BioNE
E-ZINE OF BIOLOGICAL SCIENCES
ISSN: 2456-7264 | Issue – 30 | Published On 19/09/2024

GENETIC DIVERSITY AND ITS ROLE IN SUSTAINABLE AGRICULTURE

Himashree Devi*[1], Palki Priya Khargharia[2], Parinita Khargharia[3]

[1]Ph.D scholar
Department of Genetics and Plant breeding
School of Crop Improvement
CPGS-AS, Umiam, Meghalaya, CAU (I), 793103

[2]Ph.D scholar
Department of Plant breeding and Genetics
Assam Agricultural University, Jorhat - 785013

[3]MSc student
Department of Genetics and Plant breeding
School of Crop Improvement
CPGS-AS, Umiam, Meghalaya, CAU (I), 793103

Abstract

Genetic diversity is the basis of evolutionary changes. It is a broad term which comprises all the variability that is occurring among different genotypes that are related to the same species or to distinct species, based on their complete genetic makeup. The plant genetic diversity varies with time and space. The creation of superior cultivars for crop improvement is greatly aided by genetic diversity. Sustainable agriculture minimizes its adverse effects on the environment through the reduction or elimination of toxic compounds such as pesticides and

nitrogen fertilizers, conservation of water and soil, restoration of soil fertility, preservation of agricultural biodiversity, and preservation of overall biodiversity. The genetic diversity of these plants serves as the foundation for continuous development of new crop plant varieties and aids to sustainable agriculture. Growing genetic variety is critical for managing pests and diseases, and offers opportunities for further species improvement. By incorporating adapted natural genetic variations into breeding programs, the current genetic diversity of stress tolerance and improved yield under stress can be enriched. Genetic diversity is affected by different factors like domestication, evolution, gene flow, genetic drift, natural selection, etc. Genetic erosion is the bottleneck which highly affects genetic diversity. Therefore, measures for static preservation of genetic resources are crucial. The plant breeding system is attempting to address the problem of feeding the world's expanding population based on decreasing arable land. For crop plants to sustainably create new types, genetic diversity is essential. In order to use the various genetic resources in the breeding process, it is necessary to characterize them using various statistical tools.

Key words: *Genetic diversity, environment, biodiversity, sustainable agriculture*

INTRODUCTION:

Diversity is the essence of biological world. The variation present in all species of plants and animals, their genetic material and the ecosystem in which they occur is known as Biological Diversity. According to the Convention on Biological Diversity, diversities can be found in three different contexts: genetic diversity (variation in genes and genotypes), species diversity (species richness) and ecosystem diversity (communities of species and their environment). A stable and sustainable ecosystem depends on a higher level of biodiversity. Genetic diversity was defined by Hodgkin and Rao (2002) as the existence of variations in alleles, genotypes, outcome of their performance (phenotypes), and the total sum of the genome.

No two living things are exactly similar to each other, even the maternal twins. Variability is defined as the variation in one or more characteristics of the organism. The study of genetic diversity has been the primary domain of evolutionary biologists for more than 80 years. Contrary to the popular belief, genetic variety and genetic variability are not synonymous terms. Variations in DNA/RNA sequences or gene alleles within the gene pool of a species or population are referred to as genetic variability. This results from different individuals having contrasting gene alleles, which in turn produce different phenotypes. This manifests itself as alternate phenotypic forms. On the other hand, genetic diversity is a broad term which comprises all the variability that is occurring among different genotypes that are related to the same species or to distinct species, based on their complete genetic makeup.

Crop species with narrow genetic variety are more vulnerable to newly emerging diseases and other obstacles, which reduces productivity and causes a significant drop in adaptation areas (Dyer *et al.*, 2014). According to Mohammadi and Prasanna (2003), the broad base of degree of genetic divergence is principally responsible for the success of crop improvement. The creation of superior cultivars for crop improvement is greatly aided by genetic diversity. When two distinct genetic materials are crossed, better results and more acceptable hybrids are expected than crossing two similar genetic materials. The basis of all crop improvement initiatives is the existence of intra- and inter-specific differences. The plant genetic diversity varies with time and space. The extent of genetic diversity and its distribution are determined by evolution and breeding system, ecological and geographical factors, past bottlenecks, and often by many human factors. According to CBD, Article 2, which was defined at the Rio de Janeiro Earth Summit, genetic diversity is the key element of biodiversity and diversity within and between species as well as within ecosystems.

The goal of sustainable agriculture is to minimize negative effects on ecosystems located beyond a field's edge while simultaneously maximizing the productive potential of natural resources. The foundation of agricultural sustainability rests on the principle that we must satisfy our current demands without compromising the ability of future generations. Therefore, new strategies are needed to incorporate ecological and biological concerns into the food production process, reduce the use of non-renewable inputs that harm the environment or the health of farmers and consumers, and effectively utilize the knowledge and skill to solve common agricultural and resource problems. A key component of sustainable agriculture is increasing natural capital, which can be achieved by optimizing the use of existing resources, crop genotype, animal genotypes, and the balanced ecological environments in which they are sustained. Sustainable agriculture gives consideration to long-term interests in preserving topsoil, biodiversity and rural communities, rather than short-term profit interests. It is a dynamic, site-specific strategy process that takes a system-wide holistic approach to solve issues related to farm management. Three primary goals are integrated by sustainable agriculture: environmental health, economic profitability, and social equity.

Genetic variability can be described as the fundamental basis of genetic diversity. For sustainable development of various human activities, diversity is essential. It also plays an important role in the world food supply to feed the world's rapidly growing population. The genetic diversity of crops must be properly protected and conserved in order to enhance the crop productivity through providing the appropriate protection and conservation to genetic diversity. The human population is eventually increasing in an alarming rate and is exceeding beyond the expectation of life standard which caused the scarcity of natural resources (Gholami *et al.,* 2013). For this reason, understanding genetic variability is essential in choosing genotypes for future breeding programmes that can withstand shifting environmental factors including new diseases, pests, and climates. It makes economic and social systems flourish in ways that maintain the cultural diversity of the world's nations while enabling the poorest to meet their food and nutritional needs. It is possible to distinguish between four useful components of genetic diversity: the number of diverse forms (alleles) that are eventually found in various populations, their distribution, their impact on performance, and the overall distinctness between different populations.

Forces affecting genetic diversity:

There are various factors that influence plant genetic diversity. Genetic diversity of population is influenced by a variety of evolutionary forces that alter the genetic frequencies of crop species. These factors include domestication, plant breeding, evolution, mutation, migration, and genetic drift.

Evolution: Agricultural evolution is defined as the evolution of crop plants throughout time as a result of modern breeding techniques, natural and artificial selection (Ray *et al.,* 2015). The current diversity of plants evolved gradually from the oldest and the most primitive species through a process known as evolution (Acquaah, 2009). Evolution is leading to transformation of genetic diversity through gradual processes which finally resulted in the new crop species. Charles Darwin developed the theory of evolution, which states that there is variation that exist in the original population of plants and that over time, the individuals that are best adapted survive and reproduce in larger numbers (*Hodgkin et al*., 1995).

Domestication: Domestication is the process of transforming wild progenitors into cultivated species by continuous selection for desired features in agricultural plants in order to meet human demand (Ray *et al.,* 2015). A few alleles are favoured at the expense of others by domestication or artificial selection, which increases the frequency of the selected alleles. As a result, domestication decreases genetic diversity in comparison to diversity in wild. Plants cultivated for the various desirable qualities that growers desire, throughout a range of agro-ecological conditions worldwide. In the process of domesticating crop plants for adaption, morphological and agronomical traits are altered genetically (Begna, 2020). Natural selection has a significant impact on genetic diversity as well. Disruptive selection boosts genetic diversity while directional and stabilizing selection reduces it.

Plant Breeding: Plant breeding has a significant influence on food production and is essential for global food security. To address the maximum genetic yield potential of the crops, plant breeding depends primarily on the availability of significant genetic variation and the exploitation of this variation through efficient selection for improvement (Pickersgill, 2005). Certain methods, which produce new phenotypes, such as wide-hybridization, hybridization between incompatible types, or introgression from previously isolated populations, can increase genetic diversity. On the other hand, the genetic diversity is decreased by intra-specific hybridization.

Mutation: The primary cause of genetic variety and the original source of genetic variation is mutation. Mutations can change a crop species' genetic makeup in ways that are beneficial, neutral, or harmful to the crop. The sudden heritable changes of genetic diversity that occur occasionally through aberration of genetic materials like DNA, RNA and protein within the cells are known as mutation. Mutation plays a significant role in boosting genetic variety to support the growing human population (Smith, 1989). For sustainable genetic diversity creation, mutation is the main force which uses it in further improvement. Induced mutagenesis broadens the genetic variation whereas conventional breeding approaches narrow genetic variability for improvement. Micro-mutations have smaller and gradual effects which accumulate over time and bring about changes.

Genetic drift: Genetic diversity can be decreased via genetic drift, which can result in the loss of rare alleles.

Migration: Direct transmission takes place via rhizomes in species capable of vegetative reproduction, suckers and other vegetative propagules, as well as seed and pollen distribution. In contrast, migration is the movement of genes from one place to another and results in the mixing of two or more population genes through the dissemination of seeds and pollen.

Gene flow: Gene flow within population increases the genetic diversity as new alleles are introduced.

Selection: Plants are often selected from a population based on their phenotype, which consists of both heritable and non-heritable elements. Crop genetic improvement is contingent upon the type and amount of genetic variability present in the population, as well as the degree to which yield and its constituents are correlated. This allows for the simultaneous selection of numerous yield-related features (Yilmaz and Boydak, 2006). Sufficient variation offers choices from which to choose for enhancement and potential hybridization.

Genetic diversity is also influenced by the physical distribution of the individuals of a species member. The likelihood of individuals having the same genetic makeup decreases with increasing physical dispersion among them (Ray *et al.,* 2015)

Importance of biodiversity for functioning of ecosystem:

The quantity of variation in life on Earth is known as biodiversity. It is the variety of plant, animal, and microbe species that exist on our world. It consists of living things from a wide range of environments, such as grasslands, tundra, coral reefs, deserts, and polar ice caps. Ecosystem health and sustainability depend heavily on biodiversity, and the relationship between biodiversity and genetic variety is critical to the general health of these ecosystems.

Numerous studies (Chapin *et al.,* 1997, 1998; Tilman *et al.,* 1997; Edwards and Abivardi, 1998) claim that there is a relationship between species richness and ecosystem function, and that this relationship can be utilised to argue for the conservation of biodiversity. According to these arguments, maintaining high levels of biodiversity may be necessary to maintain ecosystem services, which are the byproducts of ecosystem functions that society is interested in maintaining, *e.g*., clean air, clean water, soil fertility (Daily, 1997). Here are some key points highlighting the importance of biodiversity in ecosystems and its connection to genetic diversity:

- Ecosystem stability is improved by biodiversity. Ecosystems with greater diversity are more resilient to shocks like severe weather, disease, or invasive species.
- The genetic diversity found in organisms helps populations adjust to shifting environmental conditions. The evolution of features that can aid species in surviving in the face of environmental pressures is made possible by a diverse gene pool.
- Complex food webs are supported by biodiversity. Every species in an ecosystem has a distinct function in the food web, and species interdependence contributes to the preservation of equilibrium. These complex interactions can be upset by biodiversity loss, which can have a cascading impact on the ecosystem as a whole.
- The cycling of nutrients in ecosystems is facilitated by a variety of organisms. Decomposers, for instance, break down organic materials and replenish the soil with vital nutrients. The ecology as a whole is maintained and plant development is assisted by this process.
- A large number of plant species depend on pollinators to reproduce. A wide range of pollinator species are part of biodiversity, which is necessary for successful pollination and the development of seeds and fruits.
- Ecosystems rich in biodiversity frequently support a vast array of animal and plant species that may have therapeutic value. A loss of biodiversity could lead to the depletion of important resources used in medicine and pharmaceuticals.
- Climate regulation is facilitated by biodiversity through mechanisms such as carbon sequestration. For example, forests, with their varied plant and microbial populations, are important carbon dioxide absorbers and stores.

- Ecosystems that are rich in biodiversity are aesthetically beautiful and offer leisure activities. Diverse landscapes are frequently sought after for leisure activities and valued for their aesthetic qualities.
- Numerous businesses, such as forestry, fishing, and agriculture, depend on biodiversity. Ecosystems in good health offer resources and services that are necessary for both economic activity and human well-being. Hence, the interplay between biodiversity and genetic diversity is essential for the resilience, stability, and sustainability of ecosystems. Conserving both the variety of species (biodiversity) and the genetic variability within those species is fundamental to maintaining the health and functionality of natural systems.

Importance of genetic diversity for sustainable agriculture

Since World War II, there have been significant changes in agriculture. The productivity of food and fibre has improved dramatically as a result of new technology, mechanization, increased use of chemicals, specialization, and government policies that prioritized lowering food prices and maximizing production. Due to these modifications, fewer farmers are now able to produce more food and fibre for less money. These advancements have significantly increased expenses even though they greatly reduced risks in farming and had numerous good consequences in farming. The depletion of topsoil, pollution of ground water, air pollution, greenhouse gas emissions, decline of family farms, disregard for the living and working conditions of farm labourers, introduction of new pathogens that pose health and safety risks to humans, economic concentration in the food and agricultural industries, and dissolution of rural communities are a few of the most prominent issues. Since greater losses of characteristics in any population may restrict its chances of survival and require greater human efforts for successful production, genetic diversity is vital for agricultural species to have successful production.

Natural genetic variability within crop species has been harnessed since the dawn of agriculture to meet the need for food for subsistence. Currently, this focus is on producing excess food for expanding populations. In order to give humans a balanced diet, the attention is currently on both the productivity and quality components of the primary food crops. Additionally, creating climate-resilient cultivars is becoming increasingly crucial as the environment changes. Novel features, including as resistance to diverse air and soil pollutants, high heat, cold, and possibly new insect pests and illnesses, are necessary for the production of climate resilient cultivars. The presence of genetic diversity can help produce desirable alleles and can be represented by wild species, related species, breeding stocks, mutant lines, etc. Plant breeders can create new and improved cultivars with desirable characteristics, such as traits that farmers prefer (large seeds, high yield potential), as well as traits that breeders prefer (pest and disease resistance, photosensitivity, etc.), due to available diversity of plant genetic resources available. Growing genetic variety is critical for managing pests and diseases and offers opportunities for further species improvement. By incorporating adapted natural genetic variations into breeding programs current genetic diversity of stress tolerance and improve yield under stress can be enriched. It also makes it easier to create new lines for unconventional applications, such as biofuel types of maize, sorghum, etc. In addition to these practical uses, genetic diversity based on molecular markers is essential for genetic mapping and marker-assisted selection in breeding. Adaptability is typically conferred by diversity because a food system will have more tools and avenues to adjust to change. For the production of new kinds and the rectification of defects in current varieties, several lines are required. Therefore, the main objectives of any crop development programme are the discovery of various lines (if available), creation of diversity (if not available or limited), and their subsequent utilisation.

The basis for the sustained creation of new types of crop plants is the genetic diversity of such plants. According to the Food and Agriculture Organisation, the greatest environmental threat is the loss of genetic diversity (Smale *et al.,* 2002). Different genes must be reserved in cultivated and cultivable crop species as germplasm resources in order to meet constantly evolving breeding objectives. Breeders can choose superior genotypes to be used as parents in hybridization programmes or to be directly employed as new varieties due to existence of genetic diversity that exists both within and across agricultural plant species. To achieve heterosis and produce transgressive segregants, there must be genetic variation between the two parents. It is the backbone of a country's overall economic development and its means of ensuring food security. Therefore, it is necessary to use various statistical approaches to characterise the distinct genetic resources and incorporate them into the breeding scheme.

Methods of genetic diversity analysis:

It has been suggested that genetic diversity is declining as a result of modern breeding. In breeding for adaptation to biotic pressures, such as diseases, and abiotic challenges, such as drought or salt tolerance, narrow genetic diversity is problematic. Thus, to increase the genetic variation in wheat breeding in the future, it is imperative to explore the genetic diversity. Genetic variability is continuously evaluated both within and within populations using many methodologies. The three methods are as follows: (i) morphological, (ii) biochemical characterization or evaluation (allozyme), in the pregenomicera, and (iii) DNA (molecular) marker analysis especially single nucleotide polymorphisms (SNPs) in postgenomic era

Morphological markers are based on characteristics that are visible to the human eye, such as colour of flowers, shape of seeds, growth patterns, and pigmentation. They do not require expensive technology, but large areas of land are often needed for field experiments, which make them more expensive than molecular assessment in western (developed) countries and equally expensive in developing Asian and Middle Eastern countries due to labour costs and availability. These marker traits are frequently sensitive to phenotypic plasticity, due to which diversity can be assessed when environmental variation coexists with genotypic variation. In the field, these markers, such as spiny seeds, bristling panicles, and variations in flower or leaf color, are still advantageous and necessary for differentiating adult plants from genetically contaminated ones.

Biochemical markers, or allelic variants of enzymes known as isozymes that are identified by electrophoresis and specific staining, are a second class of genetic markers. In nature, isozyme markers are codominant. They have simple inheritance and detect diversity at the functional gene level. Small amounts of plant material are needed for its detection. However, there are only a few enzyme markers that are known to exist, and even these have unique structural issues and are not alone and have complex structure. As a result, there is little scope to investigate the resolution of genetic variety.

The third and the most used form of genetic markers are the molecular markers, which include a wide range of DNA molecular markers and can be used for both genetic and molecular variation analysis. These markers are able to identify variations resulting from chromosomal duplication, inversion, deletion, and/or insertion. Both dominant and codominant inheritance patterns are present for these markers. Because molecular markers are permanent and observable in all tissues, regardless of the growth, differentiation, development, or defence status of the cell, they have many advantages over traditional, phenotype-based options.

Erosion of Genetic Diversity due to population size: A Bottleneck

The most frequent occurrence in cross-pollinated crops is inbreeding, which is widely recognized to have negative consequences and reduce population fitness in small outcross populations by recombining undesirable genes (recessive identical alleles). Severe reduction in population size, often known as the "genetic bottleneck," occurs in natural populations which results in a loss of genetic diversity as well as an increased vulnerability to infectious pests and diseases, which in turn increases the possibility of extinction of an individual crop. Therefore, it has been recommended that plant breeders maintain the ideal population size for the conservation of any characteristic for a particular purpose and use it to improve crops. Therefore, in order to ensure that there is no bias in the assessment of diversity and that its value is not wrongly predicted, it is crucial to know the ideal population size and its representatives prior to quantifying genetic diversity.

The centres of variety for wheat, barley, chickpeas, lentils, and several other pasture and forage species are found in West Asia and North Africa (WANA). The genetic resources of WANA have influenced agricultural improvement both locally and globally. Sustainable agriculture is threatened by genetic erosion and the depletion of genetic resources, which lower the potential for evolution in several crops in WANA and beyond. The loss of genetic diversity caused by several factors over a period of time in a specific place is known as genetic erosion. Gene combinations or individual genes may be lost. According to Mahajan *et al.* (2012), genetic loss is the gradual decrease in genetic variety. The primary cause of genetic loss is agriculture modernization, which includes the replacement of landraces with newly improved kinds. Crop, variety, and allele are the three levels at which genetic loss can occur. Major factors contributing to genetic loss include urbanization, deforestation, environmental degradation, climate change, and the eradication of native landraces. Therefore, measures for the static preservation of genetic resources are crucial. These include advice on collecting priorities and methods, as well as the evaluation, rejuvenation, multiplication, and preservation of the majority of crop species.

Conclusion:

The productivity, growth, and stability of a population as well as interspecific interactions within communities and ecosystem-level processes can all be impacted by the degree of genetic diversity present in that population. The genetic variety of these plants serves as the foundation for the continuous development of new crop plant varieties. Genetic erosion and genetic diversity vulnerability need to be carefully monitored in order to protect rare and endangered plant species. The plant breeding system is attempting to address the problem of feeding the world's expanding population on decreasing arable land. However, because of the narrow genetic basis of cultivated variations in many crops, it has led to genetic vulnerability. Plant breeding must therefore undergo a paradigm change that emphasizes a variety of genetic resources. The problem faced by the world's rising food demand will need the efficient and complementary use of all molecular and technical techniques and resources by 2050. For crop plants to sustainably create new types, genetic diversity is essential. In order to use the various genetic resources in the breeding process, it is necessary to characterize them using various statistical tools.

Future prospects:

The objective of sustainable development offers a fresh drive to emphasize the use of biodiversity for food and nutrition and to connect it to the viability of agricultural systems in the future. Investigating multi-functional agricultural biodiversity is necessary to reduce environmental pollution, decrease health concerns, and prevent the loss of diversity brought on by an over reliance on chemical pesticides. In order to preserve and make use of diversity in agricultural systems, we must advance basic research. Although the significance of genetic variety has been recognized by scientists for many years, there remains a substantial gap in the understanding of the genetic resources that are accessible and how best to use them in breeding initiatives. Farmers choose to cultivate high-value crops, such as high quality and specialty rice that command higher prices on the market. Therefore, farmers will encourage a production system that enables high yield per unit land area by improving crop protection and allowing traditional and contemporary varieties to coexist. In order to serve the local community, the challenge for the future is to combine cutting-edge research with traditional farming methods.

References:

Acquaah, G. (2009). Principles of plant genetics and breeding. John Wiley & Sons.

Begna, T. (2020). Importance and impact of ecological approaches to crop domestication. J. Biol. Agric. *Healthc.,* **10**: 32-37.

Chapin III; F. S.; Walker, B. H.; Hobbs, R. J.; Hooper, D. U.; Lawton, J. H.; Sala, O. E. and Tilman, D. (1997). Biotic control over the functioning of ecosystems. *Science*, **277**(5325): 500-504.

Daily, G. C. (Ed.). (1997). Nature's services: societal dependence on natural ecosystems. Island press. Pp. 93–112

Dyer, G. A.; López-Feldman, A.; Yúnez-Naude, A. and Taylor, J. E. (2014). Genetic erosion in maize's center of origin. Proceedings of the National Academy of Sciences, **111**(39): 14094-14099.

Edwards, P. J. and Abivardi, C. (1998). The value of biodiversity: where ecology and economy blend. *Biological conservation*, **83**(3):239-246.

Gholami, A. M.; Hahne, H.; Wu, Z.; Auer, F. J.; Meng, C.; Wilhelm, M. and Kuster, B. (2013). Global proteome analysis of the NCI-60 cell line panel. *Cell reports*, **4**(3): 609-620.

Hodgkin, T. and Rao, V. R. (2002). People, plants and DNA: perspectives on the scientific and technical aspects of conserving and using plant genetic resources in Managing plant genetic diversity. Proceedings of an international conference, Kuala Lumpur, Malaysia, pp. 469-480.

Hodgkin, T.; Brown, A.H.D.; van Hintum, Th.J.L.; Morales, E.A.V. (1995). Core collections of plant genetic resources. Chichester: John Wiley & Sons, 269 p. ISBN: 0471955450.

Mahajan, G.; Chauhan, B. S.; Timsina, J.; Singh, P. P. and Singh, K. (2012). Crop performance and water-and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. *Field Crops Research*, **134**:59-70.

Mohammadi, S. A. and Prasanna, B. M. (2003). Analysis of genetic diversity in crop plants- salient statistical tools and considerations. *Crop science*, **43**(4):1235-1248.

Pickersgill, M. (2005). The taxonomy and ethology of the *Afrixalus stuhlmanni* complex (Anura: *Hyperoliidae*). *Steenstrupia*, **29**(1):1-38.

Ray, D. K.; Gerber, J. S.; MacDonald, G. K. and West, P. C. (2015). Climate variation explains a third of global crop yield variability. *Nature communications*, **6**(1):5989.

Smale, M.; Már, I. and Jarvis, D. I. (2002). Economics of Conserving Agricultural Biodiversity On-Farm. Biodiversity International.

Smith, B. D. (1989). Origins of agriculture in eastern North America. *Science,* **246**(4937):1566-1571.

Tilman, D.; Knops, J.; Wedin, D.; Reich, P.; Ritchie, M. and Siemann, E. (1997). The influence of functional diversity and composition on ecosystem processes. *Science,* **277**(5330):1300-1302.

Yilmaz, A. and Boydak, E. (2006). The effects of cobalt-60 applications on yield and yield components of cotton (*Gossypium barbadense* L.). *Pakistan Journal of Biological Sciences,* **9**(15): 2761-2769.