On-Farm Conservation and Management of Agrobiodiversity

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OPEN ACCESS

Keywords

Agrobiodiversity, On-Farm Conservation, Crop Wild Relatives, Community Seed Banks, Plant Breeding

How to cite this article:

Geetha, A. N. and Akhilraj, T. M. 2026. On-Farm Conservation and Management of Agrobiodiversity. *Vigyan Varta* 7 (06): 126-132.

ABSTRACT

Agrobiodiversity the variety of crops, livestock, and associated wild species that sustain food systems is declining at an alarming rate worldwide. On-farm conservation is the cultivation and evolutionary management of crop diversity by farmers in their own agroecosystems, has emerged as a critical complement to ex situ conservation. This review synthesises the current state of knowledge on the conceptual foundations, threats, methodological approaches, institutional frameworks, and policy dimensions of on-farm agrobiodiversity conservation. It examines the drivers of genetic erosion, the role of community seed banks, participatory and evolutionary plant breeding, and crop wild relatives in on-farm conservation.

INTRODUCTION

Agricultural biodiversity or agrobiodiversity refers to the variety and variability of living organisms that sustain food and agriculture production in the broadest sense, and that are associated with cultivating crops and rearing animals within ecological complexes (Jackson *et al.,* 2013). Agrobiodversity is an important component of biodiversity, which has a more direct link to the general well-being and livelihood of mankind than other forms of biodiversity (Dulloo *et al*., 2010). This diversity is the biological foundation upon which global food security, nutritional adequacy, and agricultural resilience rest (Di Falco, 2012). Agrobiodiversity underpins the delivery of multiple ecosystem services in agricultural landscapes, including pollination, pest and disease regulation, soil fertility maintenance, water cycling, climate regulation, and carbon sequestration (Bianchi *et al*., 2013; Wood *et al*., 2015). During the last century, the expansion of industrial monoculture agriculture, driven by the Green Revolution and the globalisation of seed markets, has resulted in a significant narrowing of the genetic base of most major food crops (Khoury *et al*., 2022). It is estimated that of the approximately 10,000 plant species used historically for food, fewer than 150 supply over 90 per cent of the global caloric intake, and only three agriculture crops such as rice, wheat, and maize account for more than half of all plant-based calories consumed globally (Hammer and Teklu, 2008; Joshi *et al*., 2023).

In response to these trends, the protection and conservation of plant genetic resources for food and agriculture (PGRFA) have become a central concern of international environmental and agricultural policy (Isakson, 2009; Dulloo *et al*., 2010). While ex situ conservation in gene banks remains the most widely employed strategy, it is increasingly recognised that ex situ approaches alone are insufficient to maintain the evolutionary processes that generate and preserve genetic diversity over the long term (Enjalbert *et al*., 2011; Bellon *et al*., 2017). On-farm conservation the deliberate maintenance of diverse crop populations in the agroecosystems where they have evolved offers a complementary stratergy that allows landraces to continue adapting to changing environmental conditions through ongoing natural and artificial selection (Wood & Lenne, 1997; Bellon, 2001; Joshi & Upadhya, 2019).

1. Conceptual Foundations and Rationale

On-farm conservation concept is rooted in the recognition that crop diversity is dynamic, shaped continuously by the factors of environmental heterogeneity, farmer selection, and genetic exchange (Negri *et al*., 2012; Joshi *et al*., 2023). Bellon *et al*. (2001) emphasized the evolutionary rationale for in situ conservation strategy by noting that continued exposure to changing environmental forces generates new genetic variation and maintains rare alleles that may be of future value to agriculture. Unlike ex situ conservation, which freezes genetic material, on-farm cultivation and management allows populations to respond to various biotic and abiotic stresses through natural selection and farmer-mediated adaptation (Ceccarelli *et al*., 2010; Enjalbert *et al*., 2011).

On-farm conservation also embodies a distinctive anthropogenic dimension. Farmers, particularly small-scale holders in centres of crop diversity, have been the architects of crop genetic diversity for millennia, selecting, saving, exchanging, and improving seeds in response to local conditions and cultural preferences (Hammer and Teklu, 2008; Isakson, 2009; Padulosi & Dulloo, 2012). On-farm conservation not merely a technical exercise in genetic resource management but a socio-ecological process linked to food sovereignty, cultural identity, and rural livelihoods (Padulosi & Dulloo, 2012).

2. Threats to Agrobiodiversity: Genetic Erosion and Its Drivers

Genetic erosion the permanent loss of alleles, genotypes, or entire landraces from a crop gene pool is the key challenge that on-farm conservation needs to address (Hammer & Teklu, 2008; Khoury *et al*., 2022). Khoury *et al*. (2022) provided a landmark synthesis of the evidence on crop genetic erosion across traditional landraces on farms, modern cultivars in agriculture, Crop Wild Relatives (CWR) in natural habitats, and accessions held in conservation repositories.

The drivers of genetic erosion are multifaceted and interrelated. The replacement of landraces with high-yielding modern varieties is the most widely cited direct cause, driven by agricultural modernisation policies, seed market integration, and the expansion of formal seed systems (Canella *et al*., 2021; Khoury *et al.,* 2022). Guzzon *et al*. (2021) documented that maize landrace cultivation in Latin America is being displaced by hybrid varieties in high agricultural potential zones, while persistence is concentrated in small-scale farming systems, marginal environments, and regions where traditional food culture remains strong. Climate change adds a new dimension of threat to genetic resources.

3. In Situ and Ex Situ Conservation

The relationship between in situ (on-farm) and ex situ conservation strategies is best understood as complementary rather than competitive. Ex situ conservation in gene banks offer a secure, and well-documented repository of genetic material that can be evaluated, and distributed to breeders and researchers (Pathirana & Carimi, 2022). Globally, approximately 7.4 million accessions are conserved in over 1,750 gene banks, representing an enormous investment in the safeguarding of crop genetic resources (Dulloo *et al*., 2010). However, ex situ conservation has recognised limitations such as it halts evolutionary processes, is vulnerable to funding cuts and infrastructure failures, and cannot capture the full range of intra-population genetic variation present in farmer fields. On-farm conservation addresses these gaps by maintaining populations under ongoing evolutionary environmental forces, thereby generating new genetic combinations and preserving locally adapted gene complexes that may be lost during the sampling and regeneration cycles of ex situ collections (Enjalbert *et al.,* 2011; Bellon *et al.,* 2017). Conversely, on-farm conservation is vulnerable to stochastic events such as drought, flood and civil conflict, shifts in farmer priorities, and market-driven replacement of landraces (Wood & Lenne, 1997). Effective national PGRFA programmes therefore require integrated strategies that consider both approaches in concert, with gene banks providing safety duplication and characterisation services while farmer-based networks maintain the dynamic component of conservation (Dulloo *et al*.,2010; Joshi & Upadhya, 2019).

4. Community-Based and Participatory Approaches

4.1 Community Seed Banks

Community seed banks (CSBs) are farmer-managed organisations that conserve, cultivate, and distribute locally adapted seeds, and they have become a fundamental to on-farm conservation programmes (Vernooy *et al*., 2014; 2020; 2024). CSBs serve three core functions include conserving genetic resources, enhancing access to diverse local crops, and supporting seed and food sovereignty (Vernooy *et al*., 2014). Joshi and Upadhya (2019) reported the evolution of CSBs in Nepal, where more than 100 CSBs have been established since 2010, complemented by community field gene banks, household seed banks, and school field gene banks. These institutions collectively conserve thousands of accessions of rice, maize, wheat, millet, pulses, and vegetables, while simultaneously providing a platform for community level seed exchange knowledge (Pokhrel *et al*., 2012).

Maharjan *et al*. (2011) reported that six CSBs in the western terai of Nepal had collected and conserved between 76 and 99 accessions of different crops each, enhancing farmers' seed systems and providing immediate access to locally adapted germplasm as a community-based climate adaptation strategy. Vernooy *et al*. (2024) reviewed the sustainability challenges facing CSBs and identified five promising strategies including value addition, nature-positive agriculture, enabling policy environments and national gene bank partnerships, networking and digitalisation, and the adoption of modern, low-cost seed quality technologies.

4.2 Participatory and Evolutionary Plant Breeding

Participatory plant breeding (PPB) integrates farmers into the selection and evaluation of new varieties, ensuring that breeding outcomes reflects local preferences and on farm agroecological conditions (Halewood *et al.,*2007; Ceccarelli, 2015). Ceccarelli (2015) found that PPB increases plant breeding efficiency as measured by the ratio of adopted varieties to crosses made, selection response, and the benefit-cost ratio because adoption begins during the selection process rather than only after variety release. Unlike conventional centralised breeding, which typically produces uniform varieties adapted to high-input conditions, PPB generates products that are adapted to the heterogeneous, low-input environments that supports world's on-farm diversity (Halewood *et al.,*2007; Ceccarelli, 2015).

Evolutionary plant breeding (EPB) builds on PPB by maintaining genetically heterogeneous populations that subjected to natural and farmer mediated selection across multiple environments, allowing adaptation to proceed dynamically over successive generations (Ceccarelli *et al*, 2010; Joshi *et al.,* 2023). Ceccarelli *et al*. (2010) promoted EPB as an approach for climate change adaptation, noting that population-based approaches provide a buffer against increasing unpredictability. In Nepal, Joshi *et al*. (2023) observed that EPB and cultivar mixtures were the most effective strategies for increasing crop genetic diversity at the field level, alongside landrace enhancement and the bulk method.

5. Crop Wild Relatives: In Situ Conservation in Agricultural Landscapes

Crop wild relatives (CWR) are wild plant species genetically related to cultivated crops that harbour valuable traits for pest and disease resistance, abiotic stress tolerance, and yield improvement (Vincent *et al.,* 2019; Engels *et al.,* 2020). Despite their importance, CWR remain under-conserved, particularly in situ. Vincent *et al.* (2019) applied species distribution modelling to 1,261 CWR species from 167 major crop gene pools and identified 150 sites globally where 65.7 percent of priority CWR species could be conserved through targeted in situ protection. However, Stolton *et al.* (2008) found that habitat protection in 34 of the world's 825 ecoregions with the highest levels of agrobiodiversity was significantly lower than the global average, with 29 ecoregions having less than 10 percent protection.

6. Policy and Legal Frameworks

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) is the primary international legal instrument governing the conservation and sustainable use of PGRFA, including on-farm conservation. The Treaty establishes a multilateral system of access and benefit-sharing and explicitly recognises Farmers' Rights in Article 9, including the protection of traditional knowledge, the right to equitably participate in benefit-sharing, and the right to participate in decision-making on matters related to PGRFA (Andersen, 2017).

7. Challenges and Future Directions

Although significant advances in knowledge and practice, on-farm conservation still faces persistent challenges. Systematic monitoring of genetic erosion remains inadequate in many countries, with few robust baselines against which to measure change (Khoury *et al.,* 2022). The development of standardised indicators, the integration of citizen science approaches, and the application of molecular markers for cost-effective diversity assessment are priority areas for methodological development.

The tension between conservation and productivity objectives continues to shape the policy landscape. The shift of climatic zones may render existing conservation sites unsuitable for current landrace populations, necessitating assisted migration and the establishment of new conservation networks (Bellon *et al.,* 2014). Addressing this risk will require multi-stakeholder approaches that bring together farming communities, researchers, policymakers, and the private sector in collaborative governance arrangements.

CONCLUSION

On-farm conservation of agrobiodiversity is an indispensable strategy for safeguarding the genetic resources of global food systems. It complements ex situ conservation by maintaining evolutionary processes, preserving locally adapted gene complexes, and engaging the farmers who have been custodians of crop diversity for millennia. Yet the magnitude of genetic erosion already observed, together with accelerating pressures from climate change and agricultural modernisation, demands a scaling up of current efforts. Future progress requires sustained investment in monitoring systems, stronger implementation of Farmers' Rights, integration of agrobiodiversity into climate adaptation planning, and market value chains that reward farmers for maintaining diversity.

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