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A Review on Genetic Diversity and Suitability of *Ex situ* Germplasm Conservation for Re-introduction

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Abstract

Genetic diversity is crucial for plant performance and adaptation to climate change, as it provides resistance to biotic and abiotic stresses. However, species with little or no genetic diversity may be more susceptible to biotic and abiotic stresses. Genetic erosion is a significant issue affecting crop plants, with modern cultivars being widely distributed and suppressing landraces principal to loss of genetic diversity. Conservation and sustainable use of Plant Genetic Resources (PGR) are crucial for sustainable development. Effective conservation involves *in situ* and *ex situ* conservation techniques. *Ex situ* conservation of wild plant species by seed banks has been used for a decade to preserve biological and genetic diversity. However, *ex situ* collection may be ineffective in preserving genetic diversity due to a decline in fitness for small and isolated plant populations, environmental pressures like replacement, fragmentation, habitat destruction, and pollution leading to potential genetic risks, growing plants *ex situ* exposes them to new environmental conditions, a loss of adaptive response and adaptation to the original environment. This raise concerns that *ex situ* cultivated plants may be less well-adapted to their original environment and less suitable for reintroduction in to the wild.

Keywords: *Ex situ* conservation; Genetic diversity; *In situ* conservation; Plant genetic resources

Introduction

Genetic diversity

Genetic diversity is the amount of genetic variation that exists among individual varieties or populations within a species. It can occur through natural or human-driven crop plant evolution. It is the product of recombination, mutation, gene flow and genetic drift of genetic material (DNA) in the genetic process, leading to variations in DNA sequence, epigenetic profiles, protein structure, isoenzymes, physiological properties, and morphological properties [1].

Genetic diversity among individuals within a population is important for enhancing plant performance. Genetic diversity is important in the context of climate change and associated contingencies as it can serve as a reservoir for many new traits and genes that confer resistance to various biotic and abiotic stresses. Various crop varieties can survive under environmental changes through genetic variation, which enables varietal adaptation.

However, species with little or no genetic diversity may be more susceptible to biotic and abiotic stresses. Genetic diversity helps breeders maintain hybrids that retain desirable cultivar traits, such as quality traits and resistance to various stresses. But over time the naturally occurring variability depleted due to, (i) Unequal breeding practices focused on improving only some traits (such as yield and its components), and (ii) The frequent use of genotypes as parents' poor selection in breed development programs. (iii) Increased genetic similarity among modern breeds due to the introduction of some outstanding cultivars worldwide. The loss of genetic diversity associated with reduced species ranges due to climate warming may reduce the potential for local adaptation and thereby increase the risk of extinction [2].

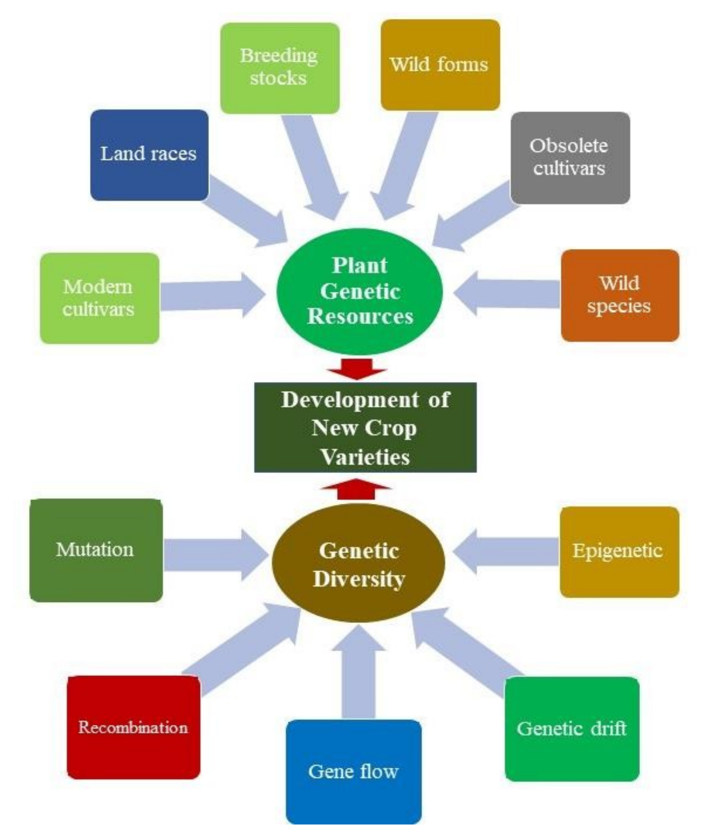

Figure 1: Different sources of genetic diversity and their potential utilization in the development of new crop varieties.

Literature Review

Importance of genetic diversity in genetic resource conservation

Plants are an important part of the world's biodiversity and are widely recognized as an essential resource for life on the planet. Human lifestyle has greatly benefited from the cultivation, protection, and use of plant species for agriculture and food production. For thousands of years, farmers have exploited genetic variation in wild and cultivated plants to develop crops. Genetic diversity is a fundamental factor in the evolution of species. It provides the raw materials for the adaptation, evolution, and survival of species and individuals, especially under changing environmental, disease, and social conditions. The future food security of all societies will depend on the use of genetic modification and allelic diversity to improve crops, and many farmers around the world will have access to edible, fodder and next-season seeds directly dependent on genetically diverse crops to sow [3].

In addition to the use of cultivated plant species for food, wood, fiber, and other industrial uses, many wild plants have economic and cultural potential as crops and commodities of the future, especially as humans coping mechanism with the new challenges of environmental and climate change. Conserved plant genetics contain genes that confer resistance to disease and pests and enhance agronomic traits, giving plant breeders the opportunity to address a variety of crop improvement programs [4].

The considerable genetic diversity of traditional crop varieties is the most directly useful and economically valuable part of global biodiversity. Subsistence farmers use landraces as a key component of their farming system. Such farmers occupy about 60% of agricultural land and provide about 15-20% of the world's food. In addition, landraces are the basic raw material used by plant breeders to develop new varieties. Recently, there has been a growing awareness of the rich diversity of exotic or wild genetic resources. This has led to more intensive use of this germplasm in breeding, thereby dramatically increasing yields in many crops [5].

Plant Genetic Resources (PGR) is a pillar upon which global food security and agriculture depend, especially as the world population grows. PGR refers to the genetic material contained within and between plant species that has current and potential economic, scientific, or societal value. Food and income security issues are of global importance, impaired by unprecedented global population growth, which leads to the overexploitation of natural resources and, in turn, the genetic diversity of plants. Plant Genetic Resources (PGR) refers to the genetic material contained within and between plant species of current and potential value. Recently, genetic diversity in landraces, weeds and wild strains has been reported to control devastating diseases, pests, and environmental changes in plant and animal populations. However, these resources are being lost at alarming rates due to human unwise utilization of natural resources and their consequences such as climate change, pollution, genetic erosion, gross mismanagement of these resources and population growth. The need for conservation and sustainable use of these resources is therefore crucial for sustainable development. PGR conservation is the management of plant cultivar diversity resulting from interactions between genes and the environment for actual or potential use and for current or future use. Complementary use of in situ and *ex situ* conservation techniques is recommended for effective conservation. Efficient research, collection, and documentation are also important. International, national, and individual recognition of the value of this vast genetic diversity would facilitate the sustainable development and utilization of these genetic resources. They need to be easily accessible, especially in hotspots and endemic areas, and effective measures need to be taken to protect them [6].

Genetic erosion

Since the beginning of agriculture, farmers have cultivated hundreds of plant species, and migration, natural mutation, crossbreeding and unconscious or conscious selection has increased the genetic diversity within these species. This gradual and continuous expansion of genetic diversity within crops continued for thousands of years until the application of scientific principles and techniques in the modern agriculture era [7].

The impact of humans on biodiversity has gradually increased with growing technology, population, production, and consumption rates. The quest for increasing food production and the subsequent success achieved in several crops has begun to replace landraces with uniform, true-breeding cultivars. The need for increased food production and the resulting success achieved in several crops has begun to replace landraces with uniform, true-breeding cultivars. In 1920's and 1930's. N. I Vavilov and Jack Herlan become the first to be aware about genetic erosion. But the two American scientists J. Herlan and M. L. Martini have been credited with first recognizing the problem of genetic erosion in crops. During the forceful transformation of local crop varieties to improved true breed cultivars in different countries between 1960 and 1970 coined genetic erosion as a loss of crop variability in a population. Variability refers to the heterozygosity of alleles and genotypes with the associated morphotypes and phenotypes. Genetic erosion is therefore the alteration and loss of existing genetic variability so that the net change in diversity declines [8].

Results

Major causes of genetic erosion

The dissemination of modern varieties to the crop improvement program is an obvious cause of genetic erosion. In 1970/71 FAO presented data on the diffusion of modern cultivars as evidence for genetic erosion. Landraces adapted to optimal local agronomic conditions are probably the crop plant genetic resources that are most at risk of future loss through habitat destruction or replacement by introduced elite germplasm. With the development of scientific plant breeding, high-quality and homogenous new varieties were quickly and widely distributed suppressing landraces. Farmers select this improved modern cultivar for their high yield potential which is the most important criterion for varietal selection. The 'Green Revolution'' contributes to the loss of genetic diversity. Population growth, urbanization, developmental pressures on land resources, deforestation, changes in land use patterns, and natural disasters are contributing to abundant habitat fragmentation and destruction of the crops and their wild relatives [9].

Droughts of just a single season could result in people consuming seed stocks, while successive years of drought can prompt changes in cropping patterns and the geographic distribution of crops. Civil unrest and war are also potential risks for genetic erosion and loss of genetic diversity. Unwise utilization and introduction of invasive exotic species are also contributing factors to the loss of genetic resources. Recently, global warming and high levels of pollution have also been identified as additional causes of biodiversity loss [10].

The traditional agricultural communities strongly pressured by the external forces (often economic, culture and political issues). The modern world promotes the introduction of high yielding varieties with high level use of chemical fertilizers and pesticides as means to increase yield of a crop. Farmers were given several socio-economic incentives to replace varieties that evolved with in their agroecosystem with improved modern varieties. It changes the decision-making by the farmers encouraged to grow high-yield varieties in monoculture using inputs of fertilizer and pesticides. In many parts of the world, farmers were given several socio-economic incentives to replace varieties that evolved within their agroecosystem with improved/introduced varieties. The consequence of genetic erosion is genetic uniformity leaves a species vulnerable to new environmental and biotic challenges and causes heavy damage to society [11].

Plant genetic resource conservations

Vavilov has explored and identified hotspot regions of plant germplasm around the world in to 12 Vavilov centers of origin/diversity of crop plants and their wild and weedy relatives. Genetic resources are stored in over 1,700 gene banks worldwide to ensure current and future food and nutritional security. It has become increasingly clear that meeting the food needs of a growing world population depends heavily on the conservation and sustainable use of the world's remaining plant genetic resources. Conservation of plant germplasm is the process of actively maintaining gene pool diversity for actual or potential use by human exploitation of that genetic diversity. The conservation practice is aimed to collect and preserve adaptive gene complexes for current or future use. The preservation and utilization of germplasm are as old as agriculture itself for more than 12,000 years; farmers have preserved seeds for future sowing, domesticated wild plants and selected varieties to meet specific needs and conditions. Different plant species have been domesticated over thousands of years, and within each species, thousands of different varieties have emerged through human and natural selection. By conserving germplasm, breeders can find the raw materials they need to develop new varieties, and farmers can adapt their crops to changing environmental conditions and markets [12].

Discussion

The two main conservation strategies are *ex situ* and *in situ* strategies, each involving a number of different techniques. Conservation products are primarily preserved germplasm, live and dry plants, cultures and preservation data. Storage products should be duplicated in multiple locations to ensure security [13].

Ex situ conservation

Ex situ conservation is the conservation of components of biodiversity outside their natural habitat. These include field gene banks, tissue culture, greenhouses, cryopreservation, seed gene banks, etc. *Ex situ* conservation allows crops to be reintroduced in areas that have been lost due to environmental degradation, substitution, or war and stored materials are readily retrievable and accessible. It is well documented, characterizable and evaluable and relatively secure against external threats. There are various *ex situ* preservation methods for the long-term preservation of plant genetic resources, but seed preservation is the most suitable. This involves drying seeds to low moisture levels and storing them at low temperatures. For vegetative propagated, resistant seed species (seeds that rapidly lose viability and cannot tolerate drought), live plants can be kept in field gene banks and/or botanical gardens. Botanical gardens are recommended for breeding rare species. It ensures freedom from pest infestation and disease. However, it is very time-consuming and costly. They also have a limited amount of genetic variation that can be stored, making them vulnerable to natural and man-made disasters. Biotechnology has created new ways to preserve genetic resources [14].

In vitro culture and cryopreservation techniques of conservation have made it possible to collect and preserve genetic resources, especially from species that are difficult to preserve as seeds. Cryopreservation (storage in extreme freezing conditions) allows many species to be preserved for very long periods and is performed using liquid nitrogen at -196°C. However, it is very expensive to maintain and requires a constant supply of liquid nitrogen. DNA and pollen conservation also contribute to *ex situ* conservation [15].

In situ conservation

In situ, conservation is the identification and management of protected areas that allow species to remain in ecosystems within a natural or well-managed ecosystem continuum. This conservation method is important for crop wild relatives and a variety of other crops, especially arboreal and forest species for which *ex situ* conservation methods have limited effectiveness. This allows the species to be preserved in conditions that allow it to continue to evolve. *In situ* conservation includes two main concepts and/or techniques that can be distinguished as 'genetic reserve conservation' and 'on-farm conservation'. Both are about maintaining genetic diversity at the site where it occurs. However, the former mainly deals with wild species in natural habitats/ecosystems, while the latter deals with species cultivated in traditional agricultural systems. Identifying, managing and monitoring the genetic diversity of natural wild populations within defined areas designated for active and long-term conservation is called the conservation of genetic reserves. An example of this approach is the establishment and management of forest reserves, particularly in areas of high biodiversity [16].

On-farm conservation refers to the conservation of genetic diversity in locally evolved crop varieties (landraces) with associated wild and weed species or forms by farmers within traditional agriculture, horticulture or farming systems. It is about managing sustainably and farmers play a key role in this effort through plant material selection techniques that influence the evolutionary process and decisions about whether to proceed with a particular landrace. Plant populations on farms have the capacity to support a greater number of rare alleles and different genotypes. The main drawbacks are the difficulty in characterizing and evaluating crop germplasm and vulnerability to hazards such as extreme weather conditions, pests and diseases. Successful agricultural conservation requires a deeper understanding of the crop populations in the agricultural systems that produce them in order to generate positive co-operation between farmers and conservationists. Complementary application of different *ex situ* and *in situ* techniques is recommended to adequately preserve the full genetic diversity of a target species or gene pool [17].

Ex situ genetic conservation challenges

Ex situ conservation of wild plant species by seed banks has been employed over the past 40 years as a conservation strategy to preserve the biological and genetic diversity of wild plants. However, it is argued here that *ex situ* collection may be ineffective in preserving genetic diversity and treating the collection of genetic variation for seed banks is a problem due to an efficient sampling of neutral allelic genetic polymorphism limitations on the types and organization of genetic variation present in wild plant species. When considering evolutionary change, we need a perspective on genetic variation, from neutral alleles to quantitative variation. Quantitative genetic variation and genetic correlations determine the extent and form of the response of polygenic traits to natural selection. The extent of quantitative genetic variation or genetic correlated structure suggests that different populations respond differently to the influences of natural selection and are therefore unique evolutionary entities. Adverse selection of individual traits can lead to indirect selection of genetically correlated traits, leading to phenotypic changes and reduced genetic diversity. The interaction between genotypes and the environment may affect the success of releasing seed bank genotypes into natural populations, as seed bank material may include genotypes with high relative fitness in the introduction habitat. Such measures may lead to the introduction of non-adaptive genotypes that affect population fitness. This is because not all types of genetic variation are strongly positively correlated [18].

According to Andreas Enslin, the problems is *ex situ* collection are

- Genetic representation of wild populations in collections, the appropriate sampling population strategies across the species range.
- Genetic erosion and divergence from wild-origin populations in collections over time.
- Reduced fitness in limited collections, possibly due to genetic drift and inbreeding suppression.
- Adaptation to the environment or loss of adaptation to the original natural environment.

Fitness decline in *ex situ* collections.

The theory of population genetics stated a high probability of decline in fitness for small and isolated plant population. Environmental pressures such as replacement, fragmentation habitat destruction and pollution limit or reduce the size of plant populations which is implications for the association of potential genetic risks with endangered small populations, particularly from inbreeding and genetic drift due to the small *ex situ* population size [19].

Genetic drift affects diversity by changing the distribution of genetic variation in two ways: (i) Reduced intrapopulation variability (loss of heterozygosity and eventual allele fixation) and (ii) Increased differentiation between populations. Inbreeding increases homozygosity within a population. In general, smaller populations should lose heterozygosity faster than larger populations.

Inbreeding is the mating of related individuals. Plants are usually inbred in two ways: (i) By self-fertilization; and (ii) By bi-inbreeding. The most extreme form of inbreeding, self-pollination can be prevented in plants by self-incompatibility or dioeciousness. Bi-inbreeding is most likely to occur when the population is small or when the population has a spatial genetic structure. Structure often occurs when gene distribution across pollen and seed is spatially restricted. Growing plants *ex situ* exposes them to new or new environmental conditions. This inevitably leads to a change in selective pressure due to the new environment, most likely leading to a loss of the plant's adaptive response and adaptation to the original environment. Therefore, there is great concern that plants in *ex situ* collections will adapt rapidly to artificial growing conditions while at the same time losing their specific and possibly costly adaptations to wild habitats that are no longer selected in *ex situ* habitats. Ultimately, as a result, *ex situ* cultivated plants may be less well adapted to their original environment and less suitable for their intended purpose of reintroduction into the wild [20].

Conclusion

The genetic variation among individual varieties or populations within a species crucial for plant performance and adaptation to climate change, as it provides resistance to biotic and abiotic stresses. Loss of genetic diversity reduces local adaptation revealing the plant to stresses and increase the risk of extinction. The genetic variability status and genetic erosion were highly affected by a deliberate artificial selection for better-yielding modern varieties which narrow the genetic base of the crop cultivar making a homogenous population. Hence plant genetic resources have to be conserved through efficient techniques for the long-term utilization of materials for plant improvement.

The review highlights the challenges of fitness decline, trait changes, and loss of stress responses in *ex situ* plant collections. Genetic drift is likely the dominant force, but more studies are needed to understand species and collections. Botanical gardens must be aware of threats to conservation potential and optimize protocols to ensure suitable plant material for reintroduction into the wild.

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