantages:

- Community seed banks contribute to the realization of farmers' rights by ensuring access to seeds, protecting traditional knowledge, enabling equitable benefit sharing, and promoting farmer participation in decision-making processes related to plant genetic resources.
- They also provide platforms for community action, social development, and income generation through the production and sale of high-quality seeds.
- In some countries, these community-based banks have successfully transitioned into recognized seed producers, supplying quality seeds to local markets and customers.

Limitations:

- Scaling up community seed bank initiatives to a national level can be challenging.
- Factors such as limited funding, lack of established guidelines, and organizational fragility can hinder their expansion and long-term sustainability.

3. Participatory Plant Breeding:

Collaboration: Participatory plant breeding (PPB) fosters collaboration among professional plant breeders, researchers, farmers, and other stakeholders in the food chain. Farmers actively engage in various stages of the breeding and selection process, from setting breeding objectives and identifying desired traits to field testing and seed multiplication.

Advantages:

- PPB ensures that the developed varieties are well-suited to local environmental conditions, agricultural practices, and farmer preferences.
- This approach can lead to higher adoption rates of new varieties, increased yields, and enhanced resilience to biotic and abiotic stresses.
- It also promotes the conservation of local crop diversity and associated traditional knowledge.

Impact:

- PPB has been shown to increase yields, improve stability, and facilitate faster uptake and wider diffusion of varieties among farmers, including marginal farmers.
- It fosters group learning and builds capacity among farmers in seed management and crop improvement.

C. Harnessing technology for enhanced conservation

Drone Technology for Remote Seed Collection and Dispersal:

Applications: Drones equipped with specialized dispensers can access remote and difficult terrains that are inaccessible to human beings, allowing for efficient collection of seeds from wild relatives and facilitating large-scale aerial seeding for reforestation and habitat restoration. This technology can accelerate tree planting, reduce labor costs, and improve the accuracy of seed distribution.

Advantages:

- Drones can minimize soil disturbance and erosion compared to traditional ground-based methods.
- Their precision allows for targeted seed placement, potentially improving the success rate of restoration projects.
- The integration of AI-powered software can further optimize seeding locations based on factors like terrain, soil quality, and weather conditions.

Challenges:

- The technology is still evolving, and challenges remain in areas like battery life, payload capacity, and navigating complex terrain.
- Ethical considerations regarding the potential impact of drone-based seeding on ecosystems also require careful evaluation.

Genomic Technologies:

CRISPR/Cas9: CRISPR/Cas9 and other genome editing technologies enable precise modifications at specific genetic loci, facilitating improvements in traits such as herbicide and insect resistance, nutritional quality, and stress tolerance. CRISPR/Cas9, in particular, offers the advantages of simplicity, efficiency, and reduced off-target effects, making it a valuable tool in both agricultural biotechnology and plant functional genomics. For instance, it has been successfully used to enhance drought tolerance in wheat, improve grain quality in maize and rice, and develop herbicide-resistant crops.

Applications in Plant Improvement:

- Genomic technologies can be used to identify and manipulate specific genes associated with desired traits, accelerating the development of improved crop varieties from the genetic material stored in seed banks.
- This can contribute to increased yields, enhanced resilience to environmental stresses, and improved nutritional value of crops, contributing to global food security.

Ethical Considerations:

- The use of genomic technologies in agrobiodiversity conservation raises ethical concerns regarding potential unintended consequences, ecological impact, and the need for public engagement and informed decision-making.

Digital Databases and Data Management Systems:**Benefits:**

- Digital databases and online platforms facilitate efficient cataloging, tracking, and sharing of genetic information among seed banks, researchers, and farmers worldwide.
- They enable better management of seed collections, monitoring of viability, and planning for regeneration cycles.
- Digital systems also foster global collaboration and knowledge exchange, accelerating research and development in agrobiodiversity conservation.

Challenges:

- Challenges include ensuring data accessibility and quality, addressing data privacy and security concerns, and ensuring compatibility between different systems and platforms.
- The lack of appropriate digital infrastructure and technical expertise in some regions can also hinder the adoption and effective utilization of these technologies.

D.Addressing societal challenges and policy support**1.Promoting Awareness and Education:**

Importance: Raising public awareness about the importance of agrobiodiversity and the crucial role of seed banks in safeguarding it is essential for garnering greater support for conservation efforts. Education programs can foster a culture of conservation and encourage individuals to take action to protect biodiversity

Methods

Educational initiatives can be implemented through various channels, including school curricula, community events, public campaigns, and online platforms. Highlighting the value of local genetic resources and traditional knowledge, as well as the benefits of sustainable

agricultural practices, can help build a stronger connection between communities and agrobiodiversity.

2. Ensuring Equitable Access and Benefit Sharing:

Frameworks: International agreements like the Convention on Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) establish frameworks for equitable access to genetic resources and the fair sharing of benefits arising from their use. These frameworks aim to recognize and reward the contributions of farmers and local communities in conserving and developing plant genetic diversity.

Challenges: Challenges remain in effectively implementing these frameworks at the national level, particularly in ensuring that local communities have genuine participation in decision-making processes and receive fair benefits from the utilization of their traditional knowledge and genetic resources.

3. Investing in Research and Infrastructure:

Importance: Governments and international organizations need to prioritize funding for research and development of new seed bank technologies and infrastructure. This investment is crucial for strengthening conservation capabilities, enhancing the efficiency of seed bank operations, and addressing emerging challenges related to climate change and biodiversity loss.

- **Areas of Investment:** This includes investing in infrastructure for advanced seed storage facilities, developing and implementing non-destructive viability testing methods, and harnessing the potential of AI and genomic technologies for improved conservation and crop breeding.
- **Investment in capacity building and training:** Investment in capacity building and training for seed bank staff and farmers is also essential to ensure effective implementation of these technologies and strategies.

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