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Genetic Diversity and Its Impact in Enhancement of Crop Plants

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ABSTRACT: *Plant breeding is a science that focuses on the development of new plant varieties in a systematic and ongoing method. It takes advantage of genetic variation among individuals within a plant species and combines desired traits to produce new and improved varieties. Plant breeding depends on genetic variety, and new variation is critical for introducing interesting characteristics into breeding programs. Genetic erosion is a term used to describe the loss of variation in crops as a result of agricultural modernization. Plant breeding has had a significant impact on food production and will continue to play an important role in ensuring global food security. Plant breeding can be broadly described as changes in plants caused by human use, ranging from unintended modifications generated by the introduction of agriculture through the use of molecular tools for precision breeding. Plant breeding based on observed variation by selection of plants based on natural variants appearing in nature or within traditional varieties; plant breeding based on controlled mating by selection of plants presenting recombination of desirable genes from different parents; and plant breeding based on monitored recombination by selection of specific genes or marker profiles. Continuous use of traditional breeding methods in a given species may reduce the gene pool from which cultivars are derived, making crops more susceptible to biotic and abiotic challenges and impeding future advancement. Plant breeding's primary objectives are 'high yield, high quality, and quantity, extension of climate and soil adaptability ability, and tolerance or resistance to pests and diseases.' Plant breeders achieve these goals by exploiting genetic differences between plants. The range of the genetic base, as measured by genetic diversity, is a limiting factor in successful adaptation to environmental conditions and plant breeding. Many challenges in plant breeding require genetic variation, which can be found in the biodiversity of plant genetic resources such as breeding lines, landraces, primitive forms, wilds and wild relatives, and weed races.*

KEY WORDS: genetic diversity; adaptation; molecular marker; diversity analysis; gene pyramiding

INTRODUCTION

The world's food supply depends on a small number of crop species. Because high-yielding cultivars dominate production but are few and genetically similar, genetic diversity in these crops is considered to have declined to extremely low levels [1]. Reduced genetic variety is terrible news for future crop productivity advances and could lead to widespread susceptibility to new diseases or insect pests, endangering long-term food and feed security [2]. The development of novel crop varieties that can survive in more severe, changing, and uncertain environmental conditions is a critical component of efforts to mitigate the effects of climate change on crop productivity and food security. Plant breeders ensure a constant supply of diverse and novel genetic variation in order to develop new crop varieties that can withstand the effects of changing growing conditions [3].

Plant breeding aims to create genetically improved crop cultivars that benefit small-scale and commercial farmers economically. Plant breeders frequently use elite varieties in their crosses, and modern cultivation practices of homogenous high yielding varieties have reduced crop genetic diversity and predisposed agricultural plants to disease and insect pest epidemics. Plant breeders must make deliberate efforts to diversify their crop's gene pools to lower genetic vulnerability in overcoming these impacts. In order to find desired genes, breeders must seek beyond the advanced germplasm pool [2]. Unadapted gene pools may include the desired genes. Transfer of genes from an unadapted genetic resource, on the other hand, is frequently associated with linkage drag and undesirable characteristics. As a result, exotic germplasm is frequently unavailable for cultivar development. Instead, the materials are increasingly incorporated into the cultivar development program by cross-breeding and selection for intermediate with new traits while retaining a large number of the adapted traits.

Plant breeding has a significant impact on food production since the early 1900s and will continue to play an important part in global food security [4]. Crop breeding has mostly focused on increasing production, adaptability, biotic and abiotic stress resistance, and end-use quality. Beyond yield improvement, however, breeding objectives have changed over time. New cultivars with the ability to attain high yields in limited systems and the genetic diversity required to sustain yield stability under changing climatic conditions must be created [5]. Enhanced weed suppressing ability, nutritional value, and plant interactions with microbial populations in the soil are just a few of the novel traits that have been improved for sustainable agriculture [6]. Conventional plant breeding has evolved to meet these challenges by incorporating methodologies from other scientific disciplines, allowing breeders to boost their efficiency and fully harness genetic resources. Haploid production [7]; the application of sterility systems and transgenic technology [8]; apomixis [9]; and molecular marker-assisted breeding are some of the novel approaches [10]. For different breeding purposes, modern plant breeding has evolved from conventional breeding to molecular breeding, and numerous breeding strategies have been used over time [11]. As a result, selective pressure within breeding populations varies at different stages of breeding for different breeding programs, resulting in genetic diversity in released cultivars of a crop that varies [12]. Between selfing and outcrossing crops, there should be more heterogeneity in varietal genetic diversity. Crop plant evolution, whether natural or induced by humans, is essentially reliant on the population's genetic diversity. The degree of differentiation between or within species is referred to as diversity. All crop improvement programs are founded on the basis of existing intra- and inter-specific differences. If all of the individuals in the species were identical, there would have been no room for improvement in plant performance for various traits.

Natural variability and divergence among crops have been extensively identified and utilized in crop improvement since the beginning of systematic plant breeding. Natural variability has been depleted over time as a result of (i) lopsided breeding practices focusing on only a few traits (such as yield and its component traits), (ii) frequent use of a few selected genotypes as parents in varietal development programs, and (iii) introduction of a few outstanding lines to many countries, resulting in increased genetic similarity between modern crop cultivars. Agricultural workers are concerned about decreased genetic variability and diversity among crop plant species. With less genetic diversity, continued crop variety improvement will be difficult [13]. Breaking yield barriers will be challenging, and plant breeders would be unable to meet the demands arising from ever-increasing demand due to population growth. In the context of climatic change and associated unanticipated events, genetic diversity becomes even more significant, as it may serve as a repository for numerous novel traits giving tolerance to various biotic and abiotic stresses. Many significant agricultural phenomena, such as heterosis and transgressive segregation, are caused by genetic diversity.

For the defect correction of commercial varieties and the production of novel varieties, a variety of lines is required. As a result, the main goals of any crop development program are to identify diverse lines (if available), create diversity (if not available or limited), and then use it. In this context, understanding all aspects of genetic diversity, such as variables impacting genetic diversity, various methods of diversity analysis, their measurement, and statistical analysis tools, is critical in order to use them wisely. Many reviews have been written on serious matters such as changes in genetic diversity under plant breeding [13], genetic vulnerability of modern crop cultivars [14], conservation and utilization of genetic resources [15], genetic diversity assessment using molecular markers [16], and genetic diversity measurement using statistical tools [16]. Plant breeding, in general, is based on the presence of significant genetic diversity in order to address the maximum genetic yield potential of crops and the exploitation of that genetic variation through effective selection for improvement.

The availability of genetic variety is a crucial requirement for successful plant breeding. The creation of genetic diversity and manipulation of genetic variability are the most critical issues in plant breeding. Although phenotypic variety is linked to genetic diversity, it is also influenced by environmental factors and genotype-environment interactions [17]. Agricultural improvement and the existence of crop plants in nature are both dependent on genetic diversity. Natural selection can use genetic variation to raise or decrease the frequency of alleles already present in the population, which is a powerful factor in evolution. Mutation (which can produce whole new alleles in a population), random mating, random fertilization, and recombination between homologous chromosomes during meiosis (which reshuffles alleles within an organism's offspring) can all contribute to genetic variation. Genetic variation is beneficial to a population because it allows certain individuals to adapt to their surroundings while still allowing the population to thrive. The rate of improvement of genetic yield potential has to be increased beyond the rates currently achieved in ongoing breeding programs to protect global food security in times of rapid population growth and climate change. The objective of the paper was to understand the role and economic importance of crop genetic diversity in food security

CONCEPTS IN PLANT BREEDING AND GENETICS

Information regarding the genetic variations that exist within and between plant populations, as well as their structure and level, can assist in the efficient use of plants [18]. The evolutionary context, gene flow mechanism, mating system, and population density are all key elements in determining the structure and magnitude of these differences [19]. Genetic diversity is vital to the effectiveness of yield improvement attempts since it broadens gene pools in any crop population. Plant breeders need genetic diversity to develop better crop varieties. No two living beings (even maternal twins) are exactly same. Variability refers to the variation in one or more traits of an organism. Genetic variability and genetic diversity are frequently used interchangeably, although this is incorrect. Variation in gene alleles or DNA/RNA sequences in a species' or population's gene pool is referred to as genetic variability whereas genetic diversity is a broad term that encompasses all the variability occurring among different genotypes with respect to total genetic make-up of genotypes related to single species or between species. The number of different genes in a gene pool can be measured to determine genetic diversity, but genetic variation can only be expected and not measured. As a result, genetic variability can be regarded of as the foundation of genetic diversity.

As recognized by Convention on Biological Diversity, there are three levels of diversity. At the highest hierarchy, lies the ecosystem diversity representing variability among different communities of species. In the next level of hierarchy, lies the species diversity representing different species within a community, also referred to as species richness. Genetic diversity is referred to the diversity present within different genotypes of same species. This is due to the fact that various alleles of the same gene produce distinct phenotypes in different people. Genetic diversity is defined by Swingland [20] as the variance of heritable characteristics found in a population of the same species. Heritable character variation can manifest as changes in morphology, anatomy, physiological behavior, or biochemical characteristics. Within an individual, genomic diversity can be defined as variation at many gene loci.

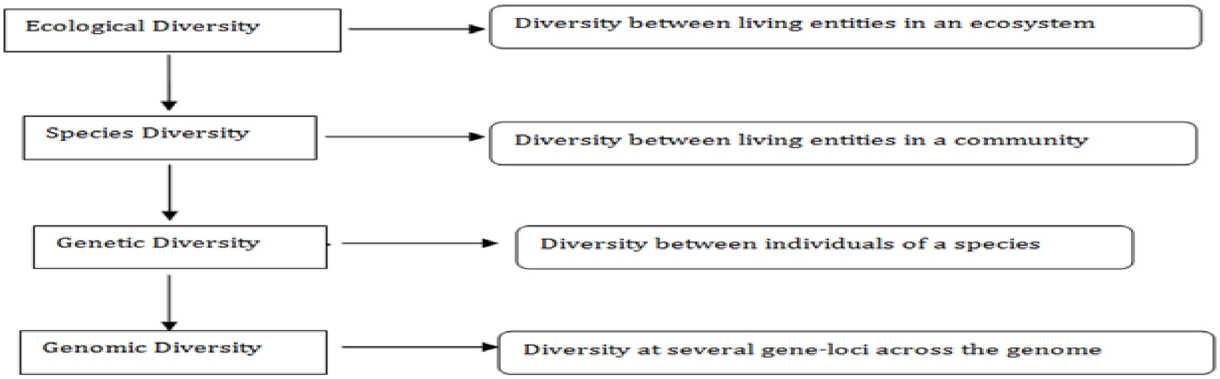

Figure 1: Hierarchy of diversity

Farmers' variety development and scientifically trained plant breeders' applications of Mendelian, quantitative, and molecular genetics continue to improve crop value for humans, which began with domestication and continue with farmers' variety development. The term 'pre-breeding' is used by Biodiversity International and the FAO's Global Partnership Initiative for Plant Breeding Capacity Building (GIPB/FAO) to describe the various activities of plant breeding research that must occur before cultivar development, testing, and release [21]. Pre-breeding or germplasm enhancement is defined by the Global Crop Diversity Trust as "the art of identifying desired traits and incorporating these into modern breeding materials," or "the process of the initial introgression of a trait from an undomesticated source (wild) or agronomically inferior source to a domesticated or adapted genotype."

Pre-breeding tries to reduce genetic homogeneity in crops by utilizing a larger pool of genetic material in order to boost yield, pest and disease resistance, and other quality traits. Depending on the source, the type of characteristic, and the presence of reproductive barriers, the process varies in complexity and duration. Hybridization followed by backcrossing to elite parents is a common approach, as is the employment of cyclical population improvement techniques. Wide crossing problems (such as sterility, negative linkage drag, and incompatibility) can occur, necessitating embryo rescue techniques. Gene transfer into elite lines can now be done without linkage drag due to contemporary molecular genetics and other biotechnological techniques [21].

Despite the confidence that conventional breeding would continue to boost yields, new technologies such as biotechnology will be required to maximize the chances of success. DNA marker technology, which is derived from molecular genetics and genomics research, holds significant promise for plant breeding. DNA markers can be used to detect allelic variation in the genes that underpin these traits due to genetic linkage. The efficiency and precision of plant breeding could be considerably improved by employing DNA markers. Marker-assisted selection (MAS) is a component of the new science of' molecular breeding,' which involves the use of DNA markers in plant breeding. The following are the main advantages of marker-assisted selection over conventional phenotypic selection.

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I) It may be less time-consuming, resource-intensive, and effort-intensive than phenotypic screening. Cereal cyst nematode and root lesion nematode resistance in wheat are two classic examples of characteristics that are difficult and time-consuming to quantify. ii) At the seedling stage, selection can be done. This could be useful for a variety of traits, but especially traits that are expressed later in development. As a result, unwanted plant genotypes can be eradicated fast. iii) Individual plants can be chosen. Plant families or plots are grown using conventional screening methods for several traits because single-plant selection is unreliable due to environmental factors. Individual plants can be chosen using MAS based on their genotype. Conventional phenotypic screening cannot differentiate homozygous and heterozygous plants for most characteristics.

II)

There are five broad areas of marker assisted selection are: **(a) Marker-assisted evaluation of breeding material:** Prior to crossing (hybridization) and line development, DNA marker data can be used for a variety of purposes, including cultivar identification, genetic diversity assessment, parent selection, and hybrid confirmation. These tasks have traditionally been carried out via visual selection and data analysis based on morphological characteristics.

(b) Marker-assisted backcrossing: For nearly a century, backcrossing has been a commonly utilized strategy in plant breeding. In most cases, the backcrossing parent has a significant number of desirable traits but is deficient in only a few [22]. Backcrossing with DNA markers dramatically improves the efficiency of selection. Marker-assisted backcrossing (MAB) can be classified into three levels. Markers can be used together with or in substitute of screening for the target gene or QTL at the first level. This could be especially valuable for traits with time-consuming or labor-intensive phenotypic screening techniques. It can also be employed in the seedling stage to select for reproductive-stage traits, allowing the best plants to be chosen for backcrossing. Additionally, recessive alleles can be chosen, which is difficult to perform using conventional methods.

The second stage entails choosing BC progeny that carry the target gene as well as recombination events between the target loci and flanking markers. Recombinant selection is the term for this process. The goal of recombinant selection is to make the donor chromosomal segment that contains the target region smaller (i.e. size of the introgression). This is significant because the rate of decrease of the donor segment is slower than that of unlinked sections, and numerous unwanted genes that negatively affect crop performance may be linked to the target gene from the donor parent, a phenomenon known as 'linkage drag.' The markers employed for recessive parent genome selection are referred to as 'Background selection' at the third level.

(c) Marker assisted gene pyramiding: The process of combining many genes into a single genotype is known as pyramiding. Pyramiding may be possible through conventional breeding, although identifying plants with many genes is usually very difficult. Individual plants must be assessed for all traits tested using traditional phenotypic selection. As a result, using destructive bioassays to evaluate plants from certain population types (F_2) or for traits may be challenging. Because DNA marker assays are non-destructive and markers for numerous specific genes can be assessed with a single DNA sample without phenotyping, DNA markers can substantially assist selection.

(d) Early generation marker-assisted selection: Although markers can be used at any stage of a typical plant breeding program, MAS has a significant advantage in early generations since it allows for the elimination of plants with undesired gene combinations. This permits breeders to focus their efforts in subsequent generations on a smaller number of high-priority lines. **(e) Combined marker-assisted selection:** There are several situations where phenotypic screening and marker-assisted selection can be strategically combined. In order to maximize genetic gain, 'combined marker-assisted selection' may have advantages over phenotypic screening or MAS alone in the first instance [23].

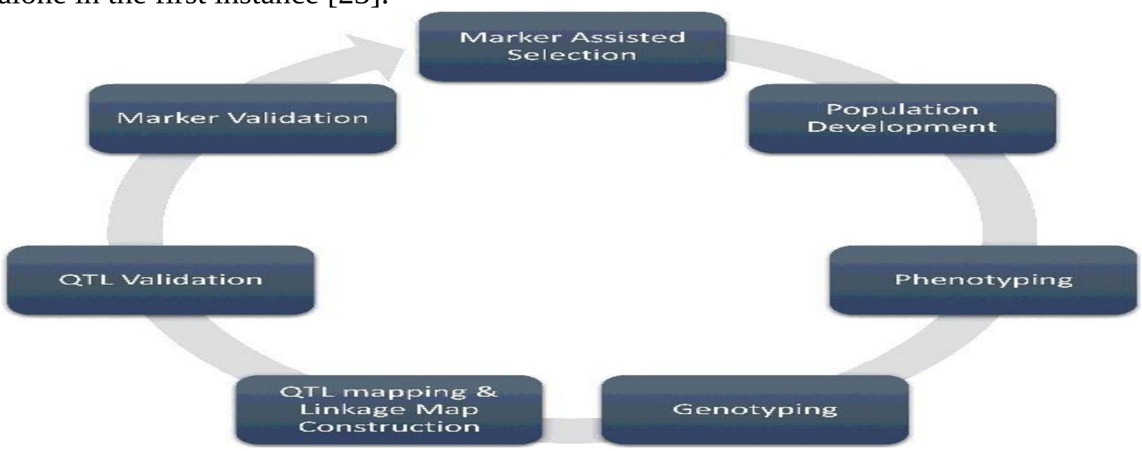

Figure 2: Some important steps involves in marker assisted selection

Importance of Genetic Diversity

Genetic diversity is the basis for survival and adaptation, and it makes it possible to continue and advance the adaptive processes on which evolutionary success and, to some extent, human survival depends; it can be defined as the variation present in all species of plants and animals, their genetic material, and the ecosystems in which they occur [24]. Breeders need genetic variety to generate new, superior crop types with desirable traits that can assure a consistent, abundant supply of food, feed, and fiber [25]. Plant breeding and the development of responses to changing environmental conditions require a high level of genetic diversity [26].

Genetic diversity is essential for plant survival in nature and agricultural enhancement. Plant breeders can use the diversity in plant genetic resources to create new and improved cultivars with desirable characteristics, including both farmer- and breeder-preferred traits (high yield potential, large seed) (pest and disease resistance and photosensitivity). Natural genetic variability within crop species has been harnessed to meet subsistence food requirements since the beginning of agriculture. Later on, the emphasis shifted to the production of surplus food for expanding

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populations. To offer a balanced diet to humans, the current focus is on both yield and quality characteristics of main food crops. Breeding climate robust cultivars is becoming increasingly important as the climate changes. The presence of genetic variety in the form of wild species, related species, breeding stocks, and mutant lines could provide a source of favorable alleles and assist plant breeders in developing climate adaptable cultivars.

Breeding climate resilient cultivars required the development of novel traits such as resistance to new insect pests and diseases, high heat and cold, and different air and soil contaminants. Different genes must be reserved in cultivated and cultivable crops species in the form of germplasm resources for ever-changing breeding goals. Because there is genetic variability within and between crop plant species, breeders can choose superior genotypes to be used as new varieties or as parents in hybridization programs. To achieve heterosis and transgressive segregants, genetic diversity between two parents is required. Breeders can develop varieties for specific traits like quality enhancement and tolerance to biotic and abiotic challenges due to genetic diversity. It also makes it easier to produce novel lines for non-traditional purposes, such as biofuel variants in sorghum and maize. Crop plant diversity is also significant in terms of adaptability to a variety of habitats, particularly in light of changing climatic conditions.

Genetic diversity: the level of biodiversity refers to the total number of genetic characteristics in the genetic makeup of a species. **Crossing over**: the exchange of genetic material between homologous chromosomes that results in recombinant chromosomes. **Phenotypic variation**: variation (due to underlying heritable genetic variation); a fundamental prerequisite for evolution by natural selection. **Genetic variation**: variation in alleles of genes that occurs both within and among populations.

Methods of Diversity Analysis

In the pregenomic era, several techniques such as (i) morphological, (ii) biochemical characterization/evaluation (allozyme), and (iii) DNA (or molecular) marker analyses were commonly used to determine genetic diversity within and between plant populations. The evaluation, size, and distribution of genetic divergence are the cornerstones of agricultural genetic variability preservation and exploitation within and between crop species. To assess the amount of similarities and differences among agricultural germplasm, morphometric, cytological, and biochemical markers were commonly used at first. In the genomics and post-genomic eras, genetic and molecular markers were produced, and they are now the most extensively used tool for estimating crop genetic divergence.

Morphological Markers

Seed shape, flower color, growth habit, and other critical agronomic characteristics can all be visually distinguished using morphological markers. Morphological markers are simple to use and do not require any special technology. They don't require any advanced biochemical or molecular techniques. Breeders have effectively utilized such markers in breeding programs for a variety of crops. The following are the main drawbacks of morphological markers: they are restricted in

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number, are influenced by plant growth phases, and are affected by many environmental conditions [27]. Humans have successfully used numerous morphological markers to investigate variation for use in plant breeding from ancient times [28].

Morphological markers are genetic polymorphisms that manifest themselves as differences in appearance, such as differences in plant height and color, different differences in response to abiotic and biotic stresses, and the presence/absence of other morphological traits [29]. These morphological markers are usually genetic variations that are simple to detect and manipulate. External plant features, which may be gained through direct visual observation and measurement, are sometimes referred to as morphological markers. They are used to classify, identify, and characterize the genetic evolution of various species or populations.

Cytological Markers

Cytological markers are markers that are connected to chromosome number, shape, size, and banding pattern variation. Chromosome karyotypes, bandings, repetitions, deletions, translocations, and inversions are all cytological markers. Chromosomes are genetic material carriers, and chromosome mutations are important sources of genetic variation. Particular cytogenetic traits, such as distinct types of aneuploidy, variants of chromosome structure, and defective chromosomes, can be discovered by investigating the morphology, number, and structure of chromosomes from different species [30]. These can be used as genetic markers to find and determine the relative positions of other genes on chromosomes, or for genetic mapping via chromosome manipulations such chromosome substitution.

The chromosome karyotype and bands show the structural properties of chromosomes. Color, width, order, and position of the banding patterns reveal the difference in euchromatin and heterochromatin distributions. Cytological markers have been widely used in physical mapping to detect linkage groups within specific chromosomes. They have limited applicability in genetic diversity analysis, genetic mapping, and marker-assisted selection due to their poor number and resolution [31].

Biochemical Markers

Isozymes, or biochemical markers, are multi-molecular versions of enzymes that are coded by different genes but perform the same tasks [32]. Biochemical markers can be used to assess gene and genotypic frequencies because they are allelic variants of enzymes. Genetic diversity, population structure, gene flow, and population subdivision have all been effectively detected using biochemical markers [33]. They are co-dominant, simple to use, and inexpensive. They are, however, less in number, detect less polymorphism, and are influenced by different extraction methodologies, plant tissues, and plant growth stages [16].

Molecular Markers

The fate of plant breeding has changed since the emergence of molecular marker technologies in the 1980s. Crop improvement has been helped by the development of various molecular markers and advances in sequencing technologies. The polymorphism existing between the nucleotide sequences of different individuals can be used to explore molecular markers, which are nucleotide sequences. These polymorphisms are based on insertion, deletion, point mutations, duplication, and translocation; however, they do not always influence genetic expression. A perfect DNA marker would be co-dominant, equally distributed throughout the genome, highly repeatable, and capable of detecting increasing levels of variation [16].

In crop genetic studies, molecular markers are very useful for assessing genetic variability and characterization of germplasm, genotype identification and fingerprinting, estimating genetic distances between populations, inbreeds, and breeding materials, detecting monogenic and quantitative trait loci, and identifying sequences of useful candidate genes [34]. Because of their great variability, better genomic coverage, high reproducibility, automation ability, neutrality, and lack of environmental fluctuations, molecular markers are the method of choice for genetic diversity evaluation. Many genetic diversity studies have reported using both morphological and molecular markers at the same time.

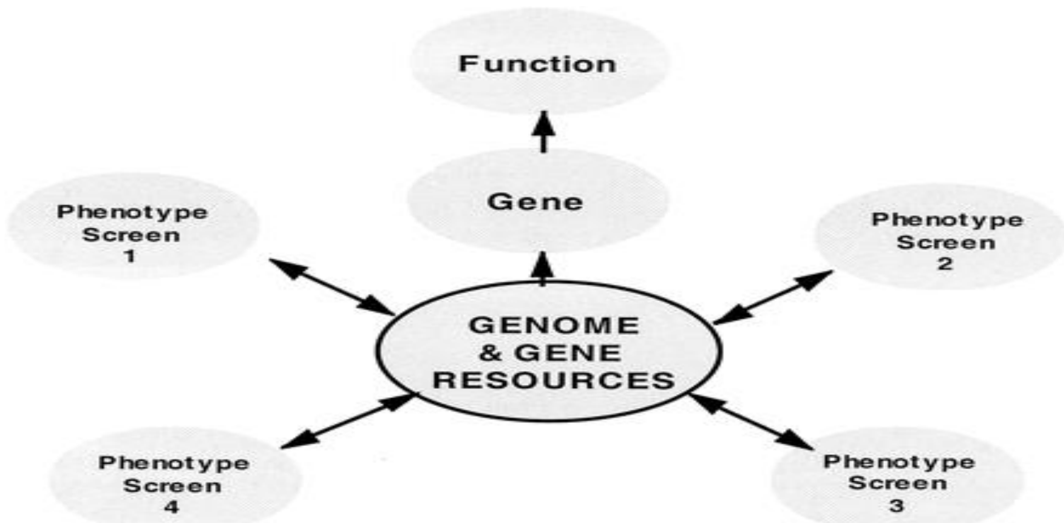

Figure 3: The genocentric view looking for the function of all the genes in the genome.

CONCLUSION

Plant breeding is facing a difficulty in feeding an ever-increasing population on land that is becoming increasingly limited. In this aspect, modern plant breeding has some success. However, because of the limited genetic base of cultivated variations in many crops, it has resulted in genetic vulnerability. As a result, a paradigm shift in plant breeding is required, with an emphasis on various genetic resources. Genetic diversity is now recognized as a distinct area that can help with food and nutrition security. A better understanding of genetic diversity will assist in deciding what to protect and where to protect it. Crop plant genetic diversity is essential for the long-term creation of new cultivars. As a result, different statistical tools must be used to characterize the diverse

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genetic resources before they can be used in the breeding program. Plant breeding, in its broadest meaning, is a human-led change in plant evolution to develop traits that are specifically helpful to humans, usually in the context of cultivation or preferences.

Agricultural improvement and the existence of crop plants in nature are both dependent on genetic diversity. It is obvious that genetic diversity provides opportunities for cultivar improvement with desired traits, including both farmer- and breeder-preferred traits. Genetic diversity is the foundation of a country's food security and overall economic success. To continuously expanding genetic yield potential, sufficient genetic variety for golden crop enhancement is becoming a difficulty. Plant breeders are currently using genetic materials such as exotic non-adapted, exotic adapted, and existing genetic material as a source of novel alleles that protect and promote genetic gain through selection without knowing their genetic background. Genetic diversity has a significant role in ensuring food and nutritional security.

For genetic improvement as well as the development of new cultivars in crops, genetic variation is essential. The quantity of genetic variation available among crop species for use in improvement programs is referred to as genetic diversity. A breeding program's effectiveness depends on the presence of adequate genetic variation. For the development of superior varieties in terms of productivity and other desirable characteristics, genetic diversity is critical. It's also important for creating excellent hybrids and desirable recombinants. Genetic diversity impacts the efficacy and efficiency of improvements that could lead to increased food production.

In terms of plant breeding, classifying genetic diversity into heterotic groups is vital for the generation of robust and remarkable hybrids with commercially important traits. Environmental stressors like as climate change, pests, and diseases are all being mitigated by genetic diversity. Plant breeding, in general, is based on the presence of significant genetic variation in order to address the maximum genetic production potential of crops and the optimal exploitation of this variation through selection for improvement. The availability of genetic variation is a crucial requirement for plant breeding success. Plant breeding focuses on the production of genetic variation and the application of appropriate selection processes to improve quantitative and qualitative traits.

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