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Drought Tolerance in Rice: Focus on Recent Mechanisms and Approaches

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Abstract

Drought stress is a serious limiting factor to rice production, which results in huge economic losses. It is becoming a more serious issue with respect to the global climate change. Keeping in view of the current and forecasted global food demand, it has become essential to enhance the crop productivity on the drought-prone rainfed lands with priority. In order to achieve the production target from rainfed areas, there is a requirement of rice varieties with drought tolerance, and genetic improvement for drought tolerant should be a high priority theme of research in the future. Breeding for drought tolerant rice varieties is a thought-provoking task because of the complex nature and multigenic control of drought tolerant traits would be a major bottleneck for the current research. A great progress has been made during last two decades in our understanding of the mechanisms involved in adaptation and tolerance to drought stress in rice. In this review, we highlighted the recent progresses in physiological, biochemical and molecular adaptation of rice to drought tolerance. A brief discussion on the molecular genetics and breeding approaches for drought tolerance in rice will be focused for the future crop improvement program for development of drought tolerant rice varieties.

Keywords: Drought Stress; Drought Adaptation ;Rice Water; Deficit Tolerance.

Introduction

Rice (*Oryza sativa* L.) is the most widely consumed staple food for a large part of the world's human population, especially in Asia. Asia is on the top in terms of production and consumption of rice. According to FAO report (2016–2017), average production of rice is estimated as 5.0×10^8 t, and due to rise in population, the requirement is expected to increase up to 2.0×10^9 t by the year 2030. The present and foreseen worldwide sustenance requests a momentous enhancement in crop productivity on the less favourable rainfed lands. Climate change, influencing the regularity and level of hydrological fluctuations, is a major threat to agriculture particularly in developing nations, and causes various abiotic stresses for plants. Amongst the abiotic factors that have created plant evolution, drought is the most imperative and major limitation for rice production in rainfed ecosystem. From the agricultural aspect, drought is a time span with low average precipitation/poor rain or higher evaporation rates causing a downfall in crop growth and yield. The intensity/severity of drought is very complex and is dependent on different reasons like frequency of rainfall, evaporation and soil moisture More than one third of the world's total cultivated area is affected by drought stress. Within that area, 33% (9.9×10^7 hm^2) belongs to developing countries, 25% (6.0×10^7 hm^2) belongs to developed nations and 42% (12.6×10^7 hm^2) belongs to under developed countries. In Asia alone, about 3.4×10^7 hm^2 of rainfed lowland and 8.0×10^6 hm^2 of upland rice exposed to drought stress. Breeding rice varieties with tolerance to drought stress offers an economically viable and sustainable option to improve rice productivity). Breeding for rice plants with drought tolerance has previously beenattempted by a number of researchers, but progress is slow because of lack of suitable donors with a high level of drought tolerance. Screening of thousands of germplasm has been conducted earlier for drought resistance in various corners of the world, however, only a few drought-tolerant varieties are yet recognized. The main reasons for the minimal success are non-availability of truly drought-tolerant genotypes and lack of suitable screening methods. During the last two decades, scientists from the International Rice Research Institute (IRRI), the Philippines, screened nearly 1000 Genebank accessions originated from 47 countries for drought tolerance [1].

They have identified 65 more drought-tolerant accessions, which are either *aus* or *indica* The highest number of drought-tolerant *aus* accessions are originated from Bangladesh.

Morphological responses to drought stress

Drought resistance is the capability of a plant to produce its maximum economic yield under water limited conditions. It is a complex trait depends on the action and interaction of different morphological, biochemical and physiological responses. Drought escape is defined as 'the ability of a plant to complete its life cycle before the development of serious soil water deficits'. Drought avoidance is defined by Kumar et al. as 'the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture'. Drought tolerance is defined as 'the ability of plants to survive under low tissue water content'. Drought has detrimental effects on crop growth parameters and ultimately declines yield. Such damage is dependent on the scale, interlude of the stress and the growth stage of the plant. The detrimental results are reflected for changes in morphological, physiological, biochemical and molecular processes of the plant and their responses under drought stress [2].

Effects of drought stress on seed germination and seedling growth

Alterations in early morphology of rice are seen when rice are exposed to water stress. Founding of a timely and optimal crop stand is vital for normal productivity. The principal impact of drought stress is blighted germination and reduced growth. Severe reduction in germination and seedling growth is observed under drought stress due to the scarcity of water. Unlike some other crops, rice is extremely sensitive to drought conditions during the germination and early

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seedling growth stage. Seed germination needs appropriate temperature and soil humidity. Drought negatively affects germination process through inhibition of water uptake and reduces the strength of seedling. Drought stress causes trouble of water balance, and damages metabolic process at cell level impairment of membrane transport, and decreases ATP production and respiration, leading to poor seed germination . There are several reports indicated that water stress causes decreases in plant height, leaf area and biomass.

Effects of drought stress on leaf traits

Leaf growth is reduced due to limited water potential under drought stress. Disrupted flow of water towards another cell from xylem, including lower turgor pressure due to water deficiency, responds in form of poor cell development and diminished leaf area in crops. The anatomy of leaf and its ultra-structure are changed in drought stressed conditions. These changes are shrinkage of leaf size, reduction in number of stomata, bulky cell wall, cutinisation on leaf surface, and poor development of conducting system. Rolling of leaf and initiation of early senescence are other important characteristics seen under drought stress. Several leaf traits have been used for the screening of drought tolerant variety, i.e. higher flag leaf area, leaf area index, leaf relative water content and leaf pigment content [3].

Effects of drought stress on root traits

Root characteristics of the plants are the vital attributes for enhancing production under drought stress. Crop function under water stress is determined by the constitution and formation of rice root system. Rice production under water stress can be forecasted by taking root mass (dry) and length into account. Diversified and varied responses are observed on root growth characteristics under water stress. observed the increase in the length of rice root under drought stress because of rise in abscisic acid concentration in the roots. Generally, rice varieties with profound and prolific root system show better adaptability in drought. In case of rice, the genotypes having profound root system, coarse roots, capacity of producing many branches and high root and shoot ratio are important for drought tolerance . The morpho-physiological characteristics of rice roots play a major role in determining shoot growth and overall grain yield under drought stress.

Physiological responses to drought stress

During drought stress, different physiological processes are negatively impacted, and plants respond to drought in order to acclimatize in adverse states. It is essential to optimize the physiological parameters and processes prior to breeding program for enhanced yield under drought conditions Scarcity of water negatively affects the physiological characteristics of rice in innumerable ways, such as decreases in net photosynthetic rate, transpiration rate, stomatal conductance, water use efficiency, internal CO_2 concentration, photosystem II (PSII) activity, relative water content and membrane stability

Effects of drought stress on leaf photosynthesis

Photosynthesis is one of the prime metabolic processes that determine the crop growth and production, and it is affected by water deficit/drought stress. Water stress changes the standard pace of photosynthesis as well as the gas exchange characteristics in plant. Stomata are closed in environmental conditions of limited water, reducing carbon dioxide influx to leaves and driving extra electrons for formation of reactive oxygen species, Mishra et al. Several factors are involved in the declining of photosynthesis, such as stomatal closure, decline of turgor pressure, reduction in leaf gas exchange and decrease in CO_2 assimilation, ultimately damaging photosynthetic apparatus. Photosynthetic capacities of leaves and water availability to the root zones are very important factors that reduce yield in susceptible rice genotypes under drought stress condition in rice. During drought stress, inequity is observed between capture and use of light, reduction and impairment in Rubisco activity, pigments and photosynthetic machinery which are the reasons for photosynthesis diminutions. Water stress damages the normal functions of PSI and PSII . PSII function is very important in reduction reaction and generation of ATP. Several studies have been carried out *in vivo* and observed that drought causes significant detrimental decrease in centers for oxygen evolution along with photosystem, leading to inhibition of electron transport chain and subsequent inactivation of PSII. Plant pigments, namely chlorophyll, are the vital predecessors of photosynthesis, mostly for obtaining light and generation of reducing powers. Water deficiency causes reduction in the potential of mesophyll cell to utilize the carbon dioxide present in it. As a consequence, the amount of lively chlorophyll declines Fall in chlorophyll and utmost quantum generations of PSII (F_v/F_m) are described in water stressed rice plants. Carotenoids are the essential components for photoprotection and act as a precursor in directing signals for the growth of plants under stress conditions. Therefore, currently special attention is being taken by plant biologists to improve the carotenoid contents in plants either by breeding or genetic manipulation [4].

Effects of drought stress on biochemical characteristics

Under drought stress, the plants try to maintain the cell turgor by accumulation of organic and inorganic solutes that lower the osmotic potential. Accumulation of osmoprotectants, such as proline, glycinebetaine and soluble sugar, provides osmotic adjustments for the plants. Protein content and profiling along with increase in the antioxidant activity for scavenging reactive oxygen species improve drought tolerance. Tissue- and time-specific expression of drought-response traits, such as abscisic acid, brassinosteroids and ethylene phytohormone pathways, improves drought response without depressing yield [5].

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Conflict of Interest

None

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