Seed Priming and Seedling Pre-treatment Induced Tolerance to Drought and Salt Stress: Recent Advances

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Contents

Abstract Plants are sessile entities and hence have to face the environmental havocs without any chance of avoiding it. Abiotic stress like drought and salinity encumbers plant growth and developmental activities rendering drastic drop in crop yields. Though plants have evolved stress response mechanisms, many a times it doesn't suffice, and the plant succumbs to stress intensity and duration. But sometimes priming and pretreatment with exogenous agents (selenium, silicon, zinc, copper, etc.) enhance the inherent tolerance capability of plants to some extent. These priming and pretreatment technologies (using sodium nitroprusside, hydrogen peroxide, etc.) are cost-effective and user-friendly for stress alleviation in various plants. This chapter centre rounds these ameliorating agents and the mechanisms involved in enhancing the tolerance capability. Various reports suggested different techniques and treatments in combinations while using variety of agents. This chapter aims to compare and summarise the technologies used. Though we mainly represent the mitigations reported in the past decade or so, this chapter is divided into two sections, with a glimpse of various inorganic and organic amendments used to alleviate salinity and drought stresses in wide range of plants.

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1 Introduction

Being sessile in nature, plant has to develop its own strategies to deal/cope with different environmental stresses (Barkla et al. 2013). Environmental stresses like high temperature, low temperature, salinity, drought and heavy metals have a great detrimental effect on crop growth and productivity worldwide (Cheeseman 2016). Among all the abiotic factors, drought and salinity are the most potent deterrents inflicting damage to 50% of world arable lands. Although conventional breeding and genetic manipulation through genetic engineering have great potential to enhance the tolerance capacity of crop plants against various abiotic stresses, seed priming or prestress exposure is emerging rapidly as an attractive alternative strategy in crop stress management and plant stress physiology to enhance plant's stress tolerance capacity under abiotic stress in the subsequent stages of development (Moshelion and Altman 2015; Savvides et al. 2016). Now both seed priming and pretreatment have emerged as an effective and practical method to enhance different abiotic stress tolerance/avoidance capacity (Bayat and Sepehri 2012; Khan et al. 2012; Hussain et al. 2016). Unlike conventional breeding and genetic engineering which are expensive, complicated and time-consuming approaches or even unacceptable in many countries, seed priming is more simple, of low cost, user-friendly and an effective method to enhance seed germination, seedling growth and crop production under adverse condition. In this method, seeds are pre-soaked with different ions, hormones, chemicals, organic compounds and antioxidants before planting (Ahmad et al. 2012; Moulick et al. 2016). Under multiple abiotic conditions, primed seeds have more stress tolerance capacity and better germination ability compared to non-primed seeds in different crop species (Zhuo et al. 2009).

1.1 Seed Priming

Increased seed quality is the need of the hour and has an increased demand in agricultural seed markets. Seed priming has emerged as less arduous approach in this direction. Seed priming technologies are said to induce 'pre-germinative metabolism' which includes activation of DNA repair pathways and antioxidant metabolism. Based on the agents used, seed priming has been characterised into hydropriming, biopriming, osmopriming, solid matrix priming, chemopriming and thermopriming. Hydropriming is the most primitive of all the priming technologies available which involves soaking of seeds under optimal temperature for partial hydration (McDonald 2000; Chen et al. 2012; Moulick et al. 2017). Here the main critical point is to maintain optimum temperature and humidity to avoid radicle protrusion. Although during this seed priming process, germination is not allowed through the controlled hydration technique, all other pre-germination metabolic activities required for embryonic and radicle growth are initiated (Jisha et al. 2013; Chen and Arora 2013; Paparella et al. 2015). So, as a result of this priming process, primed seeds have a better seed germination rate and uniform seedling growth compared to non-primed seeds (Chen and Arora 2013; Hakeem 2015). Biopriming involves the use of microorganisms or biologically active molecules as priming agents (Niranjan Raj et al. 2004). These biologically active molecules often involve plant secondary metabolites and hormones. In case of osmopriming, seeds are treated with an osmoticum at low water potential to facilitate better control of water uptake (Zhou et al. 2013). Solid matrix priming is an adaptation of osmopriming developed to reduce the huge cost of osmopriming. Instead of liquid here solid osmoticum is used like coal, sawdust, charcoal, etc. (Paparella et al. 2015). Chemopriming involves priming with chemical agents like salicylic acid, gibberellic acid, selenium, zinc sulphate, copper sulphate, sodium selenite, etc. (Hamayun et al. 2010; Moulick et al. 2018a, b, c). Thermopriming involves temperature treatment which has been reported to improve germination rate and percentage under adverse environmental conditions (Paparella et al. 2015). Besides this system of classification, different people have used different terminologies for classification based on the agents used like hormonal priming (priming with plant hormones) and redox priming (priming with ROS molecules).

Hameed et al. (2010) reported that priming the wheat seeds with ions, hormones, organic compounds and antioxidants increases the seed performance capacity against salt stress, whereas priming tomato cultivars with polyamines enhances the germination and seedling growth (Afzal et al. 2009). Application of salicylic acid (hormonal priming) and paclobutrazol in maize plants also decreased the impact of drought stress on growth and yield (Bayat and Sepehri 2012). Combination of 5-aminolevulinic acid (ALA) and drought treatment enhanced antioxidant enzyme activity and decreased ROS activity in cucumber under drought stress (Li et al. 2011). Application of ALA in low concentration alleviated the physiological changed in *Brassica napus* under salinity stress (Naeem et al. 2012). Seed priming of *Salicornia utahensis* with growth regulators like thiourea, kinetin, fusicoccin and ethephon improved salt tolerance capacity (Gul and Khan 2003). Under drought stress *Agropyron elongatum* seed priming with abscisic acid (ABA) and gibberellin (GA) induced CAT and SOD activities (Eisvand et al. 2010).

Under drought stress, priming wheat seeds with sodium silicate and ascorbic acid enhanced germination and early seedling growth (Hameed et al. 2013; Ahmed et al. 2016; Farooq et al. 2012; Jafar et al. 2012). Barley seed priming with polyethylene glycol at four osmotic potential levels (0, −7, −10 and − 14 MPa) increased germination rate and seedling growth under drought stress at 0, −3, −6 and − 9 MPa (Rouhollah Amini 2013). In this process, stored proteins are solubilised and lipid peroxidation activity is reduced. Antioxidant activities and osmolyte accumulation are increased through better metabolic processes (Jafar et al. 2012; Delavari et al. 2010). Similar results were also reported in rice, rapeseeds and basil under drought stress (Goswami et al. 2013; Zheng et al. 2016; Kubala et al. 2015; Farahani and Maroufi 2011; Srivastava et al. 2010; Zheng et al. 2016). In soybean and sunflower, seed priming with KNO_3 (osmopriming) increased seed germination rate, seedling growth and proline accumulation under salinity stress (Ahmad et al. 2012; Bajehbaj 2010). Application of exogenous spermidine ameliorated salt stress in *indica* rice varieties (Roychoudhury et al. 2011). Under drought condition, spermidine increased seed germination of white clove (Li et al. 2014) with an enhanced antioxidant enzyme activity and lower accumulation of ROS molecule and malondialdehyde (MDA) content.

Seed priming with H_2O_2 or hydrogen peroxide (redox priming) showed better performance than priming with mannitol in *Cakile maritima* which was evident from lower accumulation of oxidative stress biomarkers and higher accumulation of antioxidant enzyme activity (Ellouzi et al. 2017). In redox priming method, thiourea, a thiol compound, helped in maintaining the integrity as well as function of mitochondria in *Brassica juncea* seeds, exposed to drought stress (Srivastava et al. 2009).

Selenium priming (chemical priming) of wheat seed was found effective in seedling growth and biochemical changes under water limitation condition (Nawaz et al. 2013). In maize, seed priming with zinc sulphate ($ZnSO_4$) and copper sulphate ($CuSO_4$) (chemical priming) significantly increased the *Zea mays* L. caryopses under drought stress (Foti et al. 2008). Triticale seed priming with monopotassium phosphate (KH_2PO_4) increased seed germination percentage and seedling growth under both osmotic stresses (salt and drought) (Yagmur and Kaydan 2008). Another important chemical primer, paclobutrazol, has a significant role in periwinkle (*Catharanthus roseus*) in terms of antioxidant system under salinity stress (Jaleel et al. 2007). Application of choline to rice seeds increased salinity tolerance capacity in terms of photosynthetic ability, growth and accumulation of glycinebetaine (Su et al. 2006; Cha-um et al. 2006).

Melatonin priming of faba bean seeds increased salt tolerance capacity in plants incorporated to salt stress (Dawood and EL-Awadi 2015). Green gram seed priming with β- aminobutyric acid reduced MDA content and increased antioxidant defence mechanism (Jisha and Puthur 2016). Seed priming with exogenous spermidine and gibberellic acid alleviated salt stress in tomato and black glutinous rice seedlings (Hu et al. 2012; Saleethong et al. 2013; Chunthaburee et al. 2014). Under drought stress exogenous spermidine application alleviated drought stress in white clove through stimulation of antioxidant defence mechanism. Exogenous application of melatonin enhances plants ability to cope with different abiotic stresses like drought, high temperature, radiation, chemical stress and salinity (Li et al. 2012a, b; Wei et al. 2014; Zhang et al. 2015). Whereas, exogenous application of spermine in soybean seeds alleviated drought stress by increasing antioxidant activity and decreasing lipid peroxidation level (Radhakrishnan and Lee 2013). Application of exogenous nitric oxide in terms of sodium nitroprusside (SNP as nitric oxide donor) improved seed germination in wheat under salinity stress (Zheng et al. 2009). Alfalfa seed priming by hydrogen sulphide (sodium hydrosulphide, as H_2S donor) increases salt tolerance by reducing oxidative damage and enhancing seed germination percentage as well as antioxidant metabolism (Wang et al. 2012). Seed priming mitigation by ultraviolet light (UV-C) of range 200–280 nm decreased salt stress effect in lettuce seeds in terms of plant growth, accumulation of phenolic compounds and antioxidant properties (Ouhibi et al. 2014).

1.2 Seedling Pretreatment

Initial treatment before onset of stress pre-induces various physiological, biochemical and molecular changes for better adaptation to stress. A lot of studies showed that initial treatment or priming with appropriate levels of chemicals (organic/inorganic) enhances tolerance by modulating various physiological processes such as photosynthesis and by modulating multiple stress-responsive pathways such as the reactive oxygen species (ROS) and methylglyoxal (MG) detoxification pathways. Wheat (Hasanuzzaman et al. 2011) and rice (Corpas et al. 2011) plants showed enhanced tolerance towards salinity stress after giving sodium nitroprusside pretreatment for 24 h through enhanced induction of antioxidative defence. Similar observation was observed when roots of orange plants (Tanou et al. 2009), maize (de Azevedo Neto et al. 2005) and rice (Uchida et al. 2002) were pretreated with H_2O_2. Initial exposure of H_2O_2 in seedlings stage enhances tolerance towards salinity and drought through the modulation of various physiological processes (de Azevedo Neto et al. 2005; Chao et al. 2009; Liu et al. 2010). Seven-day-old mung bean seedlings (Hossain et al. 2011) and barley (Cuin and Shabala 2005) pretreated with proline or betaine showed an increase in GSH (reduced glutathione) and other similar metabolite contents along with antioxidative enzyme activities; potassium efflux hence decreased oxidative stress damage posed by salinity stress in a synergistic fashion.

Pretreatment with salicylic acid increases the tolerance in wheat (Kang et al. 2013), barley (El-Tayeb 2005) and bean and tomato plants (Senaratna et al. 2000). Spermine treatment in *Cucumis sativus* also alleviates oxidative stress induced by salt stress, rendered with improvement in photochemical efficiency of PSII (Shu et al. 2013). Silicon (Si), the second abundant element in soil, has been found to alleviate salinity stress after pretreatment in *Sorghum* (Liu et al. 2015), barley (Liang et al. 2006), rice (Gong et al. 2006), wheat (Saqib et al. 2008) and cucumber (Zhu et al. 2004). Alleviation of oxidative damage modulated by L-arginine was observed after pretreatment in sunflower (Nejadalimoradi et al. 2014) and rice (Kakkar et al. 2000). Polyamine pretreatment has often been applied to ameliorate the detrimental effects of salinity in maize (Pandolfi et al. 2010). Mitigation of NaCl-induced K^+ flux was also observed in barley roots after pretreatment with amino acids (Cuin and Shabala 2007). Methyl jasmonate and jasmonic acid are collectively known as jasmonates which are involved in diverse developmental processes such as root growth, fruit ripening, fertility and senescence (Creelman and Mulpuri 2002). The role of methyl jasmonate in mitigating NaCl- induced salinity stress on soybean was observed along with enhancement in endogenous level of

ABA and proline level (Yoon et al. 2009). Uses of phytohormones (indole-3-acetic acid, IAA; gibberellic acid GA_3; and kinetin Kin) in restoring the metabolic alteration caused by oxidative stress generation due to salt stress were investigated in *Vigna radiata.* The mitigation effects under salinity conditions were also observed when seedlings of *Malus hupehensis* were pretreated with melatonin, a low molecular weight molecule similar to indole acetic acid in functions (Li et al. 2012a, b).

Amelioration of drought-induced damages is also minimised by pretreatment with foliar application of glycine betaine (GB) in wheat plants (Ma et al. 2006). It mainly protects the PSII complex, which means GB enhance the photoinhibition tolerance of PSII. Improvement of yield under stress conditions is another prime goal for researchers since a long time. Foliar application of boron as a pretreatment in wheat enhanced yield grown under drought conditions (Abdel-Motagally and El-Zohri 2016). The selenium pretreatment boosted the metabolite and antioxidative defence system under drought stress conditions in rapeseed seedlings (Hasanuzzaman et al. 2011). Exogenously pretreated salicylic acid alleviated drought stress in *Nigella sativa* (Kabiri et al. 2014), maize (Saruhan et al. 2012) and wheat (Horváth et al. 2007). Brassinosteroids have been used to increase the tolerance capacity in *Chorispora bungeana* and tomato to drought stress. Malondialdehyde content, membrane permeability and proline content were less increased in EBR-pretreated plants under drought stress (Li et al. 2012a, b; Damghan 2009). The foliar application of 5-aminolevulinic acid (ALA) in cucumber leaves before onset of drought stress confers lower damage induced by oxidative stress by altering antioxidative enzyme activities (Li et al. 2011).

2 Future Prospects

Salinity and drought induces adverse effects on various field crops and hence are the most sought after research topic fetching attention of experts from around the globe. Besides inhibiting growth and reducing yield, these two abiotic stresses have perhaps the most sound impact on economy too. Several mitigation options have been investigated and reported in this direction. Among the mitigation options tried so far, breeding of tolerant varieties (conventional), generation of transgenic varieties, water management processes (alternating drying and wilting), soil health monitoring and adequate management as well as various agronomic practices are also tried side by side. Now, keeping an eye in future and remaining in vigil to climate change scenario, a comprehensive or integrated stress management system should be chosen. In such integrated crop management system, a continuous monitoring and adequate remedies like seed priming/pre-treatment should be prescribed according to regional preferences. Besides these, local, regional and international funding or governing body(s) should try to merge the gaps that exists among the various research groups or institutions working in a similar or closely related areas, and bringing them under the same roof will definitely smoothen the way ahead.

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