Vegetables Genetic Resources, Conservation and Challenges

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Abstract

Nepal harbors a rich diversity of vegetable genetic resources, with 435 species across 15 agroecosystems, constituting 6.6% of the country's agricultural genetic resources. This includes 7,500 landraces and 334 wild vegetable species. Despite the release and registration of 344 varieties from 39 vegetable crops, 95% of these are exotic, leading to a loss of 40% of the country's vegetable biodiversity. The National Genebank has adopted four major conservation strategies: Ex-situ, On-farm, In-situ conservation, and Conservation breeding. A range of conservation approaches, including seed banks, field genebanks, agro gene sanctuaries, DNA and tissue banks, community genebanks, and crop-specific parks, have been deployed. Additionally, associated banks like agro-insect field genebanks and herbal conservation gardens have been initiated. Currently, 952 accessions of 46 vegetable crops are conserved within the National Genebank, while 257 accessions are stored in foreign genebanks, 926 in the World Vegetable Center, and 25 accessions of 9 vegetable crops in USDA genebanks. Nepal has also included 7 accessions of 4 vegetable crops under the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). The main challenge is to enhance the competitiveness of site-specific native vegetable crops by promoting their cultivation through ecological agriculture, as foreign varieties undergo extensive testing and dominate the market. To address this, native landraces, which are climate-resilient, nutrient-dense, and culturally significant, need greater focus in research, education, extension, and marketing. Linking native vegetables to geographical indications and declaring broad leaf mustard as the national vegetable could support the preservation and promotion of Nepal's vegetable biodiversity. Expanding ecological agriculture that enhances the competitiveness of native crops is critical for long-term sustainability.

Keywords: Accessions, Climate resilient, Conservation banks, Genetic erosion, Vegetable crop diversity

Introduction

Vegetable genetic resources (VGRs) play a crucial role in food security, nutrition, health, environmental sustainability, and business. Due to the diverse cultivation practices of farmers over centuries, Nepal has maintained a wealth of unique, site-specific landraces across its varied agroecological zones (Upadhyay and Joshi 2003, Budathoki et al., 1993, Joshi et al., 2017, Joshi and Shrestha 2019, KC et al., 2021, Poudel and Joshi 2020). These native landraces are not only climate-resilient but are also rich in nutrients, healthy, and flavorful. However, despite their potential, native vegetables are often overlooked in research, education, and extension programs, with a greater focus placed on exotic and hybrid varieties (Budathoki et al., 1993, Joshi et al., 2020). The main challenge lies in making these site-specific native vegetable crops more competitive by adopting ecological agriculture practices (Pandey 1993). Chemical-based farming and protected agriculture have contributed significantly to the loss of genetic diversity, with native vegetables largely neglected in formal agricultural sectors. Moreover, under the guise of crop protection, many beneficial insects and organisms have been eradicated. To address this, it is recommended to shift the focus of crop protection offices toward "Crops, Agro-insects, and Microbes Conservation" and create environments that are friendly to insects, microbes, and birds. Adopting ecological pest management and creating habitats for beneficial organisms would help sustain biodiversity.

Following the establishment of Nepal Genebank, numerous approaches have been introduced to conserve and promote the sustainable use of vegetable genetic resources. These include seed banks, field genebanks, crop-specific parks, school field genebanks, agro-gene sanctuaries, community genebanks, and conservation vegetable breeding. These initiatives aim to make landraces more competitive while promoting site-specific varieties and expanding conservation efforts through fairs and diversity blocks. Associated conservation banks, such as agro insect field genebanks, aqua pond genebanks, and herbal conservation gardens, have also contributed to the preservation and enhancement of crop diversity.

To further advance conservation, the documentation and profiling of vegetable diversity at various levels (households, villages, districts) is necessary, along with the generation of passport data. A vegetable diversity index should be developed to identify centers of diversity and estimate regional diversity. Additionally, linking these efforts to geographical indication (GI) can help promote native crops like broadleaf mustard, which is grown in nearly every household and originated in Nepal. Declaring it as the national vegetable would symbolize the country's commitment to its agricultural heritage. To ensure the success of native vegetables in the market, local seed cycles should be encouraged, and product cycles should be globalized. This can be supported by providing farmers with market and irrigation guarantees, such as the establishment of collection centers in each municipality. Native vegetables tend to have fewer pest and disease issues compared to exotic varieties, offering significant advantages for both farmers and consumers. Therefore, increasing research, promoting ecological farming practices, and securing market access are essential for safeguarding Nepal's rich vegetable genetic resources.

Groups of Horticultural Genetic Resources

Horticultural genetic resources (HGRs) are one of three groups within agricultural plant genetic resources (APGRs), alongside agronomic plants and forages (Figure 1). Vegetables fall under the horticultural category and can be classified into domesticated, semi-domesticated, wild edible species, and wild relatives (Joshi et al 2023). Based on the parts used, vegetables are further categorized into leafy and stem vegetables, flowers, fruits, roots and tubers, and seeds and pods (Joshi 2022). These include both lower and higher plant species. Mushrooms are also considered important vegetables, though they are not discussed in this paper.

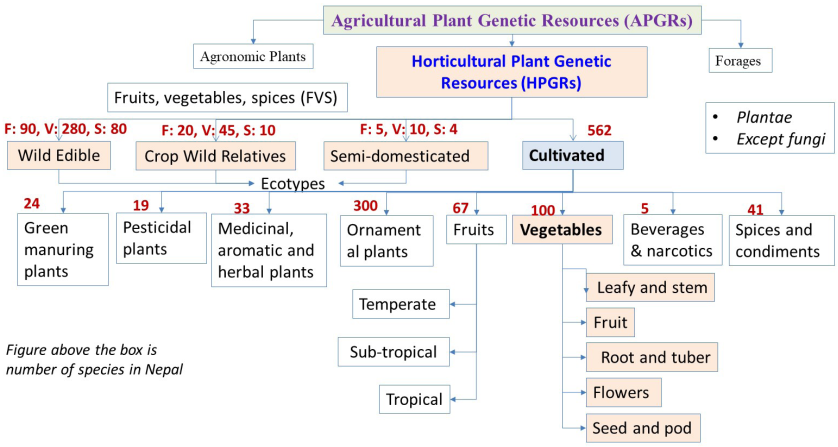


Figure 1: Classification of horticultural plant genetic resources based on economical values

Source: Joshi et al., 2020, 2022, 2023

1. Vegetable genetic resources

Vegetables play an integral role in the Nepali diet, often consumed as side dishes along with staple foods. This diverse consumption pattern is reflective of the country's rich biodiversity, which is driven by its varied climate and ethnic diversity (Budathoki et al., 1993, Joshi and Shrestha 2019, Joshi et al., 2019). As a result, Nepal is home to a large number of vegetable species, making vegetable cultivation a significant aspect of the agricultural landscape. Out of Nepal's 24,300 identified biological species, 28% are categorized as agricultural genetic resources (AGRs). Within this group, vegetables account for 6.6%, reflecting the importance of this crop group to the country's agrobiodiversity. Vegetables in Nepal are grown across a wide range of altitudes, from as low as 60 meters to as high as 4,700 meters above sea level, and are distributed across 15 different agroecosystems. The country harvest 435 species of vegetables, showcasing a remarkable variety (Joshi et al., 2022, Joshi et al., 2017). Among these, 100 species are domesticated, while 280 are wild (Figure 2) but edible, offering a vast pool of genetic diversity for research, conservation, and utilization.

This diversity exists at multiple levels: from the agroecosystem level to vegetable crop groups, species, cultivars (landraces and modern varieties), genotypes, and alleles. Both genotypic and phenotypic variations are observed, allowing for adaptation to Nepal's diverse ecological zones. This broad genetic base is crucial for maintaining resilience in agricultural systems, especially in the face of challenges like climate change and market demands. Prior to the Convention on Biological Diversity (CBD), there was a free exchange of germplasm, leading to the widespread availability of exotic varieties in Nepal. Today, the country's vegetable genetic resources comprise a mix of exotic, native, local, hybrid, open-pollinated, inbred varieties, as well as breeding lines, cultivars, and traditional landraces. These varieties serve multiple purposes, such as being used fresh, dried, in salads, pickles, soups, and even as staple foods. This diversity of uses adds to the cultural significance of vegetables in Nepalese cuisine and underscores the importance of conserving and utilizing these resources for future food security and agricultural innovation.

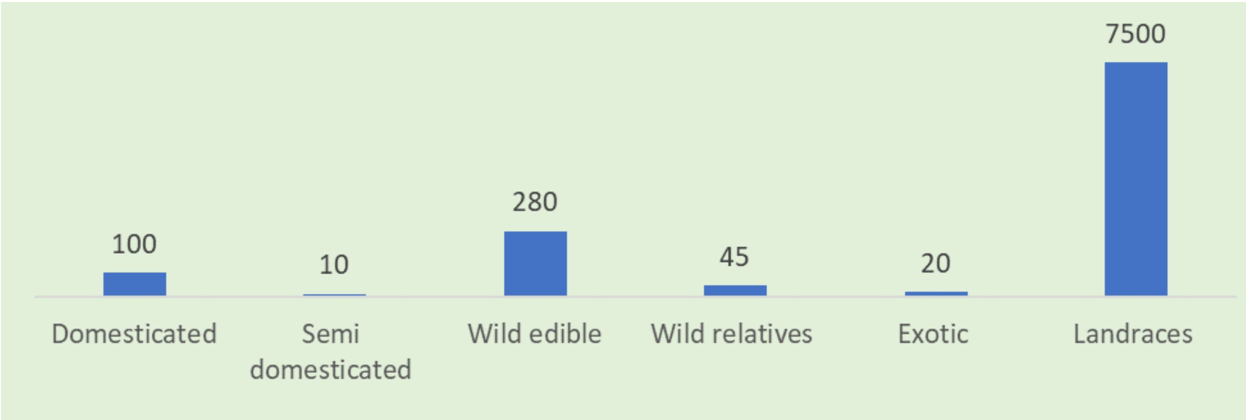


Figure 2: Number of vegetables species and total landraces in Nepal

Source: Joshi et al., 2017, 2020, 2022

2. Classification of vegetable crops

Vegetable crops can be classified based on various criteria, which aids in their effective conservation strategies (Figure 3). For instance, one important distinction is between orthodox and non-orthodox seeds. Orthodox seeds can be stored for long periods under low-moisture and cold conditions, making them suitable for storage in seed banks. However, non-orthodox seeds, which do not survive drying or freezing well, require different approaches, such as conservation in field genebanks or tissue banks. These methods ensure that non-orthodox varieties, which might be more vulnerable to environmental changes, are preserved outside their natural growing environments. In addition to the technical classification of seeds, conservation efforts also prioritize certain types of vegetables. Native and local vegetable landraces are given higher priority because they are well adapted to local conditions, offer greater genetic diversity, and often have traits like climate resilience and nutritional richness.

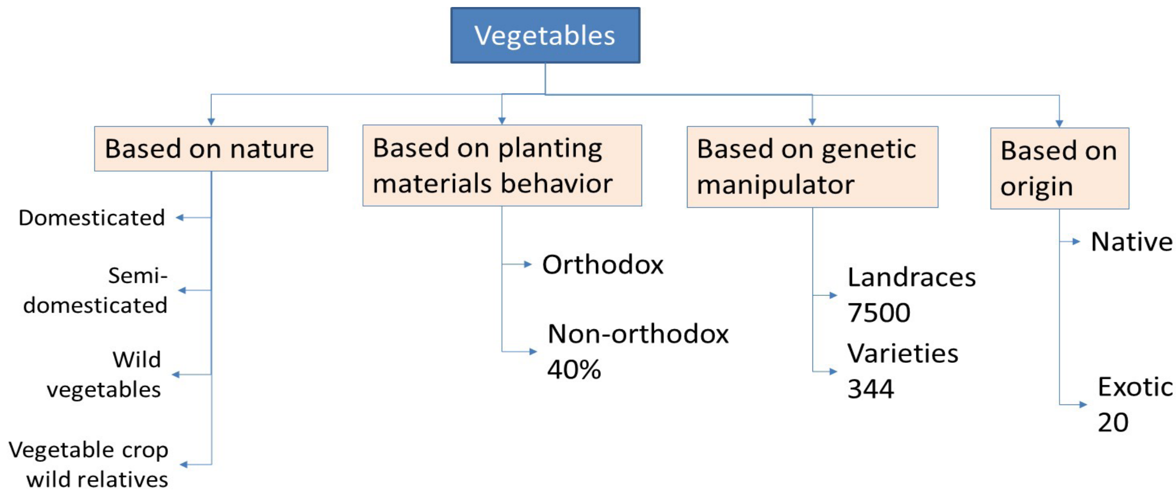


Figure 3: Classification of vegetable crops based on conservation perspective

Source: Joshi et al., 2017, 2020, Joshi 2022

3. Landraces

Landraces refer to the genotypes that have been cultivated by farmers over generations without formal breeding intervention. These varieties have naturally adapted to their local environments, making them uniquely suited to specific regions. In Nepal, it is estimated that there are around 7,500 landraces of vegetables, which play a crucial role in the country's agricultural biodiversity. Most farmers in Nepal rely on these landraces, grow organically and follow an informal seed system, where seeds are saved and exchanged within farming communities rather than purchased from commercial seed suppliers. Many of these landraces have evolved in specific sites, becoming well-adapted to local climatic and soil conditions. They are often preferred by farmers for their resilience, flavor, and nutritional value, despite the increasing pressure from hybrid and exotic varieties. By maintaining these traditional varieties, farmers contribute to the conservation of genetic diversity, which is essential for long-term sustainability and adaptability to changing environmental conditions. However, the shift towards formal breeding and the promotion of exotic varieties threatens the survival of these valuable local landraces.

4. Released and Registered (RandR) vegetable varieties

In Nepal, Released and Registered (RandR) vegetable varieties refer to any varieties officially listed under the National Seed Board. These varieties are recognized for commercial cultivation and distribution. A significant portion of RandR varieties in Nepal is dedicated to vegetables, accounting for 56% of the total. Currently, there are 409 RandR varieties across 40 vegetable crops, although 114 varieties have been denotified over time, possibly due to obsolescence or poor performance (SQCC 2024). A detailed analysis of 344 RandR vegetable varieties from 39 crops revealed that 95% of these varieties originated outside Nepal, according to a study by Joshi et al. (2017). This heavy reliance on exotic varieties reflects a trend in Nepal's agricultural sector where foreign vegetable strains, especially hybrids, are prioritized. This trend is further evidenced by the lack of data on the origin of recently registered varieties, suggesting a shift towards adopting hybrid varieties without transparent records of their genetic sources.

Despite the availability of native landraces that are climate-resilient, nutrient-rich, and flavorful, there is less focus on promoting these local varieties. Native vegetables have the potential to withstand Nepal's diverse climate challenges while offering higher nutritional and health benefits. However, the agricultural market and policies continue to favor exotic and hybrid varieties, often sidelining the ecological and cultural benefits of traditional crops. This shift towards hybrids could further erode the genetic diversity of Nepal's vegetable species, posing risks to food security and sustainability in the long term.

5. Wild vegetables

In Nepal, the number of wild vegetable species far exceeds that of domesticated vegetables, with over 334 wild species, including spices, reported across the country (KC et al., 2021). These wild vegetables are found in diverse regions, thriving naturally from as low as 60 meters to over 3,500 meters above sea level, and are available throughout the year. The majority of these species grow in the mid-hill regions of Nepal, where they are harvested by local communities. Their natural growth and unique qualities make them highly prized in the market, often fetching higher prices than cultivated vegetables (Pandey, 1999).

These wild vegetables are renowned not only for their delicious taste but also for their high nutritional value and health benefits (KC et al., 2021, Pandey, 1999). Some of them even possess nutraceutical properties, meaning they can contribute to both nutrition and medicinal benefits. For many farmers, the harvesting and selling of these vegetables play a crucial role in sustaining their livelihoods and local economies. This informal trade is essential for their income, as these vegetables are often sold in small quantities, with vendors sitting by the roadsides to offer them to passersby. The practice of gathering and selling wild vegetables connects these communities with nature while providing an important economic lifeline.

Practices Leading to Genetic Erosion

Nepal has lost 50% of its vegetable biodiversity, a stark indicator of genetic erosion (Joshi et al., 2020). This loss is a result of the cumulative impact of following agricultural practices, reducing the country's ability to sustain a diverse agricultural ecosystem and leaving it vulnerable to the challenges posed by climate change, pests, and diseases (Joshi et al., 2019, 2023).

Genetic erosion, the loss of genetic diversity, has been exacerbated in Nepal due to several agricultural practices. One significant factor is the widespread cultivation of uniform, homogenous, and exotic varieties. These varieties are often chosen for their high yield or marketability but displace native, genetically diverse varieties. This shift reduces the genetic pool of indigenous species, which are often more resilient to local environmental conditions. The practice of monoculture-growing a single variety over large areas-further amplifies genetic erosion. By focusing on one crop type, especially in large-scale farming, farmers inadvertently limit the diversity of plants in their fields. This uniformity not only makes the crops more vulnerable to pests and diseases but also reduces the natural selection processes that contribute to genetic diversity.

Additionally, the use of the same rootstock for many varieties and species contributes to this issue. While rootstock compatibility is essential for certain plants, relying on a limited number of rootstocks reduces genetic variability within crops. This can affect the plant's ability to adapt to environmental changes, further increasing the risk of genetic erosion. Another contributing factor is the practice of asexual propagation, which halts the natural process of meiotic variation. Unlike sexual reproduction, which encourages genetic diversity through recombination, asexual propagation maintains genetic uniformity. While this method can be beneficial for ensuring uniformity and specific traits, it limits evolutionary potential and prevents the introduction of new genetic traits that could help species adapt to changing environments. Protected agriculture, which often involves controlled environments like greenhouses, can also lead to a loss of associated biodiversity. By creating conditions that favor specific crops and varieties, these systems can exclude the many organisms that naturally interact with plants in an open ecosystem, thus diminishing the broader genetic diversity of the agricultural landscape.

Efforts to conserve genetic diversity through gene banks and field genebanks have been put in place, but these collections are limited to certain areas and buildings. While these repositories serve as valuable resources for preserving biodiversity, they cannot fully replace the diversity that exists in natural environments. Additionally, this method of conservation often focuses on a limited range of species, neglecting the broader spectrum of plant varieties. Legal frameworks also play a role in genetic erosion. In Nepal, the legal provision for selling and buying registered and released (RandR) varieties, along with economic incentives, often favors commercial and exotic varieties over indigenous ones. This focus on registered varieties discourages farmers from maintaining and cultivating traditional varieties, further diminishing genetic diversity in crops. Another challenge is that the seed cycle has moved outside farming communities, breaking traditional systems where farmers would save and exchange seeds within their communities. This shift to external seed sources has reduced the circulation of local varieties, limiting the diversity of plants grown and threatening the survival of lesser-known or underutilized species.

Conservation Strategies and Components

To conserve Nepal's rich vegetable genetic resources (VGRs), the National Genebank has adopted four key strategies based on the action site: Ex-situ conservation, On-farm conservation, In-situ conservation, and Conservation breeding (Joshi et al., 2020).

Ex-situ conservation involves storing and preserving VGRs outside their natural habitats, typically in seed banks, field genebanks, or other conservation facilities. This method ensures that genetic material is safely stored for future use and research. On-farm conservation focuses on preserving genetic diversity within local farming systems. This approach supports farmers in cultivating and maintaining native landraces in their fields, helping to conserve site-specific varieties in their natural agroecosystems. In-situ conservation entails protecting VGRs in their natural environments, allowing the plants to evolve and adapt to changing conditions. This strategy is essential for maintaining the dynamic nature of genetic diversity in wild and semi-domesticated vegetable species. Conservation breeding involves the deliberate breeding of native vegetables to enhance their genetic traits, making them more resilient, productive, and marketable. This strategy helps to improve site-specific varieties while ensuring their conservation.

In addition to these site-based strategies, Nepal's conservation efforts are also guided by four levels of governance: Local level, Province level, National level, and International level. These levels ensure that conservation activities are coordinated and supported from grassroots communities to global initiatives, with appropriate policies and resources allocated at each stage. Furthermore, five key conservation components have been identified and practiced to ensure the sustainable conservation of agrobiodiversity. These components, illustrated in Figure 4, provide a comprehensive framework for maintaining and utilizing VGRs, ensuring that Nepal's rich vegetable diversity is preserved for future generations.

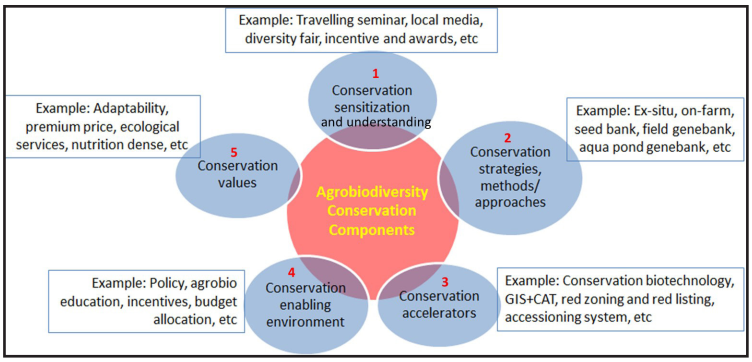


Figure 4: Components of conservation of agrobiodiversity

Conservation Approaches and Status

Nepal employs a variety of innovative conservation approaches to safeguard its vegetable genetic resources (VGRs), implemented within the framework of four key conservation strategies: **Ex-situ, On-farm, In-situ**, and **Conservation breeding**. These approaches include seed banks, field genebanks, agro-gene sanctuaries, DNA banks, tissue banks, community genebanks, school field genebanks, crop-specific parks, and aqua pond genebanks (NAGRC, 2022, Joshi et al., 2020). These diverse strategies ensure that VGRs are conserved across different contexts, from controlled environments to local farming systems (Figure 5). In addition to these, associated conservation initiatives such as agro-insect field genebanks, herbal conservation gardens, and indigenous plant nurseries (Raithane nurseries) have been established. These facilities promote not only the conservation of vegetable crops but also the broader biodiversity of insects, herbs, and other organisms that contribute to agricultural ecosystems. Together, these approaches create a dynamic system for preserving and promoting genetic diversity in Nepal's agricultural landscapes.

The first Community Genebank was established in Gaver Valley, Banke, in 2022, and there are now three such genebanks operating in Nepal, all focused on conserving vegetable genetic resources (VGRs) through active utilization. While similar to community seed banks, these Community Genebanks encompass all six components of agrobiodiversity, including crops, forages, livestock, agro-insects, agro-microbes, and aquatic agricultural genetic resources (AGRs). Community Genebanks can be operated through two primary models. The first model is village-level, where each household maintains different landraces of various species. Collectively, these households form a robust community genebank, promoting local biodiversity and knowledge sharing. The second model involves maintaining AGRs in specific areas, complemented by the construction of storage facilities and other structures to support conservation efforts. Through these innovative approaches, Community Genebanks enhance on-farm conservation, empower local communities, and contribute to sustainable agricultural practices.

The **National Genebank of Nepal** has made significant progress in conserving VGRs. It currently holds 952 accessions from 46 different vegetable crops (Figure 6). Additionally, Nepalese vegetable crops are conserved internationally, with 257 accessions stored in foreign genebanks, 926 accessions at the World Vegetable Center, and 25 accessions of nine vegetable crops maintained by the USDA. Furthermore, seven accessions from four vegetable crops have been included under the **Multilateral System (MLS)** of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which facilitates the sharing of genetic resources globally.

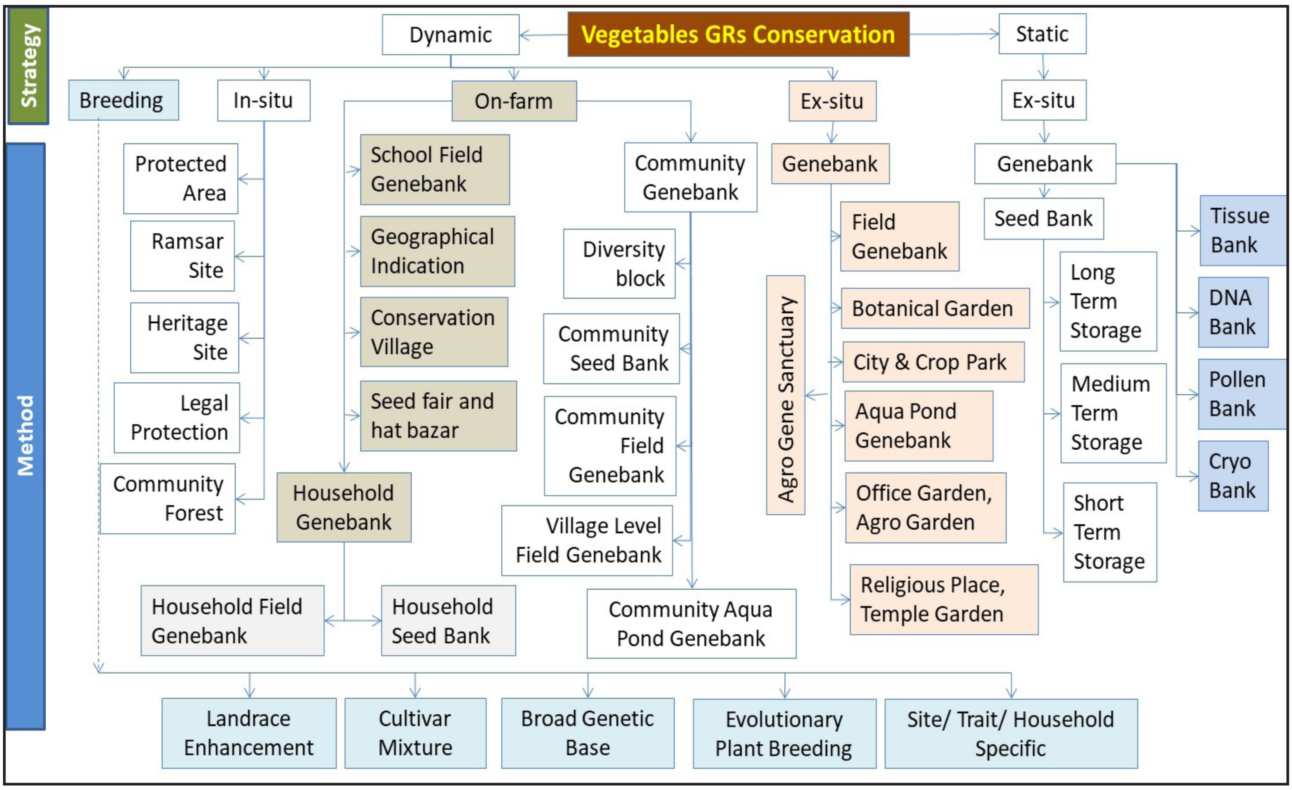
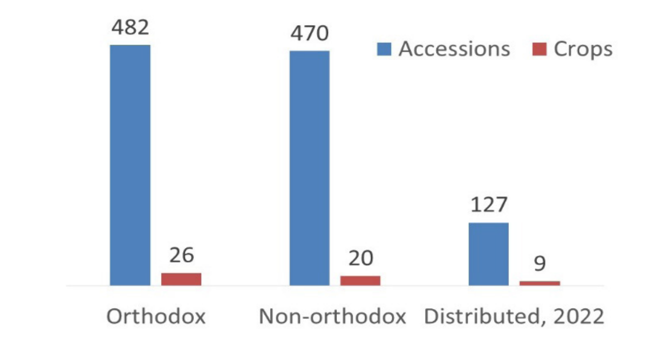
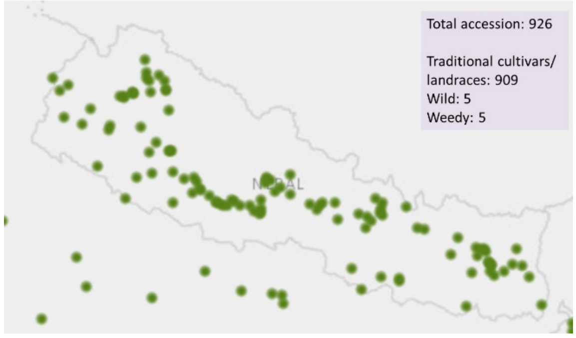


Figure 5: Action site-based conservation strategies, methods and approaches for VGRs

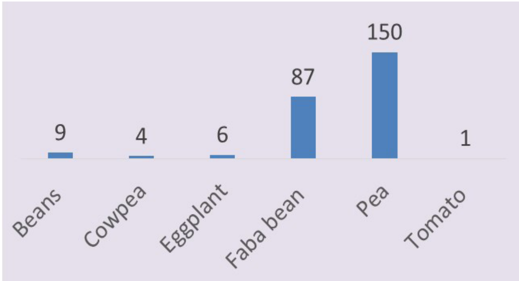


Vegetable crops conserved in Nepal Genebank and distributed for researchers and farmers

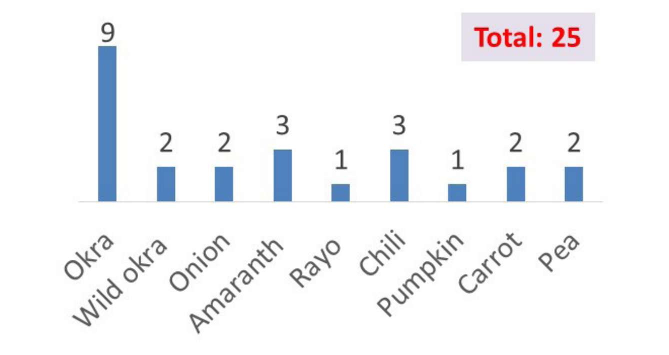


Vegetable crops collected from Nepal and conserved in World Vegetable Center, Taiwan

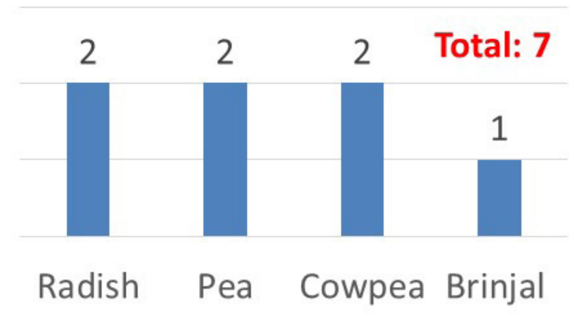
Nepalese vegetable crops database in Genesys



Vegetables from Nepal in Genesys database



Vegetables from Nepal in GRIN-Global (USDA)



Nepalese vegetables under MLS

Figure 6: Conserved Nepalese vegetable accessions in different banks

Conservation Accelerators

Conservation requires multifaceted approaches and tools to be truly effective. Among these tools, **conservation accelerators** play a crucial role in enhancing the preservation of genetic diversity (Joshi et al 2020). Defined as actions that directly or indirectly promote the continued existence of existing genetic diversity, conservation accelerators are essential components of any conservation strategy. These accelerators can encompass a wide range of practices, including the development of community engagement initiatives, the establishment of policy frameworks that support biodiversity, and the implementation of sustainable agricultural practices. Some such accelerators are described below. By leveraging these action tracks, stakeholders can create an environment conducive to the preservation and enhancement of genetic resources, ensuring that both current and future generations benefit from the rich biodiversity available in ecosystems.

1. Agrobiodiversity Impact Assessment (AIA), Red zoning and red listing

Before implementing any projects or activities in specific agricultural areas, conducting an **Agrobiodiversity Impact Assessment (AIA)** is essential. This assessment aims to identify and protect endangered and rare genotypes by facilitating their rescue, relocation, and conservation in genebanks. The Genebank has actively employed AIA in its initiatives and has advocated for relevant stakeholders to mainstream it alongside Environmental Impact Assessments (EIA) to ensure a comprehensive approach to conservation. In addition to AIA, **red zoning** and **red listing** are crucial tools for prioritizing conservation efforts (Joshi et al., 2017). Red zoning involves identifying areas where landraces are at risk, while red listing establishes a catalog of these vulnerable species. By employing these methods, conservation targets can be identified and prioritized, allowing for focused efforts to protect the most threatened genetic resources. Together, AIA, red zoning, and red listing provide a robust framework for conserving agrobiodiversity and ensuring the sustainability of agricultural ecosystems.

2. Agroecology based practices

To preserve site-specific vegetable and agricultural diversity, the Nepal Genebank has championed ecological agriculture through the development of **10 key principles of agroecology (Figure 7)**. These principles aim to enhance sustainability, resilience, and productivity within local farming systems. By promoting these agroecological practices, the Genebank encourages farmers to adopt methods that align with the natural ecosystem, thereby supporting biodiversity while improving soil health and crop yields. The implementation of these 10 keys serves as a framework for farmers to cultivate a diverse range of crops and maintain their agricultural heritage. These practices not only contribute to ecological balance but also empower communities by fostering a deeper understanding of the interconnectedness of agriculture, environment, and health. For a detailed overview of these principles.

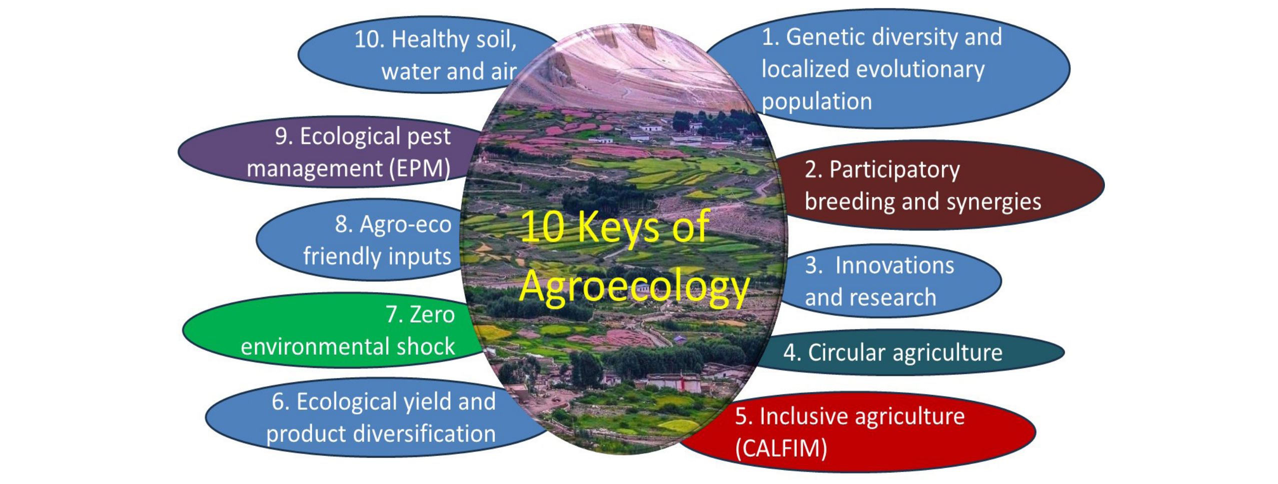


Figure 7: 10 keys of agroecology for promoting genetic diversity

3. Promoting eco-friends' cultivation practices

Focusing solely on single yields for promoting any crop variety is neither sustainable nor beneficial for health, as monoculture practices can deplete ecosystems. In response, the Nepal Genebank has initiated efforts to promote varieties that offer high ecological yields (Figure 8), emphasizing their contributions not only to human nutrition but also to the environment, animals, water, air, soil, and overall ecosystem health. By cultivating crops alongside their eco-friendly companions, farmers can enhance biodiversity and support the fertility of the soil while ensuring a healthier environment. Eco-friends of crops are companion species that help improve overall performance; these can include various combinations, such as rice grown with fish, black gram, azolla, ducks, and beneficial agro-insects. Additionally, the Genebank has begun estimating the **Food Health Index** for each food item, akin to a nutritional profile for agricultural products. This index provides a score or composition that highlights the healing properties, benefits, and potential drawbacks of different foods, particularly for individuals with health concerns. By promoting these eco-friendly practices and assessing food health, the Genebank aims to foster sustainable agriculture that supports both human health and environmental integrity.

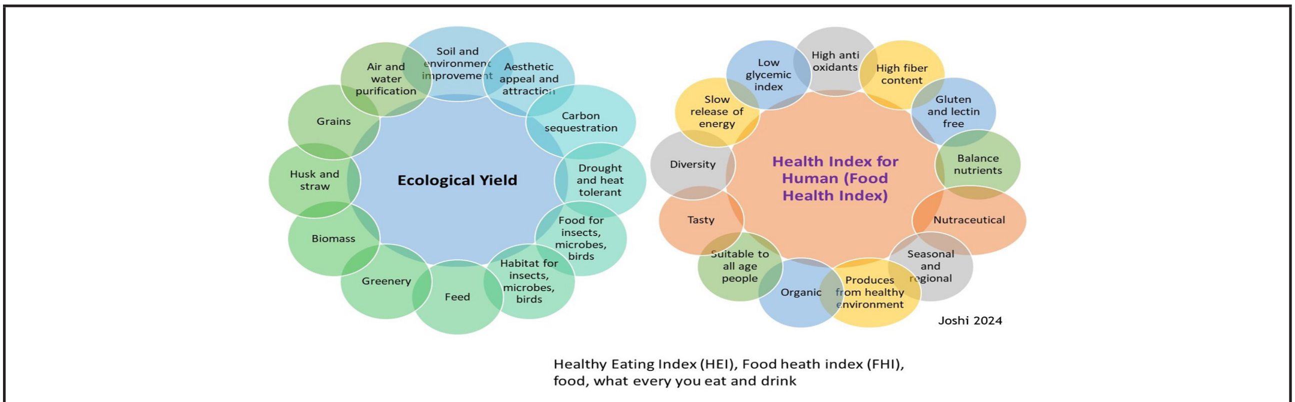


Figure 8: Contributing factors in ecological yield and food health index

4. Cultivating diversity for climate resilient and other stresses

To address the challenges posed by climate change and other environmental stresses, cultivating a higher degree of genetic diversity—both intra and inter-varietal—is essential. This approach fosters a site-specific evolving system that can better withstand unpredictable climatic conditions. Implementing strategies such as **cultivar mixtures** and **evolutionary plant breeding** allows for the enhancement of resilience in crop systems. In addition, adopting **polyculture** practices can significantly contribute to biodiversity and soil health while reducing the risks associated with monoculture farming. The integration of **climate-smart germplasm** and **climate-smart plant breeding** techniques further supports the development of varieties specifically tailored to thrive in changing environments. By focusing on these diverse cultivation strategies, farmers can create robust agricultural systems capable of adapting to climate-related challenges while ensuring sustainable food production.

5. Landrace enhancement and registration (conservation through use)

To improve the viability and attractiveness of landraces for farmers, the Nepal Genebank has implemented a participatory landrace enhancement program. This initiative has successfully led to the genetic enhancement of numerous landraces, making them more competitive in agricultural production. As a result of these efforts, communities have taken the initiative to register these enhanced landraces with the National Seed Board. So far, ten landraces from six different vegetable crops have been officially registered (Figure 9). Previously, there were no provisions for the registration of landraces; however, the persistent efforts of the Genebank have prompted a policy revision that now allows for the registration of landraces with a broad genetic base. This development not only supports the conservation of traditional varieties but also empowers local communities by recognizing their contributions to agricultural biodiversity and enabling them to access markets more effectively.

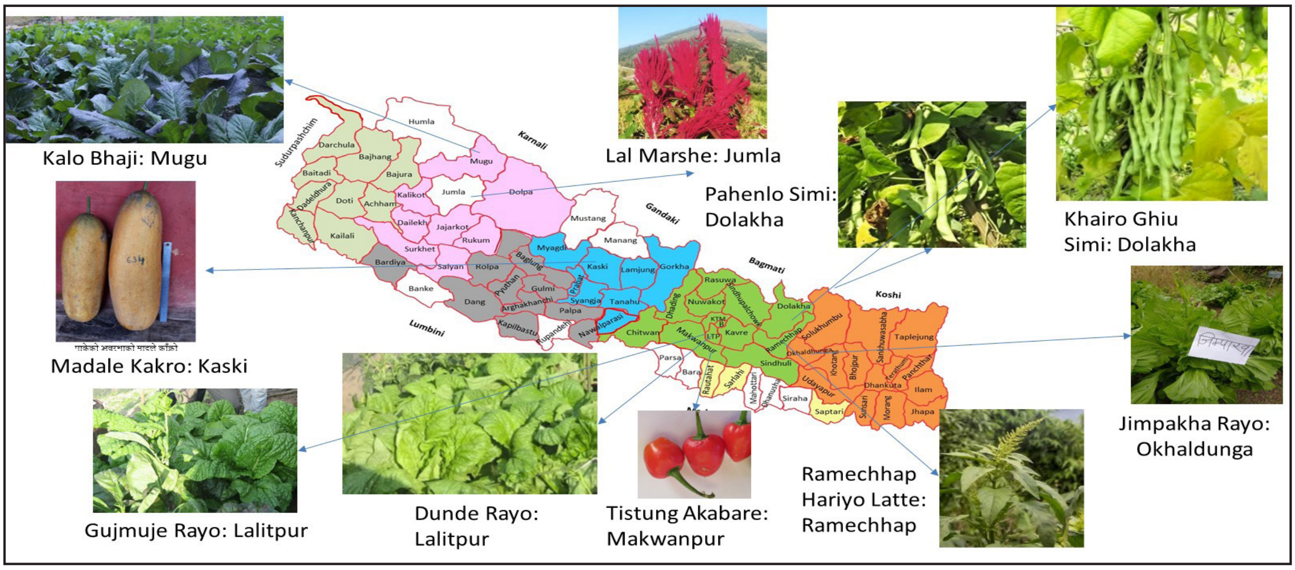


Figure 9: Registered vegetable landraces by communities

Source: SQCC 2024

6. Domesticating wild vegetables

In many forest areas of Nepal, farmers commonly collect various wild vegetables for consumption. To enhance the utility of these species, the domestication of wild vegetables is deemed essential. This practice not only promotes better utilization of these resources but also helps maintain undisturbed forest ecology by shifting cultivation efforts to private lands. In support of this initiative, the Nepal Genebank has established a wild vegetable garden focused on the domestication of several species, including **Chuke palunge, Niuro, Jaluko, Tree fern, Bethe,** and **Kaause/Chhaaki Simi**. By cultivating these wild vegetables, the Genebank aims to foster biodiversity, improve food security, and encourage sustainable agricultural practices among local communities (NAGRC, 2022).

7. Pre breeding vegetable crops

To accelerate the breeding process for vegetable crops, the Nepal Genebank has implemented regular pre-breeding activities. These efforts have led to the identification of more than 100 elite lines across various vegetable species (NAGRC, 2022), which have been shared with farmers and breeders. Pre-breeding plays a crucial role in developing high-yielding varieties by focusing on identifying site-specific broad genetic base varieties. This approach not only enhances the genetic diversity available for breeding programs but also helps ensure that the resulting varieties are well-adapted to local growing conditions.

8. Application of biotechnology, GIS and CAT

The Nepal Genebank has effectively integrated biotechnological tools into its conservation strategies for vegetable genetic resources (VGRs). These tools include the establishment of a **DNA bank** and a **tissue bank**, which facilitate the long-term preservation of genetic material. Additionally, the Genebank employs techniques such as **genetic diversity assessment** and **DNA fingerprinting** to evaluate and characterize the genetic variability within its collections. Geographic Information Systems (**GIS**) have also played a critical role in the Genebank's efforts (Joshi et al., 2017). Collection mapping and gap analysis conducted through GIS enable the identification of areas where specific VGRs are underrepresented, facilitating targeted conservation efforts. Furthermore, the **Climate Analog Tool (CAT)** is utilized to identify potential analog sites, allowing for the repatriation of germplasm and the exploration of new areas for potential germplasm collection. By leveraging these advanced technologies, the Nepal Genebank enhances its capacity to conserve and utilize the rich diversity of vegetable genetic resources effectively.

9. Farmers' market and home stay

In Nepal, it is common for farming households to waste a significant amount of native vegetable produce, such as chayote, sponge gourd, and pumpkin. However, if these products could be sold, farmers would be incentivized to grow them more actively. Establishing farmers' markets, or open markets, is an effective approach to ensure the availability of a diverse range of agricultural products and create a direct link between primary producers and consumers. Previously, "haat bazar" (weekly markets) were a common practice throughout the country, but they declined over time. Now, these markets are re-emerging, providing a platform for households to operate as local shops and sell their produce directly. In addition to farmers' markets, home or farm stays have gained popularity as a successful agro-tourism initiative. By showcasing native and local germplasm, traditional farming practices, and local foods, these stays allow visitors to experience authentic rural life while providing farmers with additional income. This dual approach not only helps farmers maximize profits from their vegetable production but also fosters a deeper connection between consumers and the rich agricultural heritage of Nepal.

10. Geo-localized famous vegetable crops

Nepal is home to many famous vegetable landraces that are closely linked to specific geographic regions, such as Jumli simi, Akabare khursani, Kuvinde Farsi, Mude Salu, Bhaktapure Kakro, Terhathume Bose Aduwa, Gujmujje Rayo, Bajhange Aalu, and Pyuthane Mula. The Nepal Genebank is actively working on documenting and gathering evidence to grant Geographical Indication (GI) tags to these products. This recognition will help farmers gain higher market benefits while promoting the continued cultivation of these landraces, ultimately contributing to their conservation.

11. Collaboration for conservation of all VGRs across the Country

Nepal Genebank collaborates with a wide range of stakeholders to ensure the conservation and availability of vegetable genetic resources (VGRs) throughout the country. Key partners include government bodies such as the **CDABCC**, **Department of Agriculture (DoA)**, **NC-PVS-CD**, and the **Ministry of Agriculture and Livestock Development (MoALD)**, along with **government farms** and **NARC research stations**. Academic institutions, including **IAAS** and **NAIAS**, as well as international organizations like **ICIMOD**, play a crucial role in research and conservation. The **Botanical Garden in Godawari**, **LIBIRD**, schools, and local communities are also involved in grassroots conservation efforts. Collaboration extends to **Raithane agro products**, municipalities, and conservation-focused organizations like **WWF** and the **Department of Plant Resources (DPR)**.

12. Digital/ Virtual Genebank and Database

Nepal Genebank has embraced digital tools to enhance the accessibility and visibility of its conservation efforts. A video documentary showcasing the Genebank's work has been developed and made available online, allowing a broader audience to understand its importance. In addition, the Genebank actively shares updates and features through social media platforms such as Facebook, Twitter, TikTok, and YouTube, making information readily accessible to the public (NAGRC, 2022).

To streamline data management, the Passport app has been developed, helping to track and document plant genetic resources. The Genebank's database is also available through the Genesys web portal, (https://www.genesys-pgr.org/a/map/v2LYApy1qK7/@28.278205,84.123929,7z) providing global access to its extensive collection of genetic resources. The Genebank's own website (https://genebank.narc.gov.np/) offers additional information, and its data is linked with the **FAO-WIEWS** platform (https://www.fao.org/wiews/data/ex-situ-sdg-251/search/en/?no_cache=1andfbclid=IwAR2I8xSwLSgZN_NTG-x__yzUn2nMK8KOFkMyXeH7Hpdp5mCbMPh-7hSQd9w#results), contributing to international conservation efforts. These digital resources ensure that information on Nepal's valuable plant genetic resources is easily accessible for research, conservation, and utilization.

Challenges

The management and utilization of vegetable genetic resources (VGRs) in Nepal face several significant challenges that hinder the preservation and promotion of native biodiversity. These challenges stem from a variety of factors, including the prioritization of foreign varieties, genetic erosion, and the marginalization of traditional farming practices. One major issue is the priority placed on testing and marketing foreign vegetable varieties by institutions like NARC, the Seed Quality Control Center (SQCC), and the Department of Agriculture (DoA). This focus has led to the underutilization of native vegetable crops in research, education, and extension programs. Indigenous landraces are often perceived as inferior, limiting their use despite their potential for resilience and adaptability in local conditions. This bias further discourages the integration of native crops into mainstream agricultural development.

Additionally, the replacement of site-specific landraces with single varieties grown over large areas contributes to genetic erosion. Instead of promoting the diversity of locally adapted varieties, wide cultivation of uniform crops leads to a loss of site-specific traits and biodiversity. Monogenotypic fields, kitchens, and markets—where a single variety dominates—are increasingly common, undermining the broad genetic base necessary for a resilient agricultural system. Genetic erosion is occurring at a rapid pace, driven by several factors. The preference for exotic vegetable varieties, especially those suited for controlled environments, has led to the displacement of traditional landraces. The narrowing of genetic diversity is especially pronounced in vegetatively propagated vegetable crops, where farmers often rely on a limited number of varieties.

Furthermore, the increasing use of chemical inputs and protected farming practices has exacerbated the destruction of agrobiodiversity. These practices, while promoting short-term yields, threaten the long-term survival of diverse plant species by creating environments that favor a narrow range of crops. Climate change, with its new stresses and unpredictable weather patterns, is accelerating the pace of genetic erosion by introducing challenges that many traditional varieties cannot withstand.

The transfer of farmers' seed rights to seed companies and the promotion of linear, industrialized vegetable farming have further complicated the situation. The emphasis on formal agricultural systems, which often rely on external inputs and commercial seed cycles, reduces farmers' ability to maintain localized, self-sustaining seed cycles. There is also a debate surrounding whether landraces, traditionally considered public goods, should be treated as private goods in modern agricultural markets. Genetic diversity, which evolves naturally within local populations, is often left unrecognized in agricultural policy. Additionally, associated biodiversity, such as pollinators and soil microbes, is largely ignored, further diminishing the ecological balance essential for sustainable agriculture. The lack of policy recognition for genetic diversity poses a significant barrier to conserving VGRs. While evolving populations in local systems continue to adapt and change, many agricultural policies favor static, non-evolving populations in commercial farming, limiting the potential for innovation and resilience in the face of environmental change.

Way Forward

Agrobiodiversity forms the foundation of life and the advancement of agricultural sciences. To address agricultural problems effectively, one must give due attention on agricultural biodiversity. The focus should be on preserving, utilizing, and advancing the rich diversity of vegetable genetic resources (VGRs) that the country possesses, as these hold the potential for sustainable development. A key strategy moving forward is to "go for local, work on local, respect local, and globalize local." This approach calls for the promotion of indigenous vegetables and technologies, ensuring they are globally competitive. Developing site-specific varieties with broad genetic bases, adapted to local conditions, is crucial for increasing the global market value of native crops. Additionally, ecological agriculture, which emphasizes the cultivation of diverse crops, should be a priority. This helps maintain the ecological balance, improves soil health, and reduces reliance on external inputs.

Protecting local landraces by granting them geographical indication (GI) tags and securing farmers' rights is essential. Farmers must be empowered to complete seed cycles themselves, ensuring that traditional knowledge and practices are preserved. Establishing banking systems for vegetable genetic resources (VGRs) is also critical. Agro-gene sanctuaries, field genebanks, crop-specific parks, and school field genebanks can serve as conservation hubs. The creation of specialized conservation banks, such as agro-insect, aqua pond, and mushroom field genebanks, along with herbal conservation gardens, will safeguard diverse species. A Himalayan seed bank should be established as a safety backup for Nepal's invaluable genetic resources.

Mainstreaming approaches like Agrobiodiversity Impact Assessment (AIA), red zoning, and red listing—together with rescuing germplasm and planting materials—will help in conserving native varieties. Passport data for germplasm should also be integrated into the National Genebank. Guaranteeing market access and irrigation for farmers is equally important to ensure the continued cultivation of native vegetable diversity. Native vegetable crops must be embedded into research, education, extension programs, and the marketplace to fully unlock their potential. Finally, to signify the importance of native vegetables, broad leaf mustard should be declared the national vegetable of Nepal.

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