Improving Crop Responses To Salinity and Drought Stressed Conditions: A Review On Proline and Its Roles When Applied Exogenously

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ABSTRACT:

Salinity and drought stresses have negative effects on the growth, development, quality, quantity and productivity of crop plants. The work done by researchers reveals that there is positive correlation between proline accumulation and plant stress. Proline is α-amino acid which plays highly beneficial role in plants that are exposed to different stress conditions. It acts as an osmolyte, metal chelator, antioxidant defense molecule and signaling molecule. Reports indicated that exogenously applied proline at low concentrations enhanced stress tolerance. This article reviews the role of proline in alleviating the negative effects caused by salt and drought stresses. Examples of successful application of exogenous proline to improve salt and drought stresses are presented.

Keywords: Salt, drought, proline, stresses

INTRODUCTION

From a global perspective, food crops refer to plants that are planted to be predominantly used as food (Pessarakli, 2011). There is an increasing need for food production as world population is expected to reach about 7.6 – 8.0 billion by the end of 21st century (Shanker and Venkateswarlu, 2011). When plants are subjected to growing conditions that are less than the optimum, the plants are considered to be subjected to stress conditions. Such conditions include heat, high and low temperature, inadequate mineral, pollution, excessive salt, drought and water logging conditions. These conditions are bound to happen as a result of industrialization, use of pesticides, change of land use and greenhouse effects.

Plants are always exposed to stressful condition due to the fact that they are sessile. They cannot dislocate from where they are planted thus they are bound to experience these stressful conditions when present. Ackerly *et al*., (2000) stated that plants show different physiological, ecophysiological, functional diversity, growth rates and productivity under different conditions. They are unable to express their full genetic potential for production when subjected to these stressful conditions. Stresses have negative effects on growth of cell, separation of membrane protein, decrease in chlorophyll content and loss of germination capability (Jaleel *et al*., 2009)

Under drought and high salinity conditions, proline is accumulated to mediate osmotic adjustment, protect protein structure from denaturation, stabilize cell membrane by interacting with phospholipids, scavenge reactive oxygen species such as super oxide, singlet oxygen, hydroxyl ion and hydrogen peroxide (Claussen, 2005). This implies that a proper concentration of proline is involved in the osmotic potential of some plants under stress (Yan *et al.*, 2011).

Various attempts to improve tolerance to drought and salinity through conventional plant breeding or transgenic methods could require excessive time and hard work; but, application of exogenous proline (Hua and Guo, 2002; Kaya et al., 2007; Hoque et al., 2007; Ozden et al., 2009) could also improve tolerance which is speedier and more convenient (Yan *et al.*, 2011). Exogenous application of proline has been reported as far back as 1980 by Rajagopal and Sinha that exogenously applied proline maintained turgidity in leaves of barley and wheat undergoing stress. The ability of exogenous proline to maintain higher water content in severely stressed seedlings might be attributed to its contribution to osmotic adjustment both directly by increasing the internal proline content and indirectly by increasing the internal contents of other amino acids. Exogenous proline increased the protein content of the shoot and root at all levels of salt stress.

Changes in growth and protein contents as a result of exogenous proline correlated with increases in the internal content of proline suggesting that proline was taken up into the roots and transported to the shoots. Ion fluxes across the plasma membrane may be regulated by low concentrations of proline in barley roots (Cuin and Shabala, 2005). The exogenous application of proline significantly alleviated the growth inhibition of plants induced by sodium chloride, and was accompanied by higher leaf relative water content and peroxidase activity, higher proline content, and lower malondialdehyde content and superoxide dismutase activity. The enhanced salt tolerance could be partially attributed to the improved water status and peroxidase enzyme activity in the leaves.

One approach to assess the metabolic consequences of proline accumulation in response to stress is to examine its exogenous application to whole organism or tissues.

RESPONSES OF CROP PLANTS TO DROUGHT AND HIGH SALINITY STRESS CONDITIONS

Drought: - Drought is defined as a period of dry weather that is injurious to crops (Metwally *et. al.,* 2014). It brings limitation to all types of agricultural products. Drought affects plant morphology, physiology and biochemistry thereby leading to low yield (Thapal *et al*., 2001). It causes reduction in size of leaf, insufficient size development in cereals, reduction in height of potatoes (*Solanum tuberosa* L.), soybeans (*Glycine max* Merr.), okra (*Abelmoschus esculentum*), cowpea (*Vigna uguiculata*) etc. (Wu *et al*., 2008; Kadioglu *et al.*, 2011). It also causes decrease in pod number of soybeans and reduction in seed weight of sunflower (*Helianthus annuus* L) (Webber *et al*., 2008), structural deformation of wheat spike (Farooq *et al*., 2011). Drought reduces germination and seedling stand (Kaya *et al*., 2006).

Okcu *et al*., (2005) reported that there was impairment of germination and early seedling growth of five cultivars of pea. Manikavelu *et al*., 2006 reported that there was a great reduction in vegetative stage of rice. In barley (*Hordeum vulgare*), drought stress reduced grain yield by reducing the number of tillers, spikes and grains per plant and individual grain weight. Post-anthesis drought stress was detrimental to grain yield regardless of the stress severity (Samarah, 2005). In pearl millet (*Pennisetum glaucum*), co-mapping of the harvest index and panicle harvest index with grain yield revealed that greater drought tolerance was achieved by greater partitioning of dry matter from stover to grains (Yadav *et al*., 2004). In pigeonpea, drought stress coinciding with the flowering stage reduced seed yield by 40–55% (Nam *et al*., 2001).

Salinity: - Currently, approximately 20% of the world's cultivated land and nearly half of all irrigated lands are affected by salinity (Zhu, 2001). High salinity is a major problem faced by plants worldwide, which results in serious metabolic perturbations reducing crop productivity and yield (Hayat *et al*., 2012). Salinity imposes two constraints on plants: an osmotic effect resulting from the lower soil water potential and an ionic effect resulting from the direct toxicity of saline ions and the ion imbalance in the plants (Munns and Tester, 2008).

When plants are subjected to salt-stressed condition, it leads to a reduction in height, root growth, bud formation, leaf area, fresh and dry weight of crops (Gusoy *et al*., 2012), reduction in growth and protein content in *Pancratium maritium* (Hayat *et al*., 2012).

PROLINE SYNTHESIS AND PHYSIOLOGICAL FUNCTION

Proline is α-amino acid, one of the twenty DNA-encoded amino acids found in proteins. It is unique among the 20 protein-forming amino acids in that the α-amino group is secondary. In plants proline is synthesized from glutamic acid through a pathway catalyzed by pyrroline-5-carboxylate synthetase and pyrroline-5-carboxylate reductase. Its accumulation under various abiotic stresses important crop plants considered as a tolerance mechanism. Proline accumulation is believed to play adaptive roles in plant stress tolerance and has been proposed to act as a compatible osmolyte and to be a way to store carbon and nitrogen. Proline has also been proposed to function as molecular chaperone stabilizing the structure of proteins, and proline accumulation can provide a way to buffer cytosolic pH and to balance cell redox status. It accumulation in plant may be part of the stress signal influencing adaptive responses. Proline has been thought to have an adaptive role in mediating osmotic adjustment and protecting subcellular structure in stressed plants. Besides acting as an excellent osmolyte, proline plays three major roles during stress, i.e. as a metal chelator, an anti-oxidative defense molecule and a signaling molecule (Hayat *et al*., 2012).

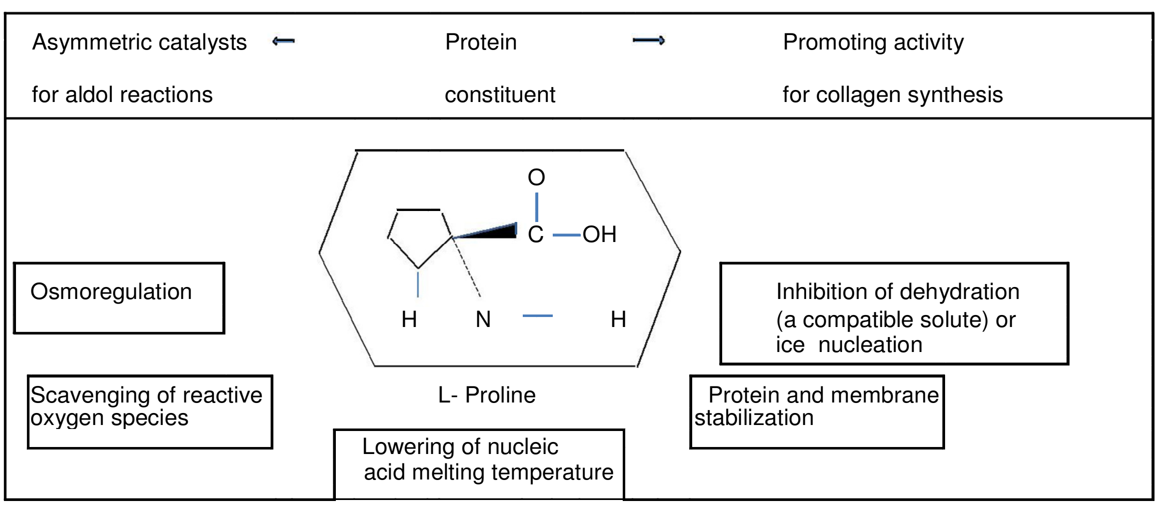

Figure 1: The physiological functions of proline
Takagi, 2008

PROLINE ALLEVIATING EFFECTS ON CROP PLANTS EXPOSED TO DROUGHT AND SALINITY STRESSES

Proline has been applied to higher plants to determine its ability to counteract the inhibitory effects of environmental stress, mainly water or salt stress. The exogenous application of proline has been suggested to be an effective approach in improving crop salt tolerance in groundnut (Jain *et al*., 2001) and melon (Kaya *et al*., 2007). 0.2 mM proline treatment enhanced the salinity tolerance of two cultivars of melon plants and alleviated their salinity-induced damage (Yan *et al.,* 2011). The addition of 100 mM proline to a Hoagland solution containing 120 mM NaCl neutralized the effect of salinity on pea plants.

The addition of 10 mM proline to cultured barley embryos increased shoot elongation under saline conditions. This effect was attributed to the ability of proline to decrease the leaf salt load. Proline allowed an enhanced K/Na discrimination in transport to the shoots and a better salt exclusion from the shoots with retention in the roots. The callus lines of chickpea (*Cicer arietinum)* grown in a medium containing 100 mM NaCl and 10 mM proline increased their fresh and dry weights. Optimal concentrations of proline increased the cellular levels of K and decreased Na and Cl levels. Spraying cotton plants grown under conditions of low soil water potential with proline solutions counteracted the effects of stress, especially at moderate and high stresses. Foliar application of proline was an effective way to improve the salt tolerance of cucumber (Huang *et al*., 2009). Gadallah (1999) reported that exogenous proline application completely alleviated salinity-induced injury in *Vicia faba*

According to Ali (2013), foliar-applied of proline significantly increased the content of seed sugar, oil, protein, moisture, fiber and ash in two cultivars of maize under well irrigated and water deficit conditions. He further stated that there was increased in oil oleic, linoleic acid, antioxidant compounds like phenolics, carotenoids, flavonoids and tocopherols contents of the maize cultivars. It improved the tolerance of somatic embryos of celery (*Apium graveolens* L. cv. SB 12). Ali and Ashraf (2011) reported significant increase in the accumulation of carotenoids from 73.33 μg g−1 to 111.7 μg g−1 in the seed oil of two maize. cultivars under water deficit conditions as a result of application of exogenous prolime.

CONCLUSION

The function of proline in tolerance to salinity and drought stresses in plants is still unclear and requires further study. It is also apparent that an excess of free proline has negative or side effects on cell growth or protein functions therefore researchers should investigate the alleviating effect of exogenous proline on all crop plants at all stages such as germination, vegetative, flowering, fruiting and maturity as well as the effective concentrations at each stage. This will provide useful recommendation for the use of exogenous proline by crop farmers.

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