The Role of Potassium in Plants under Drought Stress: Mini Review

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Abstract: Drought stress is a major catastrophe to plant productivity. Drought stress significantly reduces the crop yield and quality, and probably exceeds losses from all other stresses. Potassium (K^+) is an essential nutrient and affects the growth and development, and it also contribute significantly towards plants survival under drought stress. In this mini review we discussed the physiological, biochemical, and molecular mechanisms underlying K induced alleviation of drought stress.

Keywords: Potassium, drought stress, stomata, water uptake, membrane stability, oxidative stress.

INTRODUCTION

Water scarcity is a major limiting factor for plant growth and development, particularly in arid and semiarid regions. Drought stress results in formation of reactive oxygen species (ROS), that leads to leave damage, and thereby, reduces the crop growth and yield [1, 2]. Plants adopted different mechanism to cope with the different stresses. The use of minerals plays an important role in plants resistance against the abiotic stresses [3, 4]. Among the nutrients, K^+, plays an important role in growth and development and contributes significantly towards the plants survival under drought stress.

Drought stress restricts the root growth and K^+ diffusion rates from soil to plant root thus, limiting K^+ acquisition. Therefore, the low potassium concentration substantially reduces plant resistance against drought stress and potassium absorption as well. Therefore, maintaining the adequate K^+ for plants is, crucial for resistance against drought stress. The optimum availability and adequate soil K^+ status has very close relationship with drought resistance. In this mini review, we focus on current understanding of the mechanisms underlying K-induced alleviation of drought in higher plants.

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K^+ Induced Osmotic Adjustments

The optimization of proper water status plays a crucial role in plants survival during drought stress. Osmotic adjustment is a prime mechanism adopted by plants, which maintains the water balance and turgor potential under drought stress. Leaf osmotic adjustment is linearly related to drought tolerance in plants [5]. K^+ as a prime osmoticum in plants plays a major contribution in adjustments under water deficient conditions. Moreover, the proper availability K^+ improves the solute accumulation and decreases the osmotic potential, thereby maintains the cell turgor even under water limited conditions [3]. In conclusion, the proper availability of K^+ favors the osmotic adjustments that maintain the cellular turgor, relative water contents and also lowers the osmotic potential, and therefore, improves the plants ability against the drought stress [6].

Stomatal Regulation

Plants adopt certain important mechanisms in drought stress, like, stomatal closure and preservation plans of internal moisture. K^+ nutrition substantially controlled the turgor regulation of guard cells during stomatal movements [3]. As stomata get close, K^+ quickly released from guard cells and enters into leaf apoplast, therefore, it would be difficult for plants to remain stomata open during the water deficit conditions. Some investigations reported that K^+ deficiency closes the stomata and inhibit photosynthetic rate in numerous plants [7, 8].

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Conversely, some reports also indicated that K^+ nutrition had no significant effect on the photosynthetic rate and stomatal conductance under normal conditions, but the K^+ hunger leads to stomatal opening that results in lower photosynthetic rate and prompt loss of water via transpiration [9, 10]. However, these variations could be attributed to different plant species, experimental system and environmental conditions. Benlloch-Gonzalez *et al.* [10] also reported that stomata closure in sunflower and olive plants depends on the potassium nutrient status. Moreover, they also reported that low K^+ status in plants can lead to closing of stomata due to ethylene synthesis.

The inadequate availability of K^+ starvation increases the genes transcription involved in production of ethylene [11]. Therefore, the increase in ethylene production can reduce abscisic acid (ABA) action on stomata and can holdup stomata closing [12]. K^+ deficiency also leads to poor performance of stomata in drought stress that result in marked loss of water. However, drought stress does not decease the water use efficiency (WUE), whereas, it increases WUE by stomatal closure during water deficient conditions. Therefore, the proper availability of K^+ nutrition increased the plants resistance against the drought stress, WUE and crop growth and productivity under water deficit conditions [6].

Membrane Stability and Cell Elongation

It is valuable to improve the plant resistance against the water limited conditions through the deeper roots, bigger absorption surfaces and better water retention in tissues. Deep roots in plants can be attained by the deeper placement of K^+ along with other nutrients such as, nitrogen and phosphorus [13]. Likewise, Egilla, [14], reported that optimum availability of K^+ improves the dry matter production in crops, as compared to the poor availability. This increase in dry matter production can be attributed to stomatal regulation and substantial increase in photosynthetic rates by K^+ [3]. Furthermore, K^+ also plays an indispensible role in the translocation of assimilates in root growth [15]. Moreover, appropriate K^+ supply substantially increased the root growth, thereby; increase the root surface area with corresponding increase in the water uptake under water deficit conditions [15]. Similarly, Lindhauer [16] found that well supply of potassium ensures better leaf area, dry matter production, and water retention in osmotic stress. On the other hand, Bajji *et al.,* [17], reported that membrane integrity and stability substantially improved the drought tolerance abilities of plants. Cell membrane's stability considerably decreased under water deficit conditions, [18]. Conversely, Premachandra *et al.* [19], reported that K^+ application improved the plant resistance against drought stress and this improvement can be attributed to deemed role of K^+ in osmotic adjustments and membrane stabilities. To sum up an adequate availability of K^+ appreciably improved plants survival under water limited conditions, due to root elongation and maintenance of membrane stability and integrity.

Aquaporin

Aquaporin are channel proteins that are present in the plasma and intracellular membranes of plant cells. These proteins maintain the osmotic potential and membrane hydraulic conductivity, therefore, make changes in plant water permeability [20]. In drought conditions, gene expression of aquaporin proteins can be regulated, which helped the plants in maintaining their water balances [21]. Moreover, under drought stress, plant regulates the ion and water uptake by modifying plasma membrane intrinsic proteins (PIPs) and K^+ channel at the transcription level [22].

Kanai *et al.* [23] also reported a close relationship between K^+-channel transporters and activities of aquaporin. The inadequate availability of K^+ remarkably changed the activities of K-channel that altered the hydraulic conductance of roots and transduction of signals with the corresponding changes in aquaporin activity. They also reported that the activity of aquaporin proteins substantially decreased under K^+ deficiency and results a considerable decrease in hydraulic conductance of roots, and water supply to growing stem. Similarly, Sahr *et al.,* [24] reported that K^+ transporter and transcripts encoding the water channels are reduced in Arabidopsis roots under water deficiency. Likewise, Tazawa *et al.,* [25] also observed a substantial reduction in hydraulic conductivity by the inhibition of water and K^+ channels. Therefore, K^+ and water channels worked together to maintain osmoregulation and cytosolic osmolarity and thus to acclimatize the water stress [22].

Detoxification of Reactive Oxygen Species (ROS)

Stomata get close in drought stress and lead to a significant reduction in rate of photosynthesis due to chloroplast dehydration [1]. Moreover, reduction in photosynthetic efficiencies disturb the balance between ROS and antioxidant defense [26], resulting a significant accumulation of ROS. The ROS have a dual action, which depends on their cellular concentration [27]. Like, low level of ROS helped in stress-signaling pathway by triggering stress defense responses [27]. Similarly, high concentration of ROS is awfully injurious for cells and cellular membranes and resulting in oxidative stress and death of cells [27].

Moreover, the production of ROS can be enhanced further with K deficiency in drought stress conditions [1]. Like, K^+ deficiency considerably reduced the photosynthetic CO_2 fixation in plants by stomatal destruction; reduce conversion of light energy into chemical energy and translocation of photosynthates from source to sink [6]. As the drought stress impaired the photosynthetic CO_2, molecular O_2 is activated, and resulting in production of ROS [28] and, thereby, degradation of cellular membranes and chlorophyll. The appropriate availability of K^+ plays critical role in preventing the damage caused as a consequence of water deficiency [29]. Likewise, the adequate availability of K^+ under drought stress appreciably improved the photosynthetic efficiency of plants [6]. Moreover, K^+ also enhanced the photosynthetic CO_2 fixation and transportation of assimilates from source to sink organs and inhibit the production of ROS [1].

Nicotinamide adenine dinucleotide phosphate (NADPH)-dependent oxidase activation is also a major contributor of ROS production under stress conditions [30]. NADPH-oxidizing enzymes reduce the one electron of O_2 to $O_2^{\bullet-}$ with the aid of NADPH as an electron donor. Moreover, the activity of NADPH oxidase substantially enhanced under K deficiency, with corresponding increase in the NADPH-dependent $O_2^{\bullet-}$ production [1]. The major reason behind the increase of NADPH oxidase is probably the accumulation of ABA due to K deficiency. Moreover, the ABA substantially increased the accumulation of H_2O_2 and $O_2^{\bullet-}$ in plant roots [31], but this point needs to be interrogate further in future studies. On the other hand, Cakmak [1] reported that the improved supply of K^+ inhibits the production of ROS in water deficit conditions by reducing activity of NADPH oxidase and maintaining photosynthetic electron transport. Therefore, the supply of K is essential for detoxification of ROS under drought stress conditions.

CONCLUSION

In conclusion, optimum K^+ nutrition status, maintains cellular membranes stability, osmotic adjustments and detoxify the reactive oxygen species, thereby, contributes towards the sustainable crop growth, yield and quality under drought stress.

FUTURE PROSPECTS

1. Investigation of more details about the molecular mechanism of K^+ in drought tolerance.
2. Identification of the role of K^+ against the drought stress in different cells, tissues and organs.
3. Emphasizing on the importance of K^+ nutrition for crops, animals and humans.

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