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Review Article

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Conventional Breeding Strategies for Improvement of Drought tolerant crops: A Review

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Abstract

Drought is one of the prominent environmental stresses which is significantly hampering crop yield and its quality in the globe. Drought is mostly affects the crop which grows under the rainfed condition, represents 80% of the total cultivated area worldwide. Climate change increases the odds of worsening drought in many parts of the world in the decades ahead which damage the crop that has occurred as a result of abnormal metabolism and may reduce growth, crop death or death of crop development. The physiological activity of the crop also influenced by water stress through suppressing photosynthesis and the consumption of assimilates in the expanding leaves. Plant hormones are crucial factors in transducing the stress signal and the main player among them abscisic acid (ABA) where the stress occurred. To alleviate suitable crop productivity under the environmental stresses scientists developed different breeding strategies like conventional breeding which works for self and cross-pollinated crops and used to develop or improve cultivars using a basic conservative tool for manipulating plant genome within the natural genetic boundaries of species. Among the conventional breeding strategies pedigree, recurrent selection, Back-crossing and mutation breeding which are mostly important to develop cultivars that can tolerate drought stress.

Keywords: Drought, Conventional breeding, Photosynthesis, Crop yield

Introduction

Background

Water is the most limiting factor in crop production. In tropical regions of the world, moisture extremes are prevalent. There is either too much of it when the rain falls, or there is little or lack of rainfall. However, water stress occurs when plants unable to meet their evapotranspiration. It is induced by the unavailability of water due to erratic rainfall or inadequate irrigation and can be aggravated by other factors such as soil salinity and physical properties, and high air or soil temperature. Soil salinity makes water unavailable to plants by inducing osmotic stress. Soil texture and structure determine various properties such as porosity and surface roughness which in turn affect soil holding capacity and water infiltration. Water stress symptoms appear more rapidly on plants grown in sandy as compared to clay-textured soils, due to enhancing the storage and supply of water to the plant. High temperatures on crops are amplified by water deficits by increasing transpiration and water loss [1].

Drought is a major cause of yield and quality loss in cereal crops throughout many of the world's cereal-growing areas. Therefore, drought is responsible for severe food shortages and famine in developing countries. The Horn of Africa is strongly affected by drought almost every 12 years however, the drought exaggerated during 2009– 2011. Around 17 % of the global cultivated area was mostly affected by drought during the period of 1980-2006. Wheat yield was highly reduced by 45% in Kenya during the year 2009-2011 and by 46 % in Australia in 2006. Drought mostly affects crops that are cultivated under rainfed conditions, which represent 80% of the total cultivated area worldwide. In Asia around 20% of the total rainfed rice areas which mean at least 23 million ha are cultivated under drought-prone conditions. Even if we see in Pakistan 56% of sorghum and millet, 27% of Maize, 84% of Pulses, 77% of chickpea, 52% of barley, 33% of wheat and 100% of castor beans are cultivated under the rainfed conditions and extremely affected by drought.

During the past 50 years, many efforts have been done to improve the crop yield, most of the yield progress in wheat has been due to the gradual replacement of traditional tall cultivars by a dwarf and fertilizer-responsive varieties. When the plant height reduces, it has also increased the proportion of carbon partitioned to grain and increased the harvest index. It has also reduced the risk of yield penalties caused by lodging. The objective of the current review is to provide a comprehensive summary of the Conventional breeding for drought tolerance which may pinpoint future research directions to improve drought tolerance crops and it shows the effects of drought on physiological and developmental effects of crop.

Impact of Drought on Growth, Development, and Yield of crops

Cell division and cell growth are the two primary processes involved in plant growth. In general, cell division is considered to be less sensitive to drought when compared with cell enlargement or growth. Leaf area expansion is often limited under drought stress, such that the expansion and development of the transpiration surface is drastically decreased. Leaf expansion is among the most sensitive growth processes to drought. Drought stress most commonly alters the cell growth and metabolism in this region. Water stress is determined by a decline in cell water status, turgor and aggregate water capability of plant bringing about stomatal closure, wilting, and decreases in cell growth and development. However, extreme water stress might bring about the cessation of photosynthesis, aggravation of metabolism, loss of turgidity and lastly cell death. Low turgor pressure tremendously limits cell development, hence causing lessened plant growth and development, and yield qualities as well. Crops are generally more sensitive to drought and/or heat stress during the reproductive stages of development, which mainly influences seed numbers [2].

The effects of drought are prominent in different plant growth and development events. It is evident that drought stress seriously diminishes germination and seedling stand. Drought stress can damage the plant which has occurred as a result of abnormal metabolism and may reduce growth, plant death or the death of the plant develops. With increasing severity of drought, the percentage and rate of germination, root and shoot length were reduced in millet. The rate of germination of sorghum reduced by 23% under mild water deficit stress (-0.20 MPa) and by nearly 50% under severe water deficit stress (-0.85 MPa) conditions. Moisture deficit also affects the different levels of crop growth and delaying germination addition, the growth of shoot and reduce the production of dry matter. Besides, impacts of drought are reflected to diminish fresh and dry matter production, delayed tillering, shorter first internode, early senescence, fruit discoloration, and unexpected death. As reported by Drought which encountered at the reproductive stage causes an apparent delay in silking, while anthesis is not postponed to such a degree. Therefore, it leads to an increase in the Anthesis-to-Silking Interval (ASI) which is a critical reason for the final yield reductions under drought stress. Therefore, Drought episodes are increasing with varying intensity and duration. Drought stress imposes alterations in crucial plant growth and developmental processes, including germination, plant height, stem diameter, number of leaves, leaf size and area, dry matter production and partitioning, flower and fruit production, and maturity. More stress influence the reproductive stage through remobilization of nitrogen and carbohydrates from leaf to leaf with increasing age, Degradation of chlorophyll and light-harvesting complexes reported that drought stress on durum wheat reduced the number of days to heading, Grain filling period, number of days to maturity, plant height, number of spike per m2, peduncle length, spike length, number of grains per spike, 1000 grain weight of genotypes while it increased the chlorophyll content, grain protein content and SDS sedimentation but it shows that Spikelets per spike were not affected by drought stress. Identification of effects of drought stress on morphological attributes and morphological changes in response to drought can be promising for the selection and breeding of drought-resistant genotypes. When a crop exposed to drought stress during grain filling, grain filling rate is complete before the seed maturity stage. So severe moisture stress, further reducing the duration of grain filling, grain size as well as it affects the grain quality as reported by. Most grain crops are sensitive to lack of moisture during the growth phase because at this time the number of grains in weight and shape. According to the report of the loss of cereal is 4.9%–5.2% for the period of 1964–2007 using the superposed epoch analysis. Compared to present condition by using the 11 crop models simulation, drought-driven yield loss risk is projected to increase by 9%–12%, 5.6%–6.3%, 18.1%–19.4% and 15.1%–16.1 for wheat, maize, rice, and soybeans, respectively by the end of 21 century, without considering adaptations or CO2 fertilization effect.

Impact of drought on Crop Physiology

Photosynthesis is a key physiological process affected by drought stress in plants. Various physiological, biochemical, and molecular components of photosynthesis changes are induced by drought. Water stress influence photosynthesis either through pathway regulation by stomatal closure and decreasing flow of CO2 into mesophyll tissue or by directly impairing metabolic activities. A reduction in CO2 not only reduces carboxylation directly but also directs more electrons to form Reactive Oxygen Species (ROS). Water stress causes to reduce the leaf growth and area where it directly influences the net photosynthetic rate. A decrease in the leaf area expansion is emphatically associated with a decrease in transpiration surface and subsequently is among the most basic development mechanism under drought stress.

The photosynthetic rate of the leaf (expressed per unit leaf area) is seldom as responsive to mild water stress as leaf expansion is (Figure 1) because photosynthesis is much less sensitive to turgor than is leaf expansion. However, mild water stress does usually affects both leaf photosynthesis and stomatal conductance.

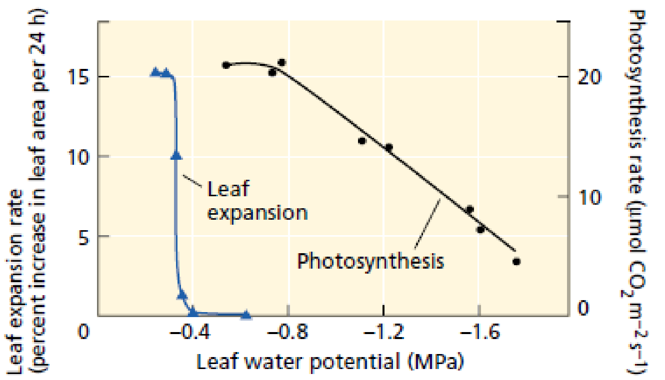

Figure 1: Effects of water stress on photosynthesis and leaf expansion of sunflower (Helianthus annuus).

Several endogenous plant hormones induce their modifications with drought effect, as the leaf continues towards maturing. A decrease in the levels of cytokinins and increase in the levels of ABA were observed in wheat. Production of ROS increases which prompts the antioxidant defense system, after exposure to drought stress. In drought-stressed wheat and rice, studies have indicated that carbon remobilization from senescing leaves to grains increases due to enhanced ABA concentrations. Demonstrated that cytokinins play a remarkable part in the regulation of source-sink translocation. Diminished cytokinin production by the roots is associated with drought stress, which can possibly hasten senescence in the older leaves by hindering its generation. Water stress decreases both photosynthesis and the consumption of assimilates in the expanding leaves. Water stress indirectly decreases the amount of photosynthate exported from leaves. Because phloem transport depends on turgor, decreased water potential in the phloem during stress may inhibit the movement of assimilates (Figure 2).

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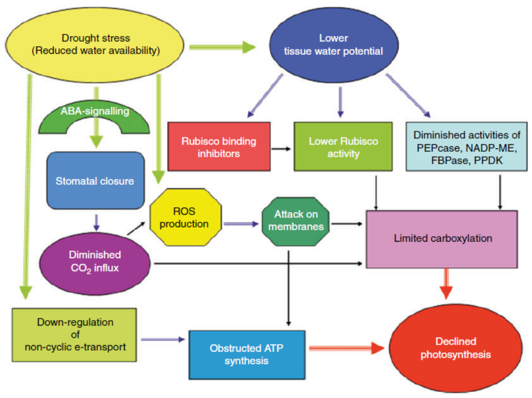

Figure 2: A Physiological Response of crop under drought stress.

Breeding strategies

Breeding for drought tolerance is further complicated because several types of abiotic stress can challenge crop plants simultaneously and many factors have been caused for water stress. High temperatures, high irradiance, scarcity of water and nutrient deficiencies are the main cause of major crop yield reductions worldwide, reducing expected average yields of the major crops by more than 50%. All these biotic stress commonly encountered under normal growing conditions and they may not be amenable to management through traditional farm practices. Certain soil properties such as composition and structure can also affect the balance of these different stresses. Higher plants have evolved multiple, interconnected strategies that enable them to survive unpredictable environmental fluctuations. However, these strategies are not always well developed in different crop cultivars grown by farmers [3].

Scientists develop a different technique of breeding strategies to overcome the drought problems. Now a day, due to the climate change affect the traditional farming practices has not been effective to alleviate agricultural productivity under the environmental stresses, therefore we have to switch the system to the modern production system like the improved agronomic and breeding strategies. There are two main approaches to improving economic yield, i.e. the empirical approach in which the plant breeder directly selects the breeding material 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.

The empirical approach results in the development of a plant population adapted to specific drought conditions and should be done in the target environment. Yield has a low heritability and therefore selection based on this complex trait is difficult and brings very slow improvement. After having used yield under drought as an exclusive breeding objective, most breeders have progressively replaced this empirical approach by 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. The selection criteria used in indirect selection should show relationships with yield under drought environment. Narrow-sense heritability of the trait(s) of interest should be high so that breeding populations show a good response to selection. Moreover, trait(s) should be, as far as possible, easily measurable and not plant destructive.

A good example of indirect selection is offered by the improvement of drought tolerance in tropical maize at the international center for Wheat and Maize Improvement (CIMMYT), in Mexico. Noted significant phenotypic correlations between yield and ears plant−1, kernels plant−1, Anthesis-Silking Interval (ASI), leaf rolling and leaf senescence. Genetic variances of yield contributing traits generally decreased with the intensity of water stress.

However, traits such as anthesis-silking interval and kernel spike−1 showed an increase in genetic variance. Heritability estimates for these traits were higher than for yield, making them useful for indirect selection. Indirect selection for yield in populations with a broad genetic basis resulted in significant drought tolerance improvement. Yield gain was 0.08-0.26 ha−1 cycle−1 in three populations under drought stress.

There was a positive gain in harvest index (0.025 cycle−1) showing that yield gains were due to better photosynthesis mobilization to ears under drought stress. The effectiveness of indirect selection was confirmed. After 6–9 cycles of selection in the source populations DTP1 and DTP2, there was a significant increase in grain yield and a significant reduction in ASI and the abortion rate of ovules. Quantitative trait loci (QTLs) have been identified for these traits and Marker-Assisted Selection (MAS) developed.

Pedigree Methods

Many efforts have been made to enhance the efficiency of selection for drought-tolerant genotypes based on yield and specific physiological traits. Pedigree selection is a widely used method of breeding self-pollinated species (and even cross-pollinated species such as corn and other crops produced as hybrids) to improve crop yield.

This method is highly appropriate for developing resistance cultivar in most of the self-pollinated crops especially if the trait is governed by major genes. One of the major advantages of pedigree selection is that the combination of many genes controlling biotic and abiotic can be achieved.

However, the major disadvantage of pedigree selection is that it is time-consuming and requires an evaluation of many lines periodically all over the planting seasons while keeping a record on selection criteria.

Among the breeding methods, pedigree selection requires high familiarity with the breeding materials and also the influence of genotype by the environment on traits of interest.

This method is not suitable for the trait under the influence of many genes (quantitative traits); in this case, the diallel mating design will be suitable for selection.

To achieve high yield (HY) and yield stability through breeding, breeders have to develop high yielding crop varieties with significantly improved tolerances to drought and salinity [4].

Generally, in most self-pollinating crops including rice, plant breeders prefer recurrent selection over pedigree selection. The overall selection procedure for the development of a new drought-tolerant crop cultivar development procedure was presented in Figure 3.

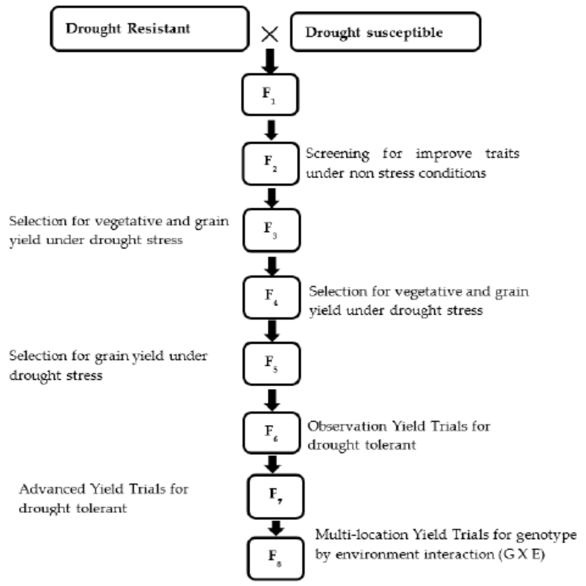

Figure 3: Pedigree selection starts with a cross of known parents whose identity is maintained through meticulous record-keeping throughout the breeding process.

Recurrent selection

Since the pedigree breeding method is not widely used for population improvement, the recurrent selection is preferably used method for population improvement. In this method of breeding, a number of plants are advanced to the next generation in which another cycle of intermating occurs. This process is repeated for several cycles (hence, recurrent selection), the outcome being an improved population (superior to the original population in mean performance as pertains to trait(s) of interest) with high genetic variability. The repeated crossing provides an opportunity for genetic recombination (also, increased opportunity for linkages to be broken) to occur to increase genetic diversity in the population.

Recurrent Selection (RS) involving dozens of parents is considered as an ideal breeding approach to steadily improve the level of quantitative traits in a breeding population. RS is used in varietal improvement which involves multiple crosses to gather favorable alleles while still maintaining genetic diversity. It provides shorter and defined breeding cycles, more precise genetic gains, and the development of highly diverse breeding lines. This method has been widely for different cross-pollinated crops mainly for maize. RS remains restricted by the hard and inefficient artificial crossing method, which was later resolved by using genetic male sterile (MS) that facilitated the application of RS in often for self-pollinated crops like rice. In wheat, this method has been successfully used for the improvement of grain yield and the percentage of grain protein. In summary, the efficacy of this method with respect to improved agronomic traits and enhancement of drought tolerance has shown that this method is superior to the pedigree selection method.

Back crossing

Backcross breeding is undertaken to transfer one or a few specific genes of interest from a source (donor parent) to an adapted cultivar (breeding line) while preserving all other qualities. This backcrossing technique is commonly used in rice breeding for introgression of desirable or target gene controlling a particular trait from donor parent to recipient parent with the aim of reducing the genome of the donor parent and subsequently increasing the high recovery of recipient parent.

This technique provides an accurate and precise way of developing a large number of advanced breeding lines. The use of backcrossing methods has led to the development of drought-tolerant varieties in rice.

The research as reported by backcross breeding combined with direct selection for yield in stressed nurseries may be a highly effective way to improve drought tolerance in rice.

Now a day, the backcross procedure is most often used to move a transgene from a good tissue culture variety that was used in the transformation to an elite experimental line or variety. It turns out that for many crops, once the transgene is in the crop species crossing is more efficient than transformation procedures.

Backcrossing is more efficient than transforming the elite line because most transformation protocols are optimized for a specific (often poorly adapted and lower-yielding) laboratory line. Many elite lines are not amenable for transformation. However, genetic engineers can transform their lab line and breeders backcross the transgene from the lab line into the elite line.

Mutation breeding

Mutation breeding is an effective technique to increase resilience to drought in crops grown in drought-prone countries. The widespread use of induced mutants in plant breeding programme across the globe has led to the official release of 3222 plant mutant varieties from 170 different plant species in more than 60 countries throughout the world the developed varieties increase biodiversity and provide breeding material for conventional plant breeding thus directly contributing to the conservation and use of plant genetic resource.

Not all countries were developed a mutant varieties to increasing food production and provide sustainable nutrition through mutation breeding. The following figure (4 and 5) shows the official number and percent of released mutant varieties in country and regions respectively.

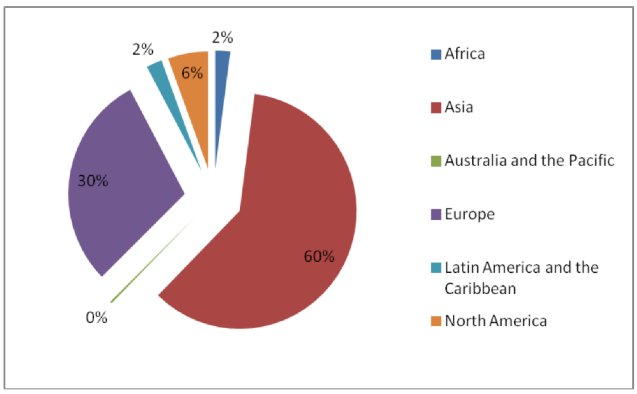

Figure 4: Cumulative percent of a number of officially released mutants in various regions of the world.

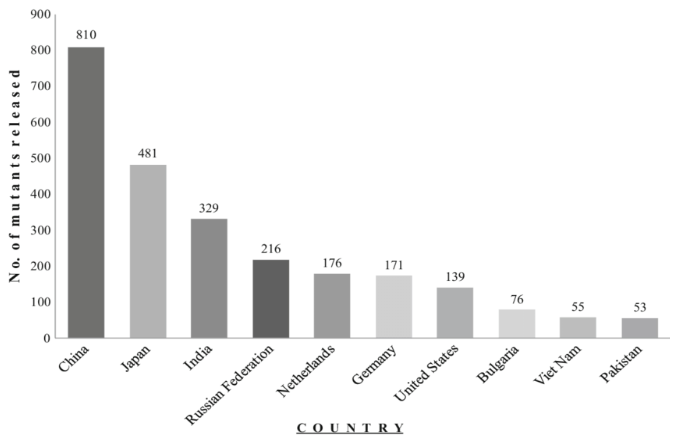

Figure 5: Total number of released mutant varieties, among top countries.

The induced mutation is the ultimate source to alter the genetics of crop plants that may be difficult to bring through cross breeding and other breeding procedures. Induced mutations have played an influential role in increasing the world food security since new food crop varieties embedded with various induced mutations have contributed to the significant increase of crop production at locations people could directly access. Now a day, climate change is a pressing issue and it also causes environmental stresses which are exerting more pressure on global food production, therefore, the producer increases their demand for stress-tolerant crop varieties. Crop productivity is challenged by abiotic stress factors mainly extreme temperatures (heat, cold, and freezing), drought, high salinity, heavy metals, etc., which limit plant growth and development. According to different climate projection, the yields of the major food crops are expected to decline in many areas in the future due to the continued reduction of arable land, reduction of water resources and increased global warming trends and climate change [5].

The conventional plant mutation breeding is used in the development of new varieties, the major advantage of induced mutation is the creation of gene alleles that are not found in nature which resist the abiotic and abiotic stresses. The new gene alleles created in the new variety can either be used directly as a commercial cultivar or in a breeding program. There are many success stories on groundbreaking rice varieties developed through induced mutation breeding method. It was also done research in Myanmar; the dry seed of rice Manawthukha was irradiated with a dose of 300 Gy of gamma rays from Co source to screen for drought tolerance by withdrawing irrigation after 90 days of transplant until harvesting. The research result indicated after the sixth generations, the two best mutant lines of MK-D-2 and MK-D-3 were released and characterized by using physiological screening techniques such as Relative Water Content (RWC), soil moisture content and yield. Similarly, revealed that an Iranian rice landrace "Tarom Mahalli" was irradiated with gamma source using an optimum dose of 230 Gy, at the fourth generations, the best 11 lines were selected with drought-tolerant characteristics which had a yield of more than 5000Kg/ha. A super green rice mutant that is high yielding and drought tolerant under low fertilizer-water efficient and water deficiency was developed through induced mutation in Indonesia. In Malaysia, two superior lines MR219-9 and MR219-4 having high yield potential and drought-tolerant character were derived from popular MR219 rice variety radiated with gamma radiation at 300Gy. Therefore there are many techniques of plant breeding to develop the drought-resistant cultivars; however in our country Ethiopia until now the breeding techniques and strategies have been poorly applied.

Conclusion

Drought has been one of the most important limiting factors for crop production, which deleteriously affects food security worldwide. Drought stress imposes alterations in crucial plant growth and developmental processes, including germination, plant height, stem diameter, number of leaves, leaf size and area, dry matter production and partitioning, flower and fruit production, and maturity. Without optional strategies of breeding and other adaptation methods, drought-driven yield loss risk is projected to increase by 9%–12%, 5.6%–6.3%, 18.1%–19.4% and 15.1%–16.1 for wheat, maize, rice, and soybeans, respectively by the end of 21 century. Therefore, drought tolerance is further complicated because several types of abiotic stress can challenge crop plants simultaneously and many factors have been cause for water stress. Scientists develop a different technique of breeding strategies to overcome the drought problems. Now a day, due to the climate change affect the traditional farming practices has not been effective to alleviate agricultural productivity under the environmental stresses, therefore we have to switch the system to the modern production system like the improved agronomic and breeding strategies. Conventional breeding and marker-assisted selection (MAS) are examples of breeding techniques carried out in drought resistance crops. In this paper, we have considered the conventional breeding for Drought Resistance (DR) which involves backcross strategy to develop new varieties with improved yield potential, Pedigree breeding method also develop the drought resistance cultivars but it consume-time and requires an evaluation of many lines. The induced mutation is another important conventional breeding method that improves the drought resistance of the crop through creation of gene alleles that are not found in nature which resist the abiotic and abiotic stresses and recurrent selection is preferably used method for population improvement which is not possible handled by a pedigree method.

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