DEFENSIVE ROLE OF NITRIC OXIDE (NO) UNDER DROUGHT STRESS IN PLANTS: MINI-REVIEW

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Abstract: There are several physiological implications of Nitric oxide (NO) gas have been reported so far in plants. Among these protection of plants from various abiotic and biotic stresses are gaining attention on priority. Presently, drought stress is the most prevalent abiotic stress in plants that affects their growth, development and overall yield. The role of NO in resisting drought stress has been investigated by many researchers. But it is still unclear about the actual involvement of NO in drought stress responses at a whole plant level. This article reviews the defensive role of NO during drought stress in plants.

Keywords: nitric oxide (NO); drought stress; abiotic stress; nitric oxide synthase (NOS); reactive oxygen species (ROS).

I. INTRODUCTION

Nitric oxide (NO) is considered as an important signaling molecule that helps the plant in normal growth and development. Actually, it is reported to be involved in both beneficial and harmful effects in plant cells. This twin role depends on the available concentration of NO that affects the rate of synthesis of biomolecules, their translocation and effectiveness. Sometimes it interacts directly with the molecules and helps in the generation of signals. It also alters the expression of genes that are involved in many roles like protection of plant during environmental stress hazard due to most of the abiotic and biotic factors. This review is focused mainly on the essential role of NO in plant signaling network, leading to the expression of defense response genes under water deficit condition.

II. EFFECTS OF DROUGHT STRESS IN PLANTS

Drought stress is most prevalent abiotic stress that occurs in plants when water loss by transpiration surpasses absorption capacity of roots, resulting in cell dehydration, damage, and ultimately cell death (Chaves, Maroco, & Pereira, 2003; Shao, Jaleel, Ni, Manivannan, & Panneerselvam, 2009). Water deficit conditions also produce injurious effects on plant metabolism, nutrient uptake and growth (Farooq, Basra, Wahid, & Rehman, 2009). Above all oxidative damage to biomolecules takes place due to the overproduction of reactive oxygen species (ROS).

III. DEFENSE MECHANISM OF NITRIC OXIDE AGAINST DROUGHT STRESS

In response to drought stress, several defense mechanisms become operative in plants such as modification of expression of genes that are involved in the synthesis of osmo-protectants, water stress protective proteins, antioxidant enzymes, plant hormones like abscisic acid (ABA) etc.(Bray, 1997; Roychoudhury, Paul, & Basu, 2013; Seki, Umezawa, Urano, & Shinozaki, 2007). ABA perform that task by mediating the activation of the NADPH oxidases like respiratory burst oxidase homolog D and F (RBOHD and RBOHF), that results in ROS production often called oxidative burst (Bright, Desikan, Hancock, Weir, & Neill, 2006; Kwak et al., 2003). Along with ROS, nitric oxide (NO) synthesis takes place (Bright et al., 2006; Desikan, Griffiths, Hancock, & Neill, 2002) which then proposed to activate mitogen activated protein kinase (MAPK) signaling cascades that ultimately drive stomatal closure (Zhang, Takemiya, Kinoshita, & Shimazaki, 2007). NO also acts as antioxidant and remove the reactive oxygen species either directly by itself conversion into peroxy-nitrile or by enhancing the expression of antioxidant enzyme producing genes (Radi, Beckman, Bush, & Freeman, 1991). Thus, NO acts as signaling molecule and essential mediator in protection mechanisms (S. Neill et al., 2008; Wendehenne, Pugin, Klessig, & Durner, 2001). Its role as signaling molecule in several plant signal transduction pathways have also been proven by reporting its interaction potential with many other signalling molecules such as hydrogen peroxide, cyclic nucleotides (cAMP, cGMP), cytosolic calcium, abscisic acid, salicylic acids etc. (Arasimowicz & Floryszak-Wieczorek, 2007; Yamasaki, 2005).

Role of NO as signaling molecule under drought stress was initially noticed in pea plant guard cells (S. J. Neill, 2002) and later on confirmed in *Vicia Faba* and *Arabidopsis* (Bright et al., 2006; Kwak et al., 2003). In wild type *Arabidopsis thaliana*, ABA has also found to be involved in stomatal closure under water deficit conditions, which was promoted by increased in extracellular Ca^{2+} bound with calmodulin that ultimately triggers a significant increase in NO levels(Allen et al., 2001; Li et al., 2009; MacRobbie, 1992; Y. Y. Wang, Hsu, & Tsay, 2012). Thus, several molecules including hydrogen peroxide, cyclic GMP, cyclic ADP ribose, and calcium ions work together with NO as part of ABA signaling in wild- type guard cells. (Daszkowska-Golec & Szarejko, 2013) also concluded NO as an important signaling molecule was involved in the control of stomata movements. Bright and his co-workers, 2006 have reported that double mutants in the probe i.e. 4, 5 diamino fluorescein diacetate was used. This probe can be used to detect NO production in real time. Increase in fluorescence was observed in the *Arabidopsis thaliana* guard cells which were treated with ABA. This was further confirmed by using inactive probe 4-diacetate diamino fluorescein that did not showed increase in fluorescence. Further to prove synthesis of NO induced by ABA is an essential component in stomatal closure, chemical compounds such as 2-phenyl-5, 5-tetrametilimidazoline-1-oxyl-3-oxide (PTIO), 2-(4-carboxyphenyl)-4,4,5,5- tretametilimidazolina-1-oxyl- 3-oxide (c PTIO) and nitric oxide synthase inhibitor i.e. NG-nitro-l-arginine methyl ester (L-NAME) also checked and found to inhibit the NO induction (Desikan et al., 2002; S. J. Neill, 2002). Application of donors of NO, such as SNP (sodium nitroprusside) was also carried out to confirm the role of NO in stomatal closure and reduction of transpiration in monocot as well as dicot plant species(Desikan et al., 2002) (García and Lamattina, 2002; Desikan *et al*, 2002; Gan *et al*, 2015). However, NO synthesis was enhanced in response to ROS (Xing et al., 2004; Z. Zhao, Chen, & Zhang, 2001).

In potato leaves, exogenous application of NO inhibited the damages caused by ROS produced under drought stress(M. V. Beligni & Lamattina, 1999, 2000, 2001; Carimi et al., 2005; Hao, Xing, & Zhang, 2008; Tun, Holk, & Scherer, 2001). In drought stressed maize leaves, exogenously treated with NOS and NR inhibitors. That results into blockage of synthesis of NO. Thus, NOS and NR are the enzymes involved in production of NO(Sang et al., 2008; Xiong et al., 2012; L. Zhao, He, Wang, & Zhang, 2008). Hao *et al*. (2008) also showed the protective role of NO in drought stressed maize seedlings. Thus, NO is a plant signaling molecule and can readily pas through cell membranes (Corpas, Barroso, & Del Río, 2001; Gupta, Fernie, Kaiser, & van Dongen, 2011; Y. S. Wang & Yang, 2005).

IV. CONCLUDING REMARKS

Further research should be carried out to identify and characterize the signaling molecular mechanisms actually involved in response to nitric oxide in plants under water deficit stress. Investigations should also be carried out to find the role of interactions between reactive nitrogen species and reactive oxygen species.

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