Drought Stress, Its Effects and Adaptation in Plants

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ARTICLE INFORMATION

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ABSTRACT

Background:

Among abiotic factors that limit the growth, drought stress is most important one which has adverse effect on plant growth and crop production. When underground water reservoir is reduced and continuous loss of water takes place through stomatal cells of plants during transpiration, such type of situation is called drought stress.

Objective:

Drought stress has effects on a number of physiological and biochemical processes in plant, as a result reduction in plant growth and its yield takes place. Plants responses towards drought stress mainly depends upon factors like intensity, duration and plant growth stage.

Conclusion:

There is worldwide risk of drought stress to the production of crops occurs when physiological and environment factors combine, which needs to be taken care of for better crop production.

Original Research Article

Introduction:

Agriculture has a worldwide challenge against abiotic stress. Any environmental conditions that differ from the optimum range has negative effect on plant growth and development. Due to growing human population and livestock industry its demand is increasing and we need to develop methods which provide better adaptations to crops against threatening environmental conditions. Advancement in next-generation sequencing (NGS) technologies and application of genome editing techniques have made it easy to identify and characterize new genes and their functions. Main purpose of growing crop is to Harvest more yield. The final yield of those crop species that are under normal condition are high (yield constituents like grain number and its size) than that of under drought stress (low grain number and its size). Decrease in the production of food is due to biotic and abiotic stresses, and under changing climate food security becomes the main concern area of interest (1). Among other abiotic stresses, drought is most important one which has severe effect on plant growth and its development and limits the growth of crops than that of any other stresses. Drought is commonly defined as a specific time period in which no rainfall occurs. Deficiency of water and salt stress are universal issues for survival of agricultural crops and supportable food production (2). Plants experience a variety of Morphological, Physiological, Biochemical and Molecular responses to survive under water deficit conditions at subcellular, cellular and organ level. Under stress conditions plants undergo internal changes to attain balanced cellular state to escape any type of injury or damage. Plants are primary producers and in terrestrial environments, photosynthesis is the most important function of plants. Certain plant varieties have ability to adjust the photosynthesis rate according to the changes in environment, so photosynthesis is used as indicator for stress condition of plants. When water potential in the leaf drops, so does its water content leading to a decrease in foliar photosynthetic rate of the plant. Plants close their stomata for preserving a valuable amount of water. Once stomata closed gasses exchange stopes as a result CO2 concentration within the cell decreases which has direct effect on photosynthetic rate (3). Stomatal opening and closure are directly linked to soil moisture content than that of leaf water potential status. One of the fastest biochemical response carried out by plant cells against abiotic stress is production of reactive oxygen species (ROS) which act as a messenger to carry out further defense reactions in plants (4). Formation of ROS results in oxidative stress which has the most serious effect among abiotic stress on plant cell. Various stress factors including extreme temperatures, drought, heavy metals, and salinity etc., cause disturbance in ROS generation and ROS scavenging, which otherwise holds a fine balance. The important mission of today's plant science is the detection of genetic features to transgenically confer drought tolerance on agriculturally precious crops. There are three major groups of abiotic stress tolerance genes in plants, based on funtion. These are functional proteins, signaling factors, and transcriptional factors. Signaling factors include signal transduction proteins, whereas, Abscisic Acid (ABA) synthesis controllers, chaperons, antioxidant protectants, and proteins for heat shock (HSPs), LEA, reactive oxygen species scavenging, and others are functional proteins. In drought stress the hormone abscisic acid (ABA) plays vital role in signal transduction. ABA is responsive for transcription factor regulation which activates the genes which are necessary for plant survival under drought stress. Those Plant genes that responding to ABA signal have a specific (ABA)–

responsive element (ABRE) in their promoter regions. Abscisic acid–responsive element binding protein1 (AREB1), basic leucine zipper (bZIP) transcription factor binds to ABREs and activate the stress responses genes and control the regulation of drought stress tolerance in an ABA-dependent manner 2. Different techniques were used in the past for the betterment of crop like conventional breeding program and genetic markers are being used by plant breeders. These are morphological traits that are controlled by single locus. Selection of traits is time consuming and plant breeders switched towards molecular breeding. After the identification of genes underlying stress tolerance in plants, introduced these genes into crops by genetic engineering for the purpose of developing stress tolerant crops. Production of Transgenic plants is straight forward technology for improving crop yield in those areas which are continually affected by abiotic stresses. Abiotic stresses induce the LRRRLK (RPK1), which is a multifunctional regulator under stress for plant growth and development. This article aims to provide a comprehensive account of drought stress in plants, its effects and relative adaptations.

Effects of Drought Stress on Morphological Characteristics

It is considered as drought stress is very basic important factor that limits the plant growth specially when its growth and establishment at their initial phase. During water stress turgor pressure become low which has effects on cell expansion and cell growth of plants. Photosynthesis rate and yield of crops depends on the leaf area of crop. Significant reduction in leaf growth and its area has been observed under drought (5). Ultimate purpose behind growing crops is harvesting more yield. Difference has been seen in the final yield of crops under drought stress as compared to crops which have not grown under drought stress. Grain number and its size is used as parameters to measure the final harvestable yield of crop, significant reduction is observed under drought stress (6).

When drought stress encounter, leaf water potential and relative water contents decreases, opening and closing of stomata depends upon the water potential of leaf which has direct effects on the photosynthetic rate so the reduction in photosynthesis has been observed.

Physiological Responses:

Stomatal cells of plants going to prevent the water losses when there is less water in underground resources of soil or leaf water potential, this is very basic phenomena of plant under drought stress condition which prevents the stomatal conductance, due to this carbon uptake by leaves decreases. Closing of stomatal cells depends upon the environmental factors like lowering in turgor pressure of leaves, water potential and low humidity in atmosphere (7). Different experiments have been carried out to check the stomatal conductance, which have shown its direct relation with moisture condition of soil than to water status of leaf. Stomatal conductance depends upon the moisture condition of soil which shows that stomata are responding (ABA) chemical signals. ABA is produced under water deficit conditions that play important role for the survival of plant under harsh environment (8). In low water condition, the pH of xylem sap increases, leading to increased production of ABA in the root xylem and its transport to the shoot. Environmental circumstances that amplify the speed of transpiration also cause raise in the pH of leaf sap, which can encourage accretion of ABA and results in reduced stomatal conductance. Due to loss of turgor pressure stomata closes because of promotion of efflux of K+ ions from the guard cells promoted by ABA. As drought encounter, stomatal closure increases for a long period of the day in plants, which started after the morning (9).

Biochemical Responses:

Formation of ROS that results in oxidative stress has the most serious effects on plant cells when plant faces the abiotic stresses. Production of ROS and ROS scavenging in plants is kept in controlled during normal growing conditions of plants, this balance is disturbed when plant encounters salinity, heavy metals, drought, extreme temperatures, or other environmental stress factors. Plant survival is mainly depending upon a balance between many important factors like growth hormone, signaling molecules, this homeostasis state of plant is disturbed by severity and duration of stress, then plant respond to changing environment by adapting the changing energy equation (10). Composition of ROS are mainly of O2, H2O2, O•−2, and OH•, any disturbance in their homeostasis level has effects on normal cellular functions and damaging the protein, DNA and lipids (11).

Adaptations against Drought Tolerance:

Plants tolerance against abiotic stresses is increased by accumulation of certain osmolytes, like glucose, fruit sugars, sucrose,proline and glycine betaine (GB). For the protection of plasma membrane integrity of cell under drought stress Proline play vital role, a positive correlation has been observed between proline accumulation, plant yield and photosynthetic activity of plants.

There is redox homeostasis level in plants which is maintained by during stressful conditions by different mechanisms like enzymatic components which are composed of catalase (CAT), superoxide dismutase (SOD), guaiacol peroxidase (GPX), glutathione-S transferase (GST) and ascorbate eroxidase (APX). Like ABA and auxins ROS also work as signaling molecule thus controlling stomatal closing and opening, defense against pathogens and programed cell death (10).

Another stress response in plant is production of polyols, which is composed of mannitol, sorbitol or cyclic polyols and its methylated derivatives Polyols are present in many species like higher plants, animals, marine algae, yeasts and bacteria which has direct correlation with drought and salinity stress tolerance. Polyols play a role against drought stress in two different ways which are interconnected to each other like osmotic adjustment and osmoprotection. During osmotic adjustment polyols works as osmolytes, which facilitate water retention in cytoplasm and allowing sodium entry to the vacuole or apoplast. Another mechanism is scavenging the active oxygen species to protect the cellular structure via interactions of polyols such as osmolytes, with membranes, protein, or enzymes of the plant cell. Zwitter ions at physiological pH such as Proline, quaternary ammonium, and tertiary sulfonium act as osmolytes because these are ionic having no net charge. Polyol function as osmoprotective in the cytosol of cell due to its unique chemistry. Under environmental stress conditions polyols act as non-reducing sugars which also store the excess carbon (12).

Molecular Mechanism:

Plants survival under drought stress depends upon its adaptations at molecular levels for the regulation of stress responsive gene to regulate the water balance. In molecular adaptation mechanisms involves the upregulation and down regulation of many stress responsive genes transcripts and proteins that provide stress tolerance to the plant in direct or indirect pathway. For making a stress tolerant plants, engineering a plant with those genes which are responsible to drought stress tolerance, coding for LEA proteins and aquaporin (13).

The role of proteins whichprovide tolerance against drought stress has been observed. Transcription factors play important role for the regulation of downstream stress-responsive genes, these genes can be transformed in important crops which is helpful for providing stress tolerance in transgenic plants (14-15)

In addition to transcription factors which bind to promoter regions of stress responsive gene and activate its transcription, some other cis-acting regulatory elements which can play important role for signaling molecules in stress regulatory networks, like ABA hormone. Arabidopsis thaliana has been used as a model plant for genetics studies to understand the molecular basis of stress tolerance, over the last decade. This has been really helpful to understand the individual gene roles in drought stress, knockout mutants are available and its successful genetic transformation (16-17). Drought-tolerant transgenic plants, including rice, tomato, soybean, maize, barley, and Arabidopsis have been made by the advancement in molecular techniques (17-18).

bZIP, NAC, AP2/ERF, and MYC are important transcription factors families of plants, which are involved in regulatory networks mechanism under drought tolerance (16). Hormones, phosphatases, protein kinases and other important components of plants during stress signaling play a role in the regulation of biochemical and physiological processes, this regulatory networking is particularly important for maintaining a cellular homeostasis of plants (19). Signal transduction under water deficit stress condition response is carried out by ABA plant hormone. Transcription factor that responses to ABA are activated which started the downstream regulation of genes that coordinate with each other for the regulation of cellular responses under drought stress.

Biotechnology and Functional Genomics:

In past different techniques have been used for making a crop against stress tolerant like Conventional breeding, hybridizations, and mutagenesis, with limited success rate. Main problems which have been faced while developing a stress tolerant variety are complexity of drought tolerance, low allelic number for good yield traits and lack the efficiency of selecting a reproducible trait. Biotechnology play important role for selection of appropriate gene with high efficiency, provide easy understanding of the plant responses towards drought at the molecular level of plant. By using molecular techniques like differential display analysis of proteins, transcript analysis by using microarray techniques, identified the number of genes which are induced by drought stress condition. These identified genes have been cloned in plant expression vectors for the further characterization of their functions, which are important for the selection of genes for making drought tolerant crops. Radical scavenging is very important in plants for its homeostasis level, genetic engineering of such type of radical scavenging used as helpful to improve tolerance in plants (11). Superoxide dismutase (SODs) play important role for the detoxification of active oxygen which are produced while plant faces the environmental stresses. Cytosol, chloroplasts, and mitochondria are the cellular sites where SOD generated (20). Transgenic tobacco plants which shows overexpression of SOD are showing more tolerant against drought stress as compared to untransformed controls (21)

Drought Responsive Genes:

Late Embryogenesis Abundant Proteins

Late Embryogenesis Abundant Proteins or LEA is a class of proteins vital to the drought response of the plant. They play key role in drought tolerant in plant responses towards environmental stresses. Abscisic acid levels increase when the expression of LEA proteins increases, this induction plays a very important role in stress tolerance (22). Expression analysis of different plant species shows that the genes coding for LEA protein is increases under drought stress. (23). E coli shows resistance against drought due to overexpression of the LEA proteins, which is confirmed by expression analysis of LEA proteins under drought.

Aquaporins:

Aquaporins protein family name is (MIP) which are involved for the regulation of water in plants and animal cells. Aquaporins makes a water channels in plasma membranes and play their role for the translocation of water molecules, solutes such as urea, boric acid, silicic acid, gases like ammonia and carbon dioxide) (24). Aquaporins family have five subgroups which are named according to their location in plant cells.

Leucine Rich Repeat Gene:

LRR-Receptor like kinases are present in plants which are the member of largest subfamily of plant. These are signaling molecules which play important role by activating those genes which are involved in drought stress responses. LRR-RLK's association with BRI1 kinase has been identified inside plasma membrane (Brassinosteroid Insensitive). The structure LRR_RLK associated with BRI1 consists of two domains one is cytoplasmic domain which is composed of N-terminus signal peptide and other is extracellular domain composed of 25 leucine-rich repeat units which act as receptor for drought stress signal. C-terminal extension domain of LRR_RLK is important for anchoring this protein in to the cell wall (25).

In drought stress the hormone ABA play vital role in signal transduction. ABA is responsive for transcription factor regulation which activates those genes that are helpful for plant survival under drought stress. Abiotic stress induces the LRRRLK (RPK1), a multifunctional regulator of plant growth and development under stress. Differential expression analysis indicated its over expression under drought stress. Stomatal cells differentiation is aided by ERCTA (ER), ERL1, and ERL2, the members of LRR-RLK family. These together regulate the patterning of stomata (26).

Drought stress effects the productivity and yield of crop plants. LRR gene has a major role in the tolerance mechanism of plant species against drought. Plant genomics \ Plant

biotechnology applications has a major role for the improvement of plant characteristics as compared to conventional breeding. The role of this gene in drought stress will be helpful to make the agricultural important crop species tolerant against drought and other abiotic stresses.

Conclusions:

Drought stress has effects on physiological and biochemical processes. In drought stress the hormone ABA play vital role in signal transduction. ABA is responsive for transcription factor regulation which activates the genes that are necessary for plant survival under drought stress. Change in the net rate of photosynthesis have been suggested as tools for the purpose of comparing and evaluating the different plant varieties against drought tolerance. An understanding of the mechanism of plant responses against drought is very important for making the stress tolerant crops.

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