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Breeding Strategies for Improvement of Drought Tolerant in Crops

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Abstract: Drought is one of the most severe abiotic stresses in many regions of the world, and it is one of the most urgent issues in the current climate scenario. Drought-tolerant varieties are in high demand, which appears to be a challenging task for plant breeders. However, difficulties are complicated by crop production challenges on genetic and physiological bases. Drought is one of the most major environmental factors affecting crop productivity and quality around the world. Drought mostly impacts crops that thrive in wetland conditions, which account for 80% of all farmed land in the world. Climate change raises the likelihood of increased drought in many regions of the world in the next decades, causing crop damage as a result of abnormal metabolism and perhaps reducing crop growth, crop death, or crop development death. Drought resistance is defined as the mechanism(s) that cause the crop to lose the least amount of yield in a drought environment compared to the highest yield in a constant-free of optimal environment. Drought stress reduces the size of the leaves, stem extension, and root proliferation inside the soil; it also disrupts plant water relations and reduces water-use efficiency, reducing the plant's yielding ability. Therefore, breeding for drought resistance is a good approach, combining both conventional and molecular approaches to develop a drought resistant variety. Root morphology research, proline estimates, and leaf rolling are all factors to take into account. Breeding improved drought-tolerant cultivars may be more effective if selection is based on a comprehensive approach to testing. Water stress also affects the crop's physiological activity by inhibiting photosynthesis and assimilates consumption in the growing leaves. Plant hormones play a key role in transducing the stress signal, with abscisic acid (ABA) being the most important among them. To alleviate suitable crop productivity under environmental stresses, scientists developed various breeding strategies, such as conventional breeding, which works for both self-pollinated and cross-pollinated crops and is used to develop or improve cultivars using a basic conservative tool for manipulating plant genomes within the natural genetic boundaries of species. Pedigree, recurrent selection, back-crossing, and mutation breeding are among the conventional breeding strategies used to generate cultivars that can withstand drought stress.

Key words: Drought · Conventional Breeding · Photosynthesis · Crop Yield

INTRODUCTION

Climate change and population increase are the two main obstacles to food security. The world's population is growing fast, which raises the need for food and imposes more pressure on resources available, particularly agricultural land [1]. By the end of 2030, the population is expected to exceed eight billion, and by the end of 2050, it will surpass nine billion [2]. In order to allay fears of acute hunger by 2050, agricultural productivity must increase by 49%. An annual growth of 1.1-1.3 percent of the major cereal crops from the current pace is required to solve the hunger and severe food crisis by 2050 [3]. The failure to boost crop productivity will negatively damage the developing countries and can lead to famines and social distress. Additionally, there are numerous reasons that negatively impacted crop productivity, including economic, agronomic, sociological, and meteorological issues. To manage this enormous burden of ensuring the safety and security of the world's food supply is a significant challenge for plant breeders and policymakers [2]. Only if agricultural productivity rises in a sustainable way is the goal of a world without hunger attainable [4].

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Extreme weather patterns caused by global warming intensify biotic and abiotic stresses and contribute to the loss of agricultural land [5]. It is difficult to breed for crop resilience under a variety of climate stressors since future predictions and implications of climate change are unpredictable [6]. The difficulty is made worse by the fact that variations in annual rainfall and temperature have a detrimental impact on crop growth and stimulate crop disease attacks [7]. According to reports, each degree of temperature increase resulted in a 10-25 percent yield reduction for major staple crops like wheat, maize, and rice [8]. This is due to an increase in temperature accelerating the metabolic activities of insects and enhancing insect's food consumption rate.

Plant breeding first became a major strategy for domesticating plants around 10,000 years ago by using wild relatives to choose the desired traits through a continual selection process over several generations for crop improvement [9]. Around the world, numerous significant crops that have undergone a breeding process are widely cultivated. Elite crop varieties have often been chosen through hybridization and a constant screening process in classical breeding [9]. By crossing plants with novel agronomic properties with wild relatives or crop landraces, basic plant breeding principles enable the assimilation of genetic variation and enable the selection of the best genotypes with exceptional traits [10].

Investigations of wild populations can offer increased genetic variation to introduce the desired traits to generate new crop types, which provide an ideal roadmap for agricultural improvement. For example, the introduction of different genetic recombination through hybridization among species may offer an excellent chance to combat climate stresses [11]. However, due to genetic drag, genetic erosion, hybridization bottlenecks, and tedious selection processes, conventional breeding strategies for crop development are of limited use [1]. A crop variety with the needed traits may take 10 to 20 years to develop, making it a challenging and time-consuming task [3]. The challenges given by conventional breeding techniques, on the other hand, have been successfully solved in the last three decades by modern breeding approaches like genetic engineering to develop genetically modified crops.

In order to improve production and quality of food components, ease of cultivation, harvest, and processing, tolerance to environmental challenges, and pest resistance, plant breeders must choose better types among variations. Each of these agronomic or nutritional value factors can be broken down into a variety of distinct traits, each with a unique range of variation. It is rather simple to manipulate a single trait while disregarding all others, but this is unlikely to produce a useful variety [12]. The difficulty of plant breeding is in simultaneously enhancing all of the desired traits. This process is complicated by genetic correlations between various traits, which may result from pleiotropic genes, physical linkages between genes in the chromosomes, or population genetic structure [13]. Correlated traits will alter when one characteristic is chosen, sometimes in the desired direction and sometimes not [14]. Because of this, selection may result in unexpected alterations. These changes, however, are typically expected and thought to not pose a risk to consumers or the environment because they fall within the normal range of variation seen in the crop. Whether this assumption is reasonable or not is a matter of debate [15].

The creation of crop types that are drought-tolerant has advanced significantly due to conventional breeding techniques [16]. However, it frequently takes many years for this labor-intensive procedure to get from the early phases of evaluating phenotypes and genotypes to initial crosses into commercial cultivars. Conventional breeding risks (indirectly) choosing only those alleles that are advantageous in all tested environments by neglecting the genetic diversity of adaptive characteristics that underlie yield. When compared to alleles whose effects are reliant on circumstance, the ones chosen in this way are less common [17]. Contrarily, context-dependent trait optimization may maximize favorable impacts on yield in particular environmental situations. In order to enhance the production of cultivars that are more adapted, future breeding programs will need to integrate desired plant traits that complement the climate, soil, and management strategies utilized in the target production systems.

The process of genetically altering crop plants' structures or functions to increase their capacity for survival and reproduction under drought conditions is referred to as improving adaption to drought [18]. It is generally accepted that improved breeding efforts and financial investments have been made under drought-prone regions for more than 50 years to improve drought tolerance [19, 20]. Drought generally ranks among the most important elements that influence crop growth and development, harming plants and perhaps reducing yields. The impact of climate change would further diminish the availability of water for agriculture, which is already a global concern. In order to increase agricultural production, cropping techniques must be better adapted, and new plant types must be created. The continued development of enhanced crop varieties that maintain higher yields with the least amount of agronomic inputs and are better suited to climate change will be crucial for ensuring future food security. At the beginning, middle, or end of the crop cycle, crops may experience varying drought conditions, ranging from mild to severe drought episodes. Understanding potential breeding techniques to improve drought tolerance in crop plants was the paper's main goal.

Impact of Drought on Growth, Development and Yield of Crops: The two main mechanisms influencing plant growth are cell division and cell growth. When compared to cell expansion or growth, cell division is generally thought to be less sensitive to drought. Under drought stress, leaf area expansion is frequently constrained, which significantly reduces the growth and development of the transpiration surface. One of the growth processes that is most vulnerable to drought is leaf expansion. The region's cell development and metabolism are most frequently altered by drought stress. Water stress is identified by a drop in the plants overall water capacity, turgor, and cell water status, which results in stomatal closure, wilting, and a reduction in cell growth and development. However, extreme water stress could bring to the termination of photosynthesis, aggravation of metabolism, loss of turgidity and eventually cell death. Low turgor pressure severely restricts cell proliferation, which inhibits plant growth and development as well as yield characteristics. During the reproductive stages of development, crops are typically more susceptible to drought and/or heat stress, which mostly affects seed production [21].

Drought is recognized as a multidimensional stress impacting plant cellular activity, growth, development and economic yield formation through alteration in metabolism and gene expression [22]. Different plant growth and development events are strongly impacted by drought. It is clear that drought stress significantly reduces seedling stand and germination. Drought stress can harm a plant whose aberrant metabolism has led to reduced growth, plant death, or the development of plant death. The percentage and rate of germination, as well as the length of the roots and shoots, decreased in millet as the severity of the drought increased. Under conditions of mild water stress (-0.20 MPa) and severe water deficit stress (-0.85 MPa), the rate of sorghum germination decreased by 23% and nearly 50%, respectively. The distinct stages of crop growth are likewise impacted by moisture deficits, which slow germination, shoot growth, and dry matter production. In addition, the effects of drought are seen in reduced production of fresh and dry matter, delayed tillering, shorter first internodes, early senescence, discolored fruit, and untimely death.

As a result, drought spells are becoming more frequent and last longer. Important plant growth and development processes, such as germination, plant height, stem diameter, number of leaves, size and area of leaves, production and partitioning of dry matter, flower and fruit production, and maturity, are all affected by drought stress. For the selection and breeding of drought-resistant genotypes, it may be promising to identify the impact of drought stress on morphological traits and morphological changes in response to drought. The grain filling rate is finished before the seed maturity stage when a crop is subjected to drought stress during grain filling. Therefore, extreme moisture stress shortens the time grains fill out, changes grain size, and degrades grain quality. Because of the growth phase's impact on grain quantity, weight, and shape, most grain crops are sensitive to dry conditions.

Conventional Breeding Strategies: The practice of creating new plant cultivars without the use of cutting-edge molecular breeding technology is known as conventional breeding. The inherent law of inheritance is not broken by conventional breeding. In conventional breeding, which employs selective breeding, plants are chosen based on their greater performance on particular traits [23]. Because multiple types of abiotic stress can pose a problem for crop plants at once and a variety of variables have contributed to water stress, breeding for drought tolerance is made more difficult. Major crop production losses are mostly caused by high temperatures, high irradiance, water scarcity, and nutritional deficiencies. Expected average yields of the major crops have been reduced by more than 50% as a result. All of these biotic stresses are frequently present during typical growing conditions, and they may not be manageable with conventional farm practices. The equilibrium of these various stresses can also be influenced by the composition and structure of the soil. Higher plants have developed numerous, related coping mechanisms that allow them to endure erratic environmental changes. However, these tactics aren't usually well established in the many farmer-grown crop cultivars [24].

To address the challenges caused by the drought, scientists create new breeding strategies. Due to the effects of climate change, traditional farming methods are no longer successful in reducing agricultural productivity when faced with environmental stresses. As a result, we must convert to a modern production system that includes new agronomic and breeding strategies. The empirical approach, in which the plant breeder directly selects the breeding stock for yield per se, and the analytical approach, which emphasizes the improvement of yield through indirect selection for morphological, physiological, or biochemical traits associated with yield, are the two main methods for increasing economic yield. The empirical technique yields a plant population that is adapted to certain drought conditions, and it should be used in the target habitat. Since yield has a low heritability, selection based on this complicated characteristic is challenging and results in only very slowly improving yield. The majority of breeders gradually replaced this empirical approach with indirect selection based on the selection for secondary traits or plant characteristics that provide additional information about how the plant performs under a given environment after having used yield under drought as an exclusive breeding objective.

The indirect selection criteria should demonstrate correlations with yield in a drought-prone environment. In order for breeding populations to respond well to selection, the trait(s) of interest should have high narrow-sense heritability. Additionally, the trait(s) should, to the extent practicable, be simple to measure and non-destructive to plants. The enhancement of drought tolerance in tropical maize at the International Center for Wheat and Maize Improvement (CIMMYT), in Mexico, serves as a good example of indirect selection. Anthesis-Silking Interval (ASI), leaf rolling, and leaf senescence were found to have substantial phenotypic relationships with yield. With increasing water stress, genetic variations of traits that contribute to yield generally reduced. Anthesis-silking interval and kernel spike-1, however, demonstrated an increase in genetic variance. These traits are advantageous for indirect selection since their heritability estimates were greater than those for yield. Significant improvements in drought tolerance were obtained in populations with a wide genetic base through indirect selection for yield.

Pedigree Methods: Numerous initiatives have been launched to improve the effectiveness of genotype selection for drought tolerance based on yield and certain physiological traits. To increase crop productivity, self-pollinated species (and even cross-pollinated species, like maize and other hybrid crops) are frequently bred using the pedigree selection method. In most self-pollinated crops, this strategy is ideal for creating resistant cultivars, especially if the trait is controlled by important genes. The ability to combine many genes affecting biotic and abiotic processes is one of the main benefits of pedigree selection.

Pedigree selection's main drawback is that it takes a lot of time and necessitates routinely evaluating numerous lines across planting seasons while maintaining a record of the selection criteria. Pedigree selection, one of the breeding techniques, demands for a thorough understanding of the breeding materials as well as the impact of genotype and environment on desirable traits. The diallel mating design will be acceptable for selection in this scenario. This strategy is not suitable for the characteristic under the impact of many genes (quantitative traits). Breeders must create high yielding crop types with significantly increased tolerances to salinity and drought in order to attain high yield (HY) and yield stability through breeding [25]. Generally, in most self-pollinating crops including rice, plant breeders prefer recurrent selection over pedigree selection.

Recurrent Selection: Hull [26] coined the concept "recurrent selection," which refers to the process of repeatedly selecting desirable traits to increase their frequency solely from crosses between high-performing individuals [27]. Crossing occurs between an inbred person and a heterozygous recurrent parent. It helps in preserving diversity and raising the gene frequency of desired traits. Cross-pollinated crop breeding is the only application of the technique [28]. Initially and widely used in maize, recurrent selection has since been used in rice, millet, wheat, and soybeans [29].

Recurrent selection is the preferred strategy for population improvement because the pedigree breeding method is not frequently utilized. Several plants are promoted to the following generation in this breeding technique, which involves another cycle of intercrossing. The result is an improved population (better than the initial population in mean performance as related to trait(s) of interest) with substantial genetic diversity. This procedure is repeated for numerous cycles (thus, recurrent selection). Repeated crossing offers a chance for genetic recombination to take place, increasing the genetic diversity of the population. This also increases the chance that links will be severed. Numerous parents are used in Recurrent Selection (RS), which is regarded as the best breeding strategy for continuously raising the level of quantitative traits in breeding populations.

Recurrent selection is used to increase the number of beneficial alleles in a population while maintaining genetic variation in varietal development. In addition to more accurate genetic benefits and the creation of extremely diversified breeding lines, it offers shorter and more defined breeding cycles. This method has been used extensively for a variety of cross-pollinated crops, mostly for maize. The use of genetic male sterile (MS), which made it easier to apply recurrent selection frequently to self-pollinated crops like rice, later, eliminated the hard and ineffective artificial crossing problem. This technique has been used successfully in wheat to increase grain yield and grain protein content. In conclusion, this strategy has been found to be more effective than the pedigree selection method in terms of better agronomic traits and enhancement of drought tolerance. Recurrent selections come in three different types [30], and they are as follows:

Simple Recurrent Selection: For characters with a high heritability, this method is used. With this approach, crops with open pollination are selected phenotypically. The chosen persons are selfed after selection. Selfed parents' offspring are raised in a crossing block and intercrossed. The offspring of intercrossed individuals are once more chosen and raised in a different crossing block. Until no additional improvement between the intercrossed parents and the chosen progenies is detected, the process is repeated.

Recurrent Selection for Combining Ability: In this strategy, tester plants and parents with superior phenotypes are chosen. These experimental plants could be homozygous or heterozygous. This strategy involves doing two things at once in the first year. First, superior parents are "selfed," and the offspring that result from this selfing are raised in a crossing block. The chosen population is test crossed with tester plants in parallel, and the offspring resulting from this are evaluated in repeat yield trials. It is anticipated that progenies with greater mean yield trial performance will have good combining ability. High performing tester progenies' selfed parents are chosen, cultivated once more, and intercrossed in a crossing block. These plants' collected seeds were sown, and the test crossing and selecting cycle is repeated as in the first year. And can repeat the cycle till you don't even get the required character. Characters controlled by either excessive or insufficient dominance respond well to this approach.

Two original open-pollinated plant populations are chosen using this procedure. These original plants serve as test specimens for one another. Each of the populations is selfed, and the offspring produced are raised in a separate crossing block. Test crosses are undertaken simultaneously, and the offspring from each test cross are then individually submitted to repeat yield trials. Parents of test progeny displaying superior performance are chosen, and test crossing and selfing are carried out once again. Until the required character is not produced, this cycle can be repeated. For character influenced by both additive and non-additive gene action, this strategy is used.

Back Cross Breeding: Backcrossing is the practice of mating an F1 hybrid with a homozygous parent to create offspring who are genetically identical to the parent [31]. Backcross breeding is a technique for transferring a desirable trait from a less developed plant into a more developed one while maintaining the latter's other traits. It is a technique for creating hybrids that are more like their parents and have more desirable traits. Backcross breeding is a common method of selection [32]. The offspring are the same repeating parents after backcrossing repeatedly for three to four generations. Nearly 98 percent of the recurrent parent genome must be recovered by a backcrossed progeny. It is produced after five to six generations of repeatedly backcrossing hybrid progeny with a common parent [33]. Selection of characters other than transferred one is ineffective in those progenies as the traits nearly matched with repeatedly backcrossed parent [34].

Uneven gene contribution in newly produced variety from two parental lines is the most frequent characteristic of backcross breeding. Fewer genes come from the donor parent and more come from the recurrent parent [35]. In this strategy, donor parents are plants that already have the desired traits, while recurrent parents are plants that get the chosen genes. To create hybrid offspring, two parents cross each other (F1). The F1 progenies are chosen based on the desired features. To create back cross hybrids, the selected F1 progenies are grown and then crossed with recurrent parents (BC1). The BC1 generations are chosen for the desired character, and the character is then cultivated in separate fields. Following that, BC1 individuals are crossed with their repeated parents once again. Up until the sixth back cross generation (BC6) is created, the process is repeated. For the purpose of making seeds, the resulting BC6 generation is grown. In the presence of the recurrent parent as the check variety, numerous yield trials are carried out at various sites. The recently developed variety should to resemble its recurrent parent.

Backcross breeding is used to maintain all other traits while transferring one or a small number of targeted genes of interest from a source (donor parent) to an adapted cultivar (breeding line). This method offers a precise and accurate method for creating numerous superior breeding lines. Drought-tolerant crop varieties have been developed as a result of backcrossing techniques. According to the research, increasing drought resistance in a variety of crop plants may be accomplished by backcross breeding, direct selection for yield, and stressed nurseries. Today, a transgene is most frequently transferred to an elite experimental line or variety using the backcross process from a good tissue culture variety that was used in the transformation. It turns out that species crossover is more effective than transformation techniques for many crops once the transgene has been incorporated into the crop. Since most transformation techniques are designed for a particular laboratory line, which is frequently poorly adapted and lower yielding, backcrossing is more effective than transforming the elite line. Transformation is difficult for many elite lines. However, breeders can backcross the transgene from the lab line into the elite line and genetic engineers can modify their lab line.

Mutation Breeding: Crops grown in areas prone to drought can become more drought-resistant through the use of mutation breeding. In more than 60 nations around the world, 3222 plant mutant varieties from 170 different plant species have been officially released as a result of the extensive usage of induced mutants in plant breeding programs. The produced varieties contribute directly to the preservation and utilization of plant genetic resources by enhancing biodiversity and providing breeding stock for traditional plant breeding. Not every nation has created mutant strains to boost food production and offer sustainable nutrition through mutation breeding. The ultimate method for changing crop plants' genetic makeup that may be challenging to achieve through cross-breeding and other breeding techniques is to induce mutations. Since new food crop varieties embedded with various induced mutations have led to the large rise in crop production in locations people could directly reach, induced mutations have played a vital role in enhancing global food security.

Climate change is a major concern today, and it also leads to environmental stresses that impose additional pressure on the world's food production. As a result, the producer raises their desire for crop varieties that can withstand stress. Abiotic stress factors, such as drought, high salinity, heavy metals, and severe temperatures (hot, cold, and freezing), pose a threat to crop output because they restrict plant growth and development. The yields of the primary food crops are anticipated to drop in many locations in the future due to the continuous loss of arable land, the depletion of water resources, and the acceleration of global warming trends and climate change, according to several climate projections [36]. The production of gene alleles that are not found in nature and that are resistant to abiotic and biotic stressors is induced mutation's main benefit over normal plant mutation breeding. A breeding program or a commercial cultivar can both employ the novel gene alleles produced in the new variety.

CONCLUSION

One of the main causes restricting agricultural production is drought, which has a negative impact on global food security. Important plant growth and development processes, such as germination, plant height, stem diameter, number of leaves, size and area of leaves, production and partitioning of dry matter, flower and fruit production, and maturity, are all affected by drought stress. The fact that multiple types of abiotic stress can simultaneously present a problem for crop plants while also causing water stress makes drought tolerance even more challenging. To solve the challenges caused by the drought, scientists create new breeding strategies. Conventional breeding and marker-assisted selection are two examples of breeding approaches used in crops that can withstand drought.

The development of new cultivars with higher yield potential through backcrossing is one of the conventional breeding procedures for drought resistance. Pedigree breeding also produces cultivars with drought resistance, but it takes time and necessitates the evaluation of numerous lines. Recurrent selection is the preferred method for population improvement, which is not possible handled by a pedigree method, and induced mutation is another important conventional breeding technique that improves the drought resistance of the crop by creating gene alleles that are not found in nature and that resist the abiotic and abiotic stresses.

To eventually meet the dietary requirements of the entire human population, crop production must rise; yet, this effort is complicated by the shifting environmental conditions. We are moving toward a warmer and drier Earth as a result of the "climate crisis" brought on by the changing climate. Drought-related losses to agriculture's worldwide economy in the last ten years came to over US $29 billion. The availability of freshwater is expected to decline by up to 50% due to increased climate variability by 2050, leading to a potential two-fold rise in water demand for agriculture. Investments in this area are urgently needed for food security, especially for the creation of high-yielding crops that are tolerant to changing climates and more effective and/or efficient at using water than their current equivalents.

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