***Review Article***

**Sowing the Seeds of Security: Unravelling Genetic Diversity for Sustainable Crop Improvement**

**ABSTRACT**

Genetic diversity, encompassing the variety of genes within a species, is crucial for feeding humanity and stands as a cornerstone for crop improvement. It aids in adaptation of crops to the changing environmental conditions, resistance to pests and diseases, and the development of resilient, high-yielding crop varieties. Now-a-days breeding practices focus mainly in development of high-yielding varieties, which inadvertently diminishes genetic diversity within crops. On the other hand, cultivation of monocrop or few varieties in larger scale makes the crops vulnerable to new strains of pathogens and pests which will impart immediate pressure on food security. This reduction in genetic diversity poses risks in the context of climate change, where diverse gene pools increase the likelihood of plants being tolerant to new conditions. The adaptability conferred by genetic diversity becomes crucial during unpredictable weather patterns and emerging agricultural challenges. In the face of a burgeoning world population and climatic uncertainties, comprehending the intricacies of genetic variation becomes paramount. As the current rate of genetic gain is insufficient to meet the future food requirement to feed the ever-growing population, new strategies need to be devised. This chapter illuminates the pivotal role of genetic diversity in enhancing crop improvement strategies and its impact on adaptability, resilience, and productivity of crops across diverse agroecosystems. Unravelling the genetic tapestry empower researchers, practitioners, and policymakers with insights crucial for steering agriculture toward a more sustainable and food-secure future.

***Key words :*** *Biotechnological tools, Crop improvement, Genetic Diversity, Food Security.*

**1.INTRODUCTION**

Evolution in plants either directed by humans or nature is based on amount of genetic diversity available. Genetic diversity is described as amount of variation present within and between the plant species. Presence of this diversity will act as base, on which plant breeding activities are carried out for attaining sustainability or food security. If there is 0 diversity, means no difference between plants, then there is no way to improve them. Having similarity also leads to vulnerability of crop. Since the beginning of agriculture, humans are exploiting the existing natural variation to meet the requirement of humans. Few practices in plant breeding such as 1) Selecting superior traits and leaving undesirable traits, which might be useful in future 2) Using only few parents repeatedly in hybridization program. These factors have led to decrease in genetic diversity and promoted uniformity, which is dangerous to food security or sustainability. So, now it is the time to focus on conserving and improving genetic diversity to obtain improved crop varieties which can compete the fluctuating climatic conditions and as well increasing population. They serve as potential source as they govern favourable alleles which is responsible for tolerance of various biotic and abiotic stress conditions. In context of this , today we are going to present in detail about genetic diversity, how it plays role in crop improvement and attaining food security , what factors affect genetic diversity, how to conserve genetic diversity along with various strategies for improving the genetic diversity usage in plant breeding .

**2.CONCEPT OF BIOLOGICAL DIVERSITY**

Biological diversity is defined as presence of variation between and within the genotypes of living world, which is essential for improvement of crop plants. Biological diversity is categorized into three major components, which include 1) Genetic diversity 2) Species diversity and 3) Ecosystem diversity, which are described in Fig.1**(Hodgkin *et al*.2015; Li *et al*.2023)**

Genetic diversity



Variation of genes within a species or population.

Species diversity



Variety of different species within an area or ecosystem.

Diversity of ecosystems, habitats, and ecological processes

Ecosystem diversity



Fig.1 Components of Biological diversity

**3.GENETIC DIVERSITY**

Genetic diversity refers to various genetic characteristics present within a particular crop or species, encompassing the range of genetic traits exhibited. Meanwhile, genetic variation represents the differences in genetic makeup among individuals pertaining to specific traits, which are seen in one or more DNA sequences. The assessment of genetic diversity often involves scrutinizing variation in DNA sequences across a population of individuals **(Choudhury *et al*.2014; Bhandari *et al*.2017).** It is this genetic variation that give rise to phenotypic diversity, representing the observable differences in traits within a given population.

“Definition of genetic diversity by Swingland”

Genetic diversity referred to availability of variation in heritable characteristics of species within the same population. **(Swingland, 2001)**

**4.IMPORTANCE OF GENETIC DIVERSITY IN CROP IMPROVEMENT**

Genetic diversity serves as a crucial for the survival of plants both in their natural habitats and in agricultural contexts. Presence of diversity in various plant genetic resources, provids a chance to plant breeder to create novel and improved varieties exhibiting desirable traits. These traits encompass having higher yield, resistance to various biotic and abiotic factors. Since agriculture started, plant breeders are using or exploiting natural genetic variability of various crops in order to meet the food demand of population. Over a period of time, this focus has expanded with an emphasis on enhancing both yield and nutritional quality to meet the requirement of balanced diet. Increasing stress due to changing climate, creat an urgency to develop climate-resilient crop varieties. The rich genetic diversity present in the form of germplasm, landraces and wild relatives serves as a valuable reservoir of favourable alleles for enhancing climate resilience through breeding programs. To create climate-resilient varieties breeders need to incorporate desirable alleles or new traits which offer tolerance to biotic and abiotic stresses posed by changing climate. To address evolving breeding objectives, it is essential to conserve the variability that existing between various source of diversity in the form of germplasm resources. These diversity enables breeders to select superior genotypes which can be released for direct use as new varieties or as parent material in various breeding programs.

Having diversity between parental lines will help in selecting distinct parents for hybridization through which heterosis and transgressive segregants can be obtained, where the obtained individuals will exhibit traits exceeding those of their parents. This diversity will even enable the creation of new lines for non-traditional uses such as biofuel production. Having diversity will help the plant to adapt to diverse environments and sustain changing climatic conditions. A list of germplasm lines with desirable gene of various crop species are presented in Table 1.

Table 1 List of Landraces with desired trait gene or QTL in various crops

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Crop | Landrace | *QTL/Gene* | Trait | method | referance |
| Abiotic stress | | | | | |
| Wheat | G61450 (Greece) | *Bo4* | Boron tolerance | Molecular mapping | Paul *et al*.1992 |
| Rice | FR13A (India) | *SUB1* | Submergence tolerance | Molecular  mapping | Xu *et al*.1996 |
| Rice | Aus, Indica, and Basmati accessions (India) | *14 QTLs* | Drought tolerance | Molecular mapping | Kumar *et al*.2014 |
| Rice | Nona Bokra (India) | *qSKC-1* | Salinity tolerance | Molecular  mapping | Ren *et al*.2005 |
| Rice | Kasalath (india) | *PUP1* | Phosphorus  Uptake increase | Molecular  mapping | Wissuwa *et al*.2001 |
| Barley | TX9425 (China) | *2QTLs* | Drought tolerance | Molecular mapping | Fan *et al*.2015 |
| Barley | TX9425 (China) | *1 QTL* | Salinity tolerance | Molecular  mapping | Fan *et al*.2015 |
| Barley | TX9425 (China) | *1 QTL* | Salinity and waterlogging tolerance | Molecular  mapping | Xu *et al*.2012 |
| *Biotic stress* | | | | | |
| Wheat | AUS27858 (Australia) | *Yr51* | Stripe rust resistance | Molecular mapping | Randhawa *et al*.2014 |
| Tetraploid wheat | Accessions from diverse geographic area | *22 QTLs* | Stem rust resistance | GWAS | Saccomanno *et al*.2018 |
| Durum wheat | PI192051 (Portugal) | *2 major and 3 minor QTLs* | Leaf and stem rusts resistance | Molecular mapping | Aoun *et al*.2019 |
| Rice | Tetep (Vietnma) | *Pi54* | Blast resistance | Molecular  mapping | Rai *et al*.2011 |
| Barley | Landrace255(ICARDA No.ICB31956) (Morocco) | *MlMor* | Powdery mildew resistance | Molecular  mapping | Piechota *et al*.2019 |
| Barley | Ethiopian and American accessions | *51QTLs* | Leaf scald and net blotch | GWAS | Daba *et al*.2019 |
| Maize | Kemater Landmais Gelb/Petkuser Ferdinand Rot (Germany) | *8 QTLs* | Gibberella ear rot | GWAS | Gaikpa *et al*.2021 |
| Maize | Pepitilla (Mexico) | *Htn1* | Northern Corn leaf blight | Map-based cloning | Hurni *et al*.2015 |
| Oat | Spanish accessions | *6 QTLs* | Crown rust and powdery mildew | GWAS | Montilla *et al*.2015 |

**5.SOURCES OF GENETIC DIVERSITY**

Genetic resources have been categorized by **Frankel (1977)** and the Food and Agriculture Organization **(FAO, 1983)**

Various sources of plant genetic diversity include.

1. land races
2. wild relatives of cultivated species
3. obsolete cultivars: cultivars of recent past
4. modern cultivars: used currently
5. advanced breeding lines
6. Genetic or cytogenetic stocks

These are briefly discussed below:

**5.1 Landraces**

Landraces, as described by **Harlan (1975)**, are resources that evolved within agricultural societies due to manmade selection influenced by factors such as natural selection, migration and exchanging seeds. These landrace varieties, distinct from the crops prevalent in modern agriculture, emerged through generations of natural selection and the practice of farmers saving diverse seeds annually. Lacking formal breeding efforts in landraces leads to exhibit high level of genetic diversity and shows resilience to various stresses, including abiotic factors like high temperature, drought, and salinity, as well as biotic factors such as pests and diseases. Despite their advantageous traits, landraces suffer from a lack of uniformity, resulting in reduced yields compared to modern cultivars. Over the past centuries, with the pursuit of higher yields and the industrialization in agriculture have led to the disappearance of many ancient landrace varieties from fields. Today, remnants of these traditional landraces are preserved as accessions in gene banks worldwide.

**5.2 Obsolete Cultivars**

Obsolete cultivars are varieties of recent past, that were developed through planned breeding programs, but recently released varieties overtook their position by replacing them. Now they are no longer in cultivation and restricted only to gene pool. In gene pool they do serve as valuable resource for several desirable traits and have been utilized in breeding programs. Example of obsolete cultivar includ wheat varieties such as K65 and pb 591 were popular tall varieties before the introduction of high-yielding semi dwarf green revolution lead wheat varieties.

**5.3 Modern Cultivars*:***

Modern cultivars, also known as improved or advanced cultivars developed through scientific plant breeding efforts, which are currently cultivated high-yielding varieties for modern intensive agriculture. These cultivars exhibit high yield potential and uniformity compared to obsolete varieties and landraces. The average life of modern varieties is relatively short (5 to 10 years) where they are replaced by more recent products of breeding programs. Despite their advantages, modern cultivars often have a narrow genetic base and lower adaptability compared to landraces **(Salgotra *et al*. 2023).**

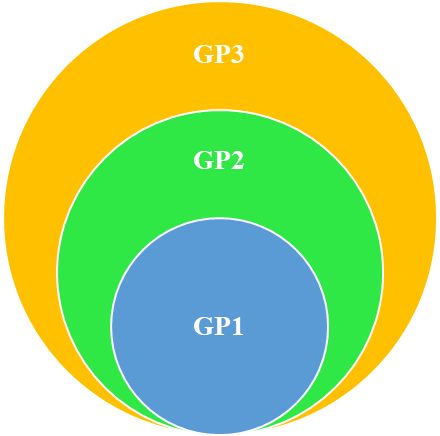
**5.4 Advanced Breeding Lines:**

Advanced breeding lines are yet to release plants which are developed through advanced scientific breeding programs. These lines are nearly homozygous and obtained through various biotech approaches, which contain desired genes. They can play a crucial role in breeding programs by being as a part of their working stocks. Breeders develop many lines in their breeding program, but only a few of them will be released for commercial production.

**5.5 Wild Forms and Wild Relatives:**

Wild relatives of cultivated species are natural plant species that share a common ancestry with crops. These are not domesticated and differ in degree of relationship with that of cultivated crop. However, many wild forms of crop species are now extinct due to habitat loss and other factors. Based on their ability to cross and transfer genes to that of cultivated crops, they are categorized into three groups (Fig.2).**(Begna *et al*. 2023).**

* Primary gene pool: Where both crop and wild relatives can intercross easily to transfer genes.
* Secondary gene pool: Here crop can intercross with wild relatives, but obtained hybrid will be sterile. Transfer of genes is difficult , but not impossible



**Tertiary pool**: Transfer genes through special techniques

**Secondary pool**: Some barrier in intercrossing

Hybrids are sterile or weak

**Primary pool**: Both Cultivar & Wild can cross easily

Fig.2 Concept of gene pool based on hybridization.

* Tertiary gene pool: Here making intercross is difficult, and transfer of genes can be done using advanced biotechnological techniques, such as transformation, gene editing etc. These advanced techniques help in transfer of genes from any species.

**5.6 Genetic or cytogenetic stocks:**

Genetic stocks include lines which are differing for single gene or single trait (morphology or molecular differences), they are artificially generated or natural variants. They have less commercial value. They serve as important germplasm resource for plant breeding activities. Cytogenetic stocks contain all variants of lines which have undergone various structural (deletions, duplication, translocation, and inversion) and numerical chromosomal aberrations (Euploidy and aneuploidy). These are important in determining location of genes. **(Gill, B. S. 2022)**

Examples of wild species with desired traits in various crops are given in Table 2.

Table 2 List of wild species with desired traits

|  |  |  |  |
| --- | --- | --- | --- |
| Crop | Trait tolerance | Wild species | Source |
| Tomato | Drought, Salt and Heat tolerance | *Solanum habrochaites* (syn.*Solanum hirsutum*) *S.pennellii S.pimpinellifolium* | Foolad *et al*.1998  Ram *et al*.2005  Gonzalo *et al*.2021 |
| Alfa-alfa | drought, salt, cold tolerance | *Medicago truncatula, Medicago polymorpha* | Young *et al*.2011  Cui *et al*.2021 |
| Cowpea | Drought and heat tolerance | *Vigna exilis,*  *Vigna hainiana* | Naito *et al*.2022 |
| Groundnut | Drought, heat and salinity | *Arachis diogoi,*  *Arachis duranensis, Arachis glabrata* | Vinson *et al*.2018 Rampuria *et al*.2022 |
| Apple | Drought, heat and cold | *Malus prunifolia ,*  *Malus sieversii* | Li *et al*.2015  Volk *et al*.2015 |
| Cranberry | cold tolerance | *Vaccinium oxycoccos* | Kawash *et al*.2022 |
| Grapevine | Drought tolerance | *Vitis yeshanensis* | Cui *et al*.2022 |

**6.FACTORS AFFECTING GENETIC DIVERSITY**

Genetic diversity is created due to crossing that occur during sexual recombination. The created genetic diversity is affected by several evolutionary factors , which include mutation, selection, migration and genetic drift. These factors will lead to change in the frequency of alleles in the population, there by affecting genetic diversity**(Ray *et al*.2015:** **Mohanty *et al*. 2024)**. Description of various factors is given below :

**6.1 Mutation:**

Mutations are defined as sudden heritable changes there by resulting changes in the sequence of DNA. Mutation will increase the genetic diversity , mutation that occurring in the genes which are quantitative in nature will lead to abrupt changes in morphology , which is eliminated over a period of time. But mutations in quantitative traits will be of small in nature and there by accumulate over a generation, which lead to evolutionary changes or creating new variation. Variation created by mutation can lead to have positive, neutral or negative effect on the plant leads to change in the frequency of alleles in the population .Spontaneous mutations have contributed significantly in creating genetic variation, which is essential for food security. Changing climate conditions can increase the rate of mutations, which cause increase in rate of evolutionary changes, by causing various structural and numerical chromosomal aberrations, creating copy number variations etc. .Previously, plant breeders relayed on existing variation created by natural or spontaneous mutation, through advancements, now mutations are induced through mutagenesis. Mutation breeding is done in order to create the desirable variation, which was absent in plant genetic resources or to enhance the frequency of desirable genotype. By mutation breeding , breeders are able to broaden the genetic diversity, through which they will be able to compete upcoming with challenges**(Salgotra *et al*.2023).**

**6.2 Selection**

Both domestication and artificial selection , will favour in presence of certain desirable traits, it will lead to increase the frequency of that particular trait in whole population. Because of domestication , genetic diversity decreases as compared to that of wild . Even natural selection do effect the allelic frequency of population. Both directional selection and stabilizing selection will decrease the genetic diversity , Whereas disruptive selection will increase the genetic diversity. Selection will operate on phenotypic expression of the plant and create variation , inheritance of these variation depends on two things , one is heritability and the other is environment interaction. Selection can be effective only if there exist genetic variation. Even improvement can be attained only if there exist genetic variation and if we know its association with various other traits. For example , if we know the correlation or association of major trait such as yield with several other traits, it will help us in indirect selection for yield and other traits can be selected at a time. Having genetic variation also help in selecting parents for hybridization **(Bhandari *et al*.2017; Salgotra *et al*.2023)**

**6.3 Genetic drift**

Loss of alleles which are in smaller frequency from the population constitutes genetic drift. This will lead to decrease in genetic diversity in the population. It is completely a random process, where we can’t predict any pattern. Changes become increasingly predictable when the population size is large enough. According to **Masel (2012)**, genetic drift results from what he terms as "accidents of sampling,". In everyday language, sampling typically involves selecting individuals from an existing population, as seen in scenarios like founder and bottleneck effects. This situation represents taking small subset which means sample from a population which is large, which later on evolve separately. Sampling don’t create any allelic variation in the population . Allelic variation is created due to crossing over or mutation. Genetic drift acts on this population on which allelic variation is created **(Klymkowsky, M. W. 2023).**

**6.4 Mating system**

The kind of mating system will affect the genetic diversity. If a population undergoing inbreeding, it eventually leads to decrease in genetic diversity. If it undergoes cross pollination, it will increase genetic diversity due to crossing over and recombination .

**6.5 Physical distance**

Distance between individuals of a species will determine genetic diversity , if the physical distance is large , then those two species cannot be same.

**6.6 Hybridization**

Certain techniques such as wide hybridization or somatic hybridization, creating hybridization between incompatible genotypes or introgression, all these techniques will lead in genetic diversity. As the above process will lead to creation of new phenotype

**7.CONSERVATION OF GENETIC DIVERSITY**

In the beginning of agriculture itself, people started collecting and conserving locally adapted crops termed as landraces. It continued till the rediscovery of “Mendal’s” findings, which lead to development in plant breeding and promoted to work on high yielding and stress tolerant varieties for biotic and abiotic factors. Later on, green revolution took place .Which exponentially increased the yield ,but mostly led to monoculture farming by replacing land races. Now more than 75% genetic diversity in genetic resources and 90% landraces are replaced from farmer’s land. This creates an urgent need to conserve the existing genetic resources. There are various organizations dealing with conservation and utilization of genetic resources , which are explained below **(Panis *et al*.2020;FAO,2004).**

**7.1 International Treaty on Plant Genetic Resources for Food and Agriculture*….***

ITPGRFA became functional or came into force in 2004, it is working along with CBD. It helps in attaining sustainability and long-term food security. It will look after conservation and utilization of genetic resources for promoting crop improvement and equitable profit sharing based on benefit attained through use of plant genetic resources. Conservation and utilization of genetic resources is crucial for attaining sustainability in food security or for crop improvement or in order to compete with these fluctuating climatic conditions.

**7.2** **Nagoya protocol**….

It became functional in 2014. It deals with ease access of genetic resources and utilization there by promote crop improvement, equitable sharing of benefit obtained through utilization of genetic resources. It provides funding for conservation of genetic resources.

**7.3 Svalbard Global Seed Vault**

This seed vault is present in Norway and taken care by Norway government. It contains duplicates seed of almost all varieties of the world. It will act as backup , if there are sudden disasters in areas where traditionally seed is stored. An online public database is available to get information about stored seed in the vault. It offers long term protection; it is one of important resource in the world. It is mainly meant for backup and securing seed for future generations.

**7.4** **The Cartagena Protocol on Biosafety**

It deals with proper handling of genetic resources , mainly in those organisms which are genetically modified. Its work is to look after safe handling and transport of living modified organisms(LMO) which cause threat towards genetic diversity. They should also look after the risk posed on humans through modified organism developed by advanced biotechnological techniques.

Increasing food demand followed by changing climatic conditions, made everyone to think about conserving PGRs for future food security(**Srujana *et al*. 2024**). Conserving PGRs which include wild relatives, landraces, obsolete varieties, modern lines etc. whose use in plant breeding will help in attaining sustainability. Conserving PGRs is an international issue , that made everyone to sign on Convention on Biological Diversity at Rio de Janeiro summit (1992). Reduction in genetic resources and their importance in agriculture along with their conservation is discussed in this summit. CBD is made to perform, Conservation and utilization of genetic resources for attaining sustainability, it also deals with equitable profit sharing of benefit attained by using genetic resources. There are several methods through which genetic diversity is conserved which include : (Fig.3)

1. In-situ conservation
2. Ex-situ conservation
3. Biotechnological approaches

**7.5** **In-situ conservation**

In case of in-situ conservation , plant species are conserved within the area of their habitat. This will give species an advantage of growing in their original habitat. Here plant species are conserved with minimalistic disturbance or human interference . It will promote evolution of genetic diversity, in order to create new variation. There are two types in in-situ conservation,1st one is farm or field conservation , 2nd is Genetic reserve conservation. In farm conservation, they grow traditional varieties and landraces, whereas in genetic reserve conservation they grow wild relatives of original habitat, they keep boundary marking to indicate region such as forest reserves etc. Even in farmers field they grow certain genetic resources and do selection, thereby promoting evolution. In in-situ conservation, open pollination takes place between various genotypes and increases genetic diversity by creating new combinations. Both in-situ and ex-situ conservation should be used hand in hand to make effective conservation **(Ogwu *et al*.2014; Rajasekharan *et al*.2015)**



Release of new variety

Explore and collect the Plant genetic resources

Characterization and Evaluation of genetic resources

Conservation of genetic resources

Ex-situ

Conservation

In-situ

Conservation

Seed bank

Cryopreservation

Invitro culture

DNA bank

National park

Biodiversity hot spots

Field farm

Utilizing genetic resources for crop improvement

Characterization and evaluation of genetic resources



Release of improved variety

Fig.3 Various steps involved in conservation of plant genetic resources

**7.6** **Ex-situ conservation**

In ex-situ conservation, plant species are kept or conserved outside from natural habitat. Such species which are over exploited, endangered by human interference are conserved away from habitat, which may undergo degradation and will make genetic resource to extinct. Ex-situ conservation is done by various methods such as seed storage, invitro propagation or cryopreservation etc. Among all seed storage methods invitro propagation is most preferred as it promote long term storage in less space and easy handling. Orthodox seeds are most preferred as they can resist low temperature storage **(Panis *et al*.2020).**

Conservation of seed takes place in two methods one is base collection, where seed is stored for long period of around 100 yrs. Temperature ranges around -180  to -200 C. Moisture content ranges between 3 to 7 %.Seed is stored until there maximum viability. And the second one is Active collection, where seed is stored for short period of 10 to 20 yrs. Temperature ranges between 50 to 110 C. Based on storage, they are divided into 3 types 1) Long term storage – storing as base collection for long time at temperature of -180 to -200 C. 2) Medium term storage – where period of storage is less than 5 yrs., with temperature of 00 to 100 C . 3) short term storage is for 1 or 2 yrs. with temperature of 220 to 24 0 C. For long term storage at low cost, seed storage is best option. But it involves storing low temperature and reducing the moisture content. But recalcitrant seed can’t be stored at such low temperature. Ex-situ conservation preserves many of the PGRs or diverse rare alleles, which help in attaining food security for future. List of some important wild species along with traits presented in Table. 2**( Long *et al*.2003)**

**7.7 Biotechnological approaches :**

Various biotechnological approaches are providing unique opportunities for conservation. Technique such invitro culture , tissue or plant culture will help in storage or transportation these plant genetic resources. Micropropagation or tissue culture is being used for mass multiplication of varieties . These invitro culture techniques help in aseptic transfer of material. Apart from NGS , various biotech approaches of cryopreservation, gene editing , genetic engineering will help in precise conservation of germplasm . These techniques will also conserve vegetatively propagated material along with forest or wild species . Some plant material cannot be propagated or conserved using traditional conservative approaches, it can be conserved using techniques such as cryopreservation, invitro culture etc. Some species possess reproductive barriers, they can overcome by using biotechnological tools. There are various methods which comes under biotechnological approaches which are used for conserving germplasm are explained below **(Cruz-Cruz *et al*.2013).**

**7.7.1 Invitro culture**

Invitro propagation is growing plant species in artificial media. It is most trusted by global agencies, as it promote phytosanitary transport. It is mainly advantageous because it is free from biotic factor such as pest and diseases, less space required, less time , easy to handle . It promote mass multiplication for whole round of the year. In this method callus is obtained by culturing explant, which could be leaf, shoot, seed, etc. This will further regenerate into a whole plant. Once the culture is established , it can be obtained in enough quantity through continuous subculturing in fresh media. However continuous subculturing may lead to risk of microbial contamination ,which may create somaclonal variations.

As a first step, developing successful stable plant and propagating is necessary for conservation. In-order to prevent somaclonal variation, shoot is taken as explant, which promote slow growth. Slow growth propagation help in medium term storage of 15 yrs. Using different techniques such as low light, reduced supply of oxygen and growth retardant will help in attaining slow growth **(Salgotra *et al*.2018).**

**7.7.2 Cryopreservation**

In this technique plants are stored at extremely low temperature of -1960 C mostly in liquid nitrogen .At this temperature all metabolic process such cell cycle etc will cease . There by it promotes long-term preservation. It is one of the cost effective and best technique , we can conserve any kind of material for long duration. There is no subculturing , so no somaclonal variation generated. We can even implement cryotherapy technique , to prevent pathogen from material. For that we use meristem as explant, which has high dividing capacity and pathogen free material. In the 1st step freezable water content is removed from tissue through osmotic dehydration. Then it is subjected to ultra-fast freezing. Freezable water can be removed by vitrification, in which water is prevented from crystallization by converting into amorphous in nature **(Kaviani *et al*.2011).**

**7.7.3** **DNA gene-bank**

Conserving DNA is one of the cost-effective methods of storing PGRs. It is considered as one of the important alternatives, as it preserves any material , even it is near to extinction. It is very difficult to preserve all kind of material , mainly which are near to extinct due to climatic and human made disturbance. DNA of such material can be easily preserved in DNA libraries. It can be preserved as DNA, cDNA, RNA in libraries. Preserved genetic diversity contains all the alleles which can be used in future breeding program. At -200C it can be preserved for short duration of 2 yrs., for long term storage it need to be preserved at -700C in liquid nitrogen. Like other we cannot propagate or reconstitute whole plant in this method. We need to transfer whole DNA into somatic cell and propagate in tissue culture **(Pandotra *et al*.2015)**.

**8. RELATIONSHIP BETWEEN GENETIC DIVERSITY AND FOOD SECURITY**

If we see traditional or conventional or modern plant breeding approaches, genetic diversity is considered as important resource to promote sustainability and food security for now and even in future . Having genetic diversity in crops , provides ability to withstand various biotic and abiotic stresses such as pest, diseases, climatic fluctuations etc. A variety performing well under drought, poor soil conditions, giving good yield under pest attack or adverse climatic conditions is mainly due to presence of genetic variation in that crop. These genetic resources is further used up in various plant breeding activity to develop a superior variety . Without genetic diversity, thinking about long term sustainability or food security is meaningless. Farmers in developing countries are mainly responsible preserving this genetic diversity , which is crucial in providing food, nutrition and sustainable livelihood. In fact, global food supply relays on conserved genetic diversity by local community , farmers and people who are residing in the regions near to the centre of origin and diversity of genetic resources **(Sufiyan *et al*.2022).**

**9. ROLE OF GENETIC DIVESITY IN PROMOTING FOOD SECURITY**

Around seven thousand plant species are being consumed by human beings , in that 150-160 plants have commercial importance , 110 plants constitute 90% of the human food intake. Crops such as Rice, Wheat, Maize constitute 60% of both protein and caloric intake. Loss of genetic diversity will affect global food security , due to adverse climatic conditions. It will even increase risk at individual farmer level, as it affects sustainability of agriculture. Genetic diversity will help in successful running of plant breeding , by providing variation to develop new and improved varieties with desired characteristics. Genetic diversity is pooled up with various desirable genes, which will play critical role in providing sustainable production and nutritional diversity across wide range of fluctuating temperatures. Even though wild relatives of cultivars are agronomically undesirable, they do possess many useful or desirable genes , using them in plant breeding help in providing resistance pest, diseases etc. They are even good source of various quality and nutritional traits. In current scenario of reduction in food production and declined genetic diversity will directly impact global food and nutritional security of economically weaker sections of the society. So it is advised to carefully preserve and wisely use the existing genetic diversity **(Sufiyan *et al*.2022).**

**10. STRATERGIES FOR USING GENETIC DIVERSITY IN CROP IMPROVEMENT**

How can we improve production of genetic diversity, such that it will be suitable to meet the demand created through changing climatic conditions? For that we are supposed to incorporate novel strategies . One of such strategy is visualization of genetic diversity for ideal phenotype (VGDIP). In normal genetic diversity analysis , we evaluate all the lines in each population of all PGR. Later on, we narrow down selection, which lead to elimination of many undesirable genotypes, which are useful in next generation . Through VGDIP , we are going to control genetic diversity, which promote 1) increase in genetic diversity 2) at the same selecting superior phenotype 3) Going to balance various traits within the genotype(Fig.4,5)**(Ikegaya *et al*.2023).**

Qualitative traits which governed by few genes were easily modified and improved. But quantitative traits, which governed by many genes will be difficult to modify or improve . In that situation, marker assisted breeding will help to solve the issue. To improve management of genetic diversity, where utilization of germplasm is time consuming, as it involves steps such as Collection, evaluation, conservation and distribution. Use of genetic engineering, or approaches such as forward genomics and reverse genomics will help to overcome problems associated with normal conventional breeding.

**11. CONCLUSION**

Agriculture is facing issue with rapid expansion of population on one side and reduction in cultivable land on other side. However, advancement in plant breeding has attained certain amount of success to meet it. But this has led to narrowing genetic diversity, it may end up with genetic vulnerability in future. Now there is urgent need for plant breeding to shift its focus towards genetic diversity. Genetic diversity plays a very key role in offering desirable gene to promote sustainability in long term food security. Detail understanding of genetic diversity is necessary , which will help us to know what to conserve and where to conserve. Conservation of genetic resources is the prior concern of both national and international societies. Proper conservation by preventing loss of genetic resources from erosion will help in preserving endangered species with desirable alleles. Financial support should be provided to farmers and local communities which involve in preserving of genetic diversity. Biotechnological tools should be used for characterizing the germplasm which will help in attaining precision. No technique is perfect , so combination of in-situ and ex-situ to be used for effective conservation. Use of Genomics and transcriptomics will help in development of superior genotypes. Current biotech approaches may help in two ways , either creating improved variety by utilizing the genetic resources or creating new variation among the germplasm. VGDIP will help in controlling the genetic diversity and will open up new opportunities for plant breeders to meet future demands.

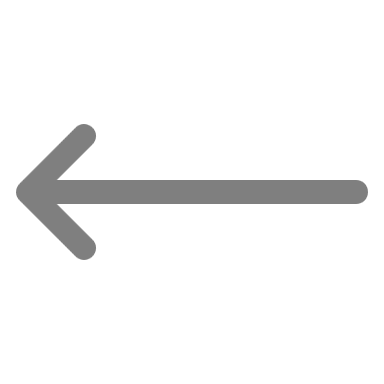
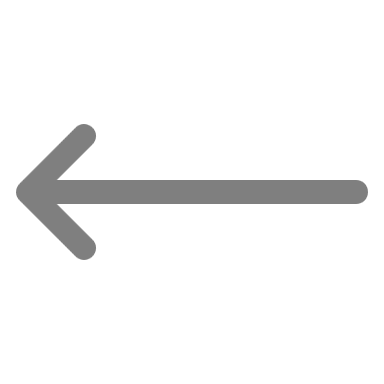
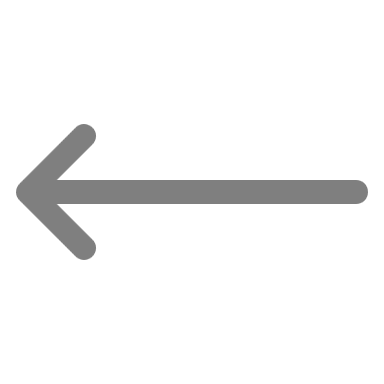


Fig : 4 It represent changes that taking place during evaluation of genetic diversity(Superior genotype is developed ). As per VDGIP we are strategically incorporating lost diversity into the superior genotype.

**Genetic resources**

**Elite line**

**Elite line**

Fig.5 ***Example of VDGIP in rice :*** In the 1st step various germplasms selected from the PGR , 2nd they are crossed in all possible two-way, four-way and eight-way crosses ,3rd step obtained F1 are crossed to that of superior genotype selected through normal diversity analysis **(Ikegaya *et al*.2023).**

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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**ABBREVATIONS**

AVRDC : Asian Vegetable Research and Development Centre in Taiwan

CBD : Convention on Biological Diversity

CIAT : International Centre for Tropical Agriculture in Colombia

CIMMYT : International Centre for Maize and Wheat Improvement in Mexico

CIP : International Centre for Potato in Peru

GWAS : Genome Wide Association Mapping

ICARDA : International Centre for Agricultural Research in Dry area in Syria

ICRISAT : International Crops Research Institute for Semi-Arid Tropics in Hyderabad

IITA : International Institute of Tropical Agriculture, in Nigeria

INIBAP : International Network for the improvement of Banana and Plantain, in France

IRRI : International Rice Research Institute in Philippines

ITPGRFA : International Treaty on Plant Genetic Resources for Food and Agriculture

LMO : Living modified organisms

PGR : Plant genetic resources

VGDIP : Visualization of genetic diversity for ideal phenotype

WARDA : West African Rice Development Association, in Liberia