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Genetic Variability and Its Benefits in Crop Improvement: A review

Temesgen Begna and Temesgen Teressa

Ethiopian Institute of Agricultural Research, Chiro National Sorghum Research and Training Center P. O. Box 190, Chiro, Ethiopia

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ABSTRACT

Plant breeders face multiple global challenges that affect food security, productivity, accessibility and nutritional quality. One major challenge for plant breeders is developing environmentally resilient crop cultivars in response to rapid shifts in cultivation conditions and resources due to climate change. Plant breeders rely on different crop genetic resources, breeding tools, and methods to incorporate genetic diversity into commercialized cultivars. Breeders use genetic diversity to develop new cultivars with improved agronomics, such as higher yield, biotic and abiotic stress tolerance, and to improve the nutritional quality of foods for a growing world population. Genetic variability is the fundamental requirement for any plant-breeding program to develop a superior cultivar. The presence of genetic variation is a key prerequisite for genetic improvement in plant breeding and plays a pivotal role in germplasm usage in breeding programs. Genetic variability is well defined as the formation of individuals varying in the genotype. Genetic diversity is the range of different inherited traits within a species, which is the prerequisite of the breeding program. Genetic diversity leads to the selection of superior cultivars and their traits. Genetic variation is a measure of the genetic differences that exist within a population. Variation in crop plant can come either from environment or from genetic difference. Genetic variability is the occurrence of variation among individual, due the difference in genetic composition. Variability is pre-request for crop improvement in plant breeding. Without variation among individual or species no need of crop improvement. The paper, therefore, aims to reviewing the overview of genetic variability and it is implication in crop improvement. Variation in crop plant can either due to genetic or environmental variation. There are different method of creating variability in crop for breeding purpose like, genetic recombination, mutation, ploidy modification, transposable element, gene transfer and soma-clonal variation. Genetic variation is important in natural selection that allows for increase or decrease in frequency of population. The existence of variation in crop plant enable individual to adapt new or changing environment. Variation in crop plant also important for adaptation of individual to changing or new environment, yield improvement and development of disease resistance. Therefore, exploiting available genetic variation in crop plant or creating variation is corner stone for plant breeding program.

Keywords: Crop Improvement, Environmental Variability, Genetic Variability, Phenotypic Variability, Crossing Over

1. Introduction

Genetic variation refers to variation (change or difference) of the gene among the members of the same species or individuals. Genotype is the total sum of genetic determinants carried by a cell that is transmitted from generation to generation. Genotype is determined by the genetic information contained in the entire DNA content of the genome in the chromosome (Begna, 2021). Genes carry instructions that are used for building protein. Differences in DNA sequence or gene between individuals are also known as genetic variations, and each variation of a gene is called an allele. Genetic variation occurs in entire species, known as genetic diversity. Genetic variation is essential for the

Corresponding Author: Temesgen Begna, Ethiopian Institute of Agricultural Research, Chiro National Sorghum Research and Training Center P. O. Box 190, Chiro, Ethiopia.
E-mail: - tembegna@gmail.com

natural selection process because natural selection can only decrease or increase the allelic frequency already present in the population. Genetic variation plays an advantageous role in the population because it favours some individuals to adapt to the environment (Haun *et al*., 2011). Mutation, gene flow, sexual reproduction, random mating between organisms, random fertilization, and crossing over are the main cause of genetic variation. Genetic variation along with environmental variation causes phenotypic variation in a population. An example of phenotypic variation is the height of a plant.

Plant breeders use diversity in genetic resources to develop new and improved crop cultivars to address global challenges that affect food security, sustainability and adaptation to climate change. Genetic diversity is the range of genetic characteristics in a crop or species, whereas genetic variation is the genetic differences among individuals for a specific characteristic, where these genetic differences reside in one or more DNA sequences. Genetic diversity can be assessed by examining differences in the DNA sequence in a population of individuals (Haun *et al*., 2011). Genetic variation gives rise to phenotypic variation, which is differences in observable traits within a population. Plant genomes are dynamic and evolutionarily labile in nature, which results in more frequent genetic and epigenetic changes in plants that serve as the sources of a large amount of genetic and phenotypic diversity, even between cultivars within a species. Greater genetic diversity in plants gives them a remarkable ability to adapt to sudden environmental changes (Raza *et al*., 2019).

Variability is the primary capital for plant breeders in improving plant characteristics. The variability in a population was due to genetics, environment and interaction between genetic and environmental factors. The variability used in plant breeding is variability due to genetic factors (Azrai *et al*., 2018). A genetic variability is number that measures the appearance variation due to genetic factors. Genetic variability can describe individual variation in a population (Kristamtini *et al*., 2014). The higher trait genetic variability gives the greater desired good traits combination chance so the plant breeding program success will be increased (Hapsari *et al*., 2018). The success of crop improvement lies in efficiently identifying and incorporating genetic diversity from various plant genetic sources including currently cultivated cultivars, newly developed cultivars, landraces, wild and near relatives of cultivated cultivars, and germplasm collections with elite and/or mutant plants. Various genomic tools and breeding methods have improved the efficiency and precision of incorporating genetic diversity into commercialized crop cultivars, but plant breeding remains a time- and resource-intensive process (Vaughan *et al*., 2007).

The term variability refers to variation in one or more than one characters of living organisms. The cumulative influence of environment and the genetic factors brings about variations in a specific trait. Genetic variation refers to variation in sequences of genes between individuals in a population. Allelic variation is the building block of hereditary variation that is expressed in the form of different phenotypes. Genetic variability provides baseline for genetic diversity; a broader term that reflects the degree or amount of variation existing within a population. Without genetic variability, populations fail to adapt to varying climatic conditions and are prone to extinction. Genetic variability is a source of natural selection that is the key driver of evolution of living organisms. Plant breeding is dependent on genetic variation, and new variation is fundamentally important for introduction of new traits in breeding programs.

Diversity in plant genetic resources provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics, which include both farmer-preferred traits (yield potential and large seed, etc.) and breeders preferred traits (pest and disease resistance and photosensitivity). From the very beginning of agriculture, natural genetic variability has been exploited within crop species to meet subsistence food requirement, and now it is being focused to surplus food for growing populations. Genetic diversity is usually defined as the number of genetic characteristics (alleles and genotypes) in a species (Ellegren and Galtier, 2016). Analysing the genetic diversity in populations is essential to understand evolutionary and adaptative process for most species (Wright, 2001). The genetic diversity is also very useful to implement conservation strategies and crop management.

Presence of genetic diversity is the vital element of all variety development programs. Existence of genetic diversity in crop germplasm aides in the efficient selection of high yielding, better adapted crop plants with possible uses of direct introduction as a variety or one of the parents in crossing scheme of breeders for variety development programs. Since genetically diverse germplasm offers wider tolerance to biotic and abiotic stresses; such programs extensively involve exploring and exploiting diverse crop germplasm. Climate smart agriculture relies on cultivars with novel biotic or abiotic stress tolerance traits. However, depletion of natural variability persists in existing crop germplasm. Targeted breeding to improve specific traits and repeated use of few breeding parents has narrowed the genetic base of existing major crop varieties, raising serious concerns about genetic vulnerability of modern crops and making breeder's task even harder. Crop genetic diversity is the core element of climate smart agro ecosystem to promise sustainable food availability and thereby to alleviate hunger and poverty.

The progress of an effective plant-breeding program is associated with the existence of genetic variability. The performance of selection largely depends upon the value of genetic variability present in the plant population (Begna, 2021). Thus, the success of genetic betterment in any character depends on the nature of variability present in the gene pool for that character. Accordingly, an insight into the magnitude of variability present in the gene pool of a crop species is of utmost importance to a plant breeder for starting a judicious plant-breeding program. In earlier years, visual observations used to be the measurement of variability in a plant population. Now biometrical methods are available for systematic assessment of variability (Pasipanodya *et al*., 2022). The phenotypic expression of the plant characters is mainly controlled by the genetic combination of the plant and the environment in which it is growing. In addition, the genetic variance of any quantitative trait is composed of additive variance (heritable) and non-additive variance and includes dominance and epistasis (non-allelic interaction) (Kumar *et al*., 2017). It is necessary to separate the total variation into heritable and non-heritable components with the help of genetic parameters i.e. genotypic and phenotypic coefficient of variation, heritability and genetic gain (Kahrizi *et al*., 2010).

The genetic diversity of the population is fundamentally, what drives crop plant evolution, whether it is occurring naturally or as result of human interventions. Diversity is the level of variation between or within species. Genetic diversity is degree of differentiation between or within species. The existing intra and inter-specific difference provides the basis of all crop improvement initiatives. There would have been no possibility for improvement in plant performance of various traits if every individual in the species had been identical. It is possible to identify genetic variation at both molecular and gross morphological levels. Plant breeders can analyses the genetic variability of their materials at the molecular level by using some biotechnological technologies (such DNA markers). Some of compositional or chemical traits, such as the protein content or sugar content of a plant component, require different tests or devices to be evaluated, while some genetic variation manifests itself as apparent variation in morphological traits (e.g., height, color, size) (Acquaah, 2004).

Plant breeding is a discipline for targeted and continuous development of new plant varieties. It utilizes the genetic variation between individuals within a plant species and combines the desired properties into new and improved varieties. Plant breeding is dependent on genetic variation, and new variation is fundamentally important for introduction of new traits in breeding programs. However, in cases where a specific genetic trait is not immediately available to be crossed into breeding materials, the genetic variation in a crop species can be expanded by other means (Holme *et al*., 2019). In order to progress rapid and efficient crop improvement through plant breeding there should be genetic variability because superior genotypes can be selected from different population. The papers, therefore aim to reviewing the overview of genetic variability and it is implication in crop improvement.

2. Type of Variation in Crop

2.1 Environmental Variation

Due to the non-uniform environment, plants growing in the field will have variations in the expression of several traits. The effects of the environment are not inherited. It may, however, affect heritable variation. Plant breeders want to be able to choose a plant based on its genetics (nature) rather than its environment (nurture) of growth. In order to achieve this goal, evaluations of breeding material are carried out as uniformly environment as possible. Additionally, the selection environment frequently resembles the environment in which the crop is grown for commercial purposes (Acquaah, 2004).

2.2 Genetic Variability

Genetic or heritable variation is defined as variation that can be attributed to genes that encode particular traits and can be transmitted from one generation to the next. Generation after generation, heritable variability is consistently expressed. A mutation, however, has the power to fundamentally change an original expression (Acquaah, 2004). According to Allard (1960), genetic variability is the occurrence of variation among individuals due to differences in their genetic make-up or environment of upbringing. Falconer and Mackay's (1996) also define genetic variability as the tendency of individual genotypes within a population to differ for certain traits of interest.

Genetic variation is an important force in evolution as it allows natural selection to increase or decrease frequency of alleles already in the population. Genetic variation can be caused by mutation (which can create entirely new alleles in a population), random mating, random fertilization, and recombination between homologous chromosomes during meiosis (which reshuffles alleles within an organism's offspring). Genetic variation is advantageous to a population because it enables some individuals to adapt to the environment while maintaining the survival of the population. Genetic variation is a measure of the genetic differences that exist within a population. The genetic variation of an entire species is often called genetic diversity. Genetic variations are the differences in DNA segments or genes between individuals and each variation of a gene is called an allele. For example, a population with many different alleles at a single chromosome locus has a high amount of genetic variation. Genetic variation is essential for natural selection because natural selection can only increase or decrease frequency of alleles that already exist in the population.

Genotypic variability is a component of variation that results from genotypic differences among individuals within a population (Singh, 2001). Genetic variations of particular trait are interest to plant breeders since it has remarkable impact on the performance of the crop. In order to develop breeding techniques for crop improvement in the future, studies on genetic variability provide fundamental knowledge about genetic features of populations (Khleshtkina *et al*., 2004). In order to determine how much genetic variation is there in the genotypes, components of genetic parameters like genotypic coefficient of variation and phenotypic coefficient of variation have a greatest significance. Genetic variation is advantageous to a population because it enables some individuals to adapt to the environment while maintaining the survival of the population.

2. Method of creating variability in crop

2.1. Genetic Recombination

Meiosis is the sort of cell division that generates gametes, when genetic recombination takes place. Homologous chromosomes join up and form a structure known as a tetrad during this process. The chromosomes can then crossover and exchange genetic material, creating novel allele combinations. It only applies to species that reproduce sexually and serves as those species' main source of variation for plant breeders (Acquaah, 2004).

Genetic recombination is a greatly complex process. It involves the alignment of two homologous DNA strands (the requirement for homology suggests that this occurs through complementary base pairing, but this has not been definitively shown), precise breakage of each strand, exchange between the strands, and sealing of the resulting recombined molecules. Both eukaryotic and prokaryotic cells experience this process with high precision and regularity (Clancy, 2008).

Consider a cross between two parents having different genotypes AAbb and aaBB. A cross between them will generate an F1 of genotype AaBb. In the F_2 segregating population, and according to Mendel's law, the gametes (AB, Ab, aB, and ab) will mix to form variability, some of which will be old (like the parents - parental), while others will be new (unlike the parents-recombinants).

2.2. Ploidy Modification

Ploidy modification refers to only changes in the number of chromosome sets, i.e., not single chromosomes. We use the term 'genome instability' to refer to an increased frequency of mutations, agnostic of mechanism, typically involving an increased rate of chromosome gain or loss.

Natural changes in chromosomal number due to hybridization (between genotypes that are not identical) or irregularities in the nuclear division processes (spindle malfunction) may result in the emergence of new variability. Incorrect chromosome numbers transferred to cells, such as polyploidy (individuals with multiples of the basic set of chromosomes for the species in their cell), can result from the spindle process failing during karyo-kinesis or even before that. Aneuploidy is the term for when plants are created with multiple copies of just some chromosomes or deficits of other chromosomes rather than changes affecting entire sets of chromosomes. Sometimes, plants are produced with half the number of chromosomes in the somatic cells (called haploids) (Acquaah, 2004).

2.3. Mutation

Mutation is any change in the DNA sequence of a cell. Both exposure to environmental DNA-damaging chemicals and mistakes made during cell division can result in mutations. It is the main source of biological variation. They develop spontaneously in nature because of mistakes in cellular functions including DNA replication (or duplication) and chromosomal abnormalities (deletion, duplication, inversion, and translocation). Plant breeders may also cause mutations using chemicals and radiation. Many beneficial mutations, such as dwarfs and nutritional quality genes, have been discovered in nature or created by plant breeders. They persist in the population in the heterozygous state as recessive alleles and become expressed only when in the homozygous state, following an event such as selfing (Acquaah, 2004).

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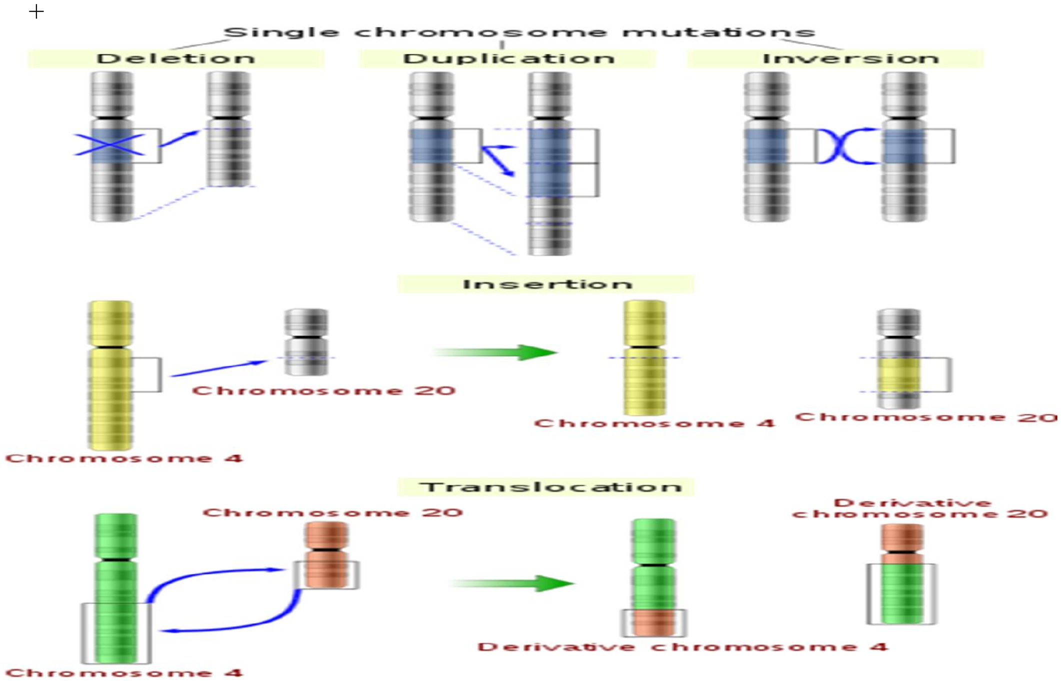

Fig. 1: Five types of chromosomal mutation

2.4. Transposable Element

Transposable elements are defined as DNA sequences that are able to move from one location to another in the genome. Transposable elements have been identified in all organisms, prokaryotic and eukaryotic, and can occupy a high proportion of a species genome. The mobilization of transposable elements is termed transposition or retro-transposition, depending on the nature of the intermediate used for mobilization.

2.5. Gene Transfer

The most advanced method of gene transfer for creating genetic variability for plant breeding is rDNA technology. The DNA is universal, with a few tiny exceptions. Consequently, a plant may receive DNA from an animal. Genes from distant sources may be incorporated using biotechnology methods into adaptable cultivars (Acquaah, 2004). Variation in biological traits is a result of the natural process of gene transfer from a living thing to another. Gene transfer in plants, also known as plant transformation, depends on the effective integration of foreign DNA into the target plant cells as well as the subsequent growth of a full plant from the transformed cells. Plant transformation methods therefore require an efficient way to introduce DNA into cell and the regeneration of the transformed cells or tissues into whole plants.

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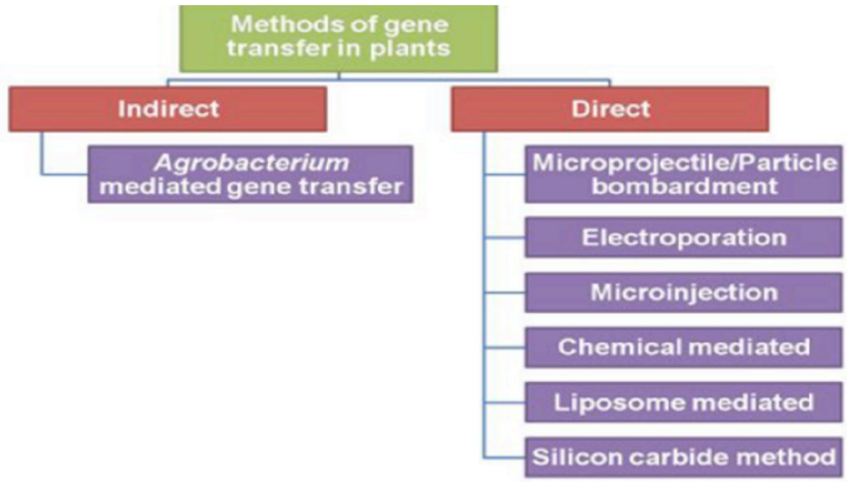

Fig. 2: Method of gene transfer in plant

The transfer of genes from the nucleus and cytoplasm occurs in plants through protoplast fusion. Although the fusion product must be backcrossed to, the recipient line for several generations to establish a new, stable line and the desired form from the donor must be present in this line for the fusion to be successful. Fusion joins the genomes of two parents, just like traditional breeding; however, results are often acquired more quickly. Protoplast fusion can be used for transferring genes that are hard to identify, isolate, and clone or for polygenic traits. Furthermore, protoplast fusion can be used for plants that cannot be crossed sexually (although plants regenerated from such fused hybrids may sometimes be sterile) (NRC, 1987).

2.6. Soma-Clonal Variation

Soma-clonal variation is the variation seen in plants that have been produced by plant tissue culture. Chromosomal re-arrangements are an important source of this variation. Soma-clonal variation is not restricted to, but is particularly common in, plants regenerated from callus.

3. Scale of Variation

The difference in one or a few traits of the organism is referred to as variability. In common, parlance, genetic variability and genetic diversity are considered synonym to each other, which is erroneous. Genetic variability is the variation in alleles of genes or variation in DNA/RNA sequences in the gene pool of a species or population. This expresses itself in terms of alternate forms in phenotype. Genetic diversity, on the other hand, is a broad term encompassing all the variability occurring among different genotypes with respect to total genetic make-up of genotypes related to single species or between species (Swingland, 2001). Genetic diversity can be measured by counting the number of different genes in a gene pool, but genetic variation can only be expected to occur and cannot be measured. Genetic variability thus, can be considered as the building blocks of genetic diversity.

3.1. Quantitative Variation

Quantitative traits are measurable phenotypic traits of degree, such as height, weight, skin color, susceptible to pathological disease or intelligence in human, the quantity of flowers, fruits, seeds, milk or eggs produced by plants or animal. These traits are economically significant phenotypic traits. The quantitative traits are also called metric traits. They do not show clear-cut difference between individual and form a spectrum of phenotypes which blend imperceptivity from one types to another genes (polygenic inheritance) with effect that are too small to be individual distinguished. They are sometimes called minor gene. The variation in environmental condition that plants in the population are exposed to considerably alters how quantitative traits are expressed (Acquaah, 2004).

3.2. Qualitative Variation

Qualitative variation is simple to categorized, study and applies in breeding. It is simply inherited (regulated by one or a few genes) and can be studied using Mendelian genetics. The qualitative traits are the traditional Mendelian traits of kinds like form (round or wrinkled seeds of pea), structure (horned or hornless condition in cattle's), pigments (black or white coat of guinea pigs), antigens and antibodies (blood group types of people), and so on. A single gene with two or more alleles may be responsible for a particular qualitative characteristic, and there may be little to no environmental interference with the gene's effects. It is believed that the organisms that exhibit qualitative traits belong to distinct (independent) phenotypic classes and show discontinuous variations (Acquaah, 2004).

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

4. Implication of Genetic Variability in Crop Improvement

Genetic diversity has been the basis of plant breeding since the earliest days of agriculture. It serves as the raw material for plant breeders to develop new cultivars that can address grower needs, adapt to climate change, and meet the increasing food demand globally. Diversity in plant genetic resources provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics, which include both farmer-preferred traits (yield potential and large seed, etc.). Genetic diversity helps breeders to maintain the crossbred varieties, which leads to sustaining the desirable traits of the varieties, such as quality characteristics and tolerance to various stresses. Maintaining high genetic diversity allows species to adapt to future environmental changes and avoid inbreeding. Inbreeding, which happens when there are small, isolated populations, can reduce a species' ability to survive and reproduce. Genetic variability for agronomic traits is the key component of breeding programmes for broadening the gene pool of both rice and other crops (Acquaah, 2004).

Creating sufficient genetic variation for golden crop improvement is becoming challenges to keep improving genetic yield potential. Nowadays, plant breeders are utilizing genetic materials without knowing its genetic background such as exotic non-adapted, exotic adapted and existing genetic material as a source of new alleles that protect and improve genetic gain through selection. In ensuring food and nutritional security, genetic diversity is contributing very amble quantity (Begna, 2021). Knowledge of genetic diversity of the genetic material is very critical in crop improvement. Effective selection is highly important in any crop improvement where the sufficient genetic variation is available for different characters. The genetic variability analysis of crop cultivars for different agronomical and morphological characters are very critical in providing opportunity to select a number of promising cultivars. Genetic variation is the foundation for the continuous development of new superior varieties. Hence, characterization of genetic materials using different statistical tools is critical in the crop improvement program. Improvement for both qualitative and quantitative traits are primarily relying on the genetic diversity (Begna, 2021).

Genetic diversity is the base for crop improvement and existence of crop pant in nature. It clear that the genetic diversity offers opportunity for improvement of cultivars with desired traits, which consist both farmer-preferred traits and breeder-preferred traits. To meet subsistence food requirement, genetic variability has been used in beginning of agriculture. Nowadays, climate adapted cultivar development is the issues of plant breeder since the climate components are fluctuated and causing adverse problems on the normal growth and development of crop plants (Begna, 2021). The availability of genetic diversity directly related with presence of desired alleles and help to develop in breeding climate resilient varieties. Sustainability of crop production and food security is being threatened by the increasing unpredictability and severity of drought stress due to global climate changes.

The incorporation of the adapted natural genetic variations into breeding programs can enrich the current genetic diversity of stress tolerance and improve yield under stress. Genetic diversity enable for the development of high yields of farmers and breeders preferred improved quality cultivars. Genetic diversity also playing paramount role towards the development of potential varieties against new diseases, insect pests, extreme heat and extreme cold. Genetic diversity facilitates the development of varieties for specific traits like abiotic and biotic stresses tolerance and quality improvement. Food and Agriculture Organization reported the depletion of genetic diversity as the most serious environmental concerns (Smale *et al*., 2002). In general, genetic diversity strictly the amount genetic variation available between crop species (Cardinale *et al*., 2012).

Genetic variation is essential for natural selection because natural selection can only increase or decrease frequency of alleles that already exist in the population. A population benefits from it because it allows some individuals to adapt to their surroundings while still ensuring the population's survival. Genetic variability study for agronomic traits is a key component of the breeding program for boarding the genetic pool of crop (Singh, 2001). Variation allows some individual within a population to adapt to the changing environment. A population with more genetic variability typically has more phenotypic variability since natural selection only affects phenotypes directly. New alleles can improve an organism's capacity for reproduction and survival, which helps to ensure the allele's survival in the population. Other novel alleles could be instantly harmful (for example, a malformed oxygen-carrying protein), and the organisms that contain these mutations will eventually become extinct. Neutral alleles are neither selected for nor against and usually remain in the population. The ability of some individual and, consequently, a population, to survive in spite of a changing environment is one of the benefits of genetic variability.

5. Conclusion

Generally, plant breeding primarily depends on presence of substantial genetic variation to address the maximum genetic yield potential of the crops and exploitation of this variation through effective selection for improvement. The availability of genetic variation is the key prerequisite to successful plant breeding. Plant breeding is focusing on the creation of genetic variation and applying appropriate selection procedures for improvement of quantitative and qualitative characteristics. Sufficient genetic variation offers alternatives from which selections are made for improvement of crop plants. Phenotypic expression is the result of genotype, environment and genotype-environmental interaction and yield is the result of several different factors.

Genetic variability, which decides the fate of effective plant breeding program. The existence of tremendous genetic variation and efficient selection are two essential prerequisites in plant breeding. There is a possibility to broaden genetic variability through utilizing wild related species in conventional crosses, whereas novel genetic characters can be obtained through induced mutation. Crop improvement is imperative process to address the increased human population and climate. A success in crop improvement is depending on the quantity of genetic variation exist in the genetic materials and selection for genetically superior genotypes.

Determination of genetic diversity and their relationships among breeding materials is very crucial in crop improvement strategies. Characterization and evaluation of germplasm is pre-requisite to screen out the desired genetic materials for the genetic improvement programs. The collection of germplasm relies on the several number of accessions it possesses and the genetic materials available in those accessions for yield and yield components. Climate change and geographical isolation are identified as two majors in the formation of new species. The other sources of germplasm diversification and evolution are biotic factors like competition and predation among themselves. Phenotypic characters are the most important conventional tools to analyse variation among the genetic materials and the visible morphological traits are very crucial tools in genetic diversity investigation. Plant breeding is primarily relied on the variation exist in the genetic diversity of cultivated and their wild relatives together for further improvements. Plant phenotyping is defined as the investigation of plant characters by researchers for yield, quality and resistance to biotic and abiotic stresses. Genetic variation and selection are the two basic principles of plant breeding.

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