



E-ISSN: 2278-4136

P-ISSN: 2349-8234

www.phytojournal.com

JPP 2021; 10(2): 1035-1041

Received: 18-01-2021

Accepted: 21-02-2021

C Tamilselvi

Assistant Professor (Crop Physiology), Agricultural College and Research Institute, Eachangkottai, Thanjavur, Tamil Nadu, India

Venkateshwaran R

Final Year Students of Agricultural College and Research Institute, Eachangkottai, Thanjavur, Tamil Nadu, India

Jeevapriya S

Final Year Students of Agricultural College and Research Institute, Eachangkottai, Thanjavur, Tamil Nadu, India

R Anitha

Assistant Professor (CRP), Sugarcane Research Station, Cuddalore, Tamil Nadu, India

S Arulselvi

Assistant Professor (PBG), Agricultural College and Research Institute, Eachangkottai, Thanjavur, Tamil Nadu, India

Corresponding Author:**C Tamilselvi**

Assistant Professor (Crop Physiology), Agricultural College and Research Institute, Eachangkottai, Thanjavur, Tamil Nadu, India

Physiological studies on the effect of plant growth regulators for mitigation of drought in rice (*Oryza sativa* L.)

C Tamilselvi, Venkateshwaran R, Jeevapriya S, R Anitha and S Arulselvi

Abstract

Water is the most abundant material in a growing plant. It comprises of 80 percent or more of the plant weight. It is the main carrier for food materials and other substances transporting inside the plant body. The reactions of plants to water stress differ significantly at various structural levels depending upon intensity and duration of stresses as well as plant species and its stage of growth. The present review highlights the effect of drought stress on rice crop productivity. Plant growth and productivity of rice is adversely affected by various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. Water stress is a limiting factor in agriculture production by preventing a crop from reaching the genetically determined theoretical maximum yield. In plants, a better understanding of the morphological and physiological basis of changes in water stress resistance could be used to select or create new varieties of crops to obtain a better performance under water stress conditions.

Keywords: Rice, water stress, gibberellic acid, salicylic acid, potassium nitrate and calcium silicate

Introduction

Under drought stress, plants experience the higher rate of transpiration and lack sufficient water near the roots. Drought significantly impairs the growth, development and yield of rice. When the water is lacking, rice typically stops or slow down the growth. Among crop production factors, water scarcity is one of the severe environmental limitations to crop productivity in chronic areas. It destabilizes the crop production in drought prone areas. Water deficit is a major problem for crop production worldwide, limiting the growth and productivity of many crop species, especially in rain-fed agricultural areas. It is a yield limiting factor common to all type of rainfed rice cultures: wetland, upland and deep water. Drought stress is a global issue to ensure survival of agricultural crops and sustainable food production. It reduces the plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters. The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stresses as well as plant species and its stage of growth. Water stress causes detrimental effect on yield. So, foliar application of phytohormones like Gibberellic acid, Salicylic acid, Potassium nitrate and calcium silicate are required to nullify the ill effect of drought stress on growth and yield of crop. Drought stress negatively affects many physiological plant processes, such as photosynthesis, transpiration, stomatal conductance, chlorophyll contents and metabolite accumulation which cause considerable reductions in plant productivity. Higher electron leakage in photosynthetic and respiratory processes under drought stress induced oxidative stress in the plant cell resulting in reactive oxygen species (ROS) production. The degree of damage due to drought stress depends upon the type of genotype, intensity and duration of stress and developmental stage of the plant. Drought is the most detrimental abiotic stress affecting the plant growth and development globally. In rice, drought causes a reduction in growth by impairing germination, root growth, shoot growth, and reduced leaf area due to loss of turgor. Photosynthesis, the prime important process is also disturbed by drought mainly due to stomatal closure, reduced chlorophyll contents, restricted activity of enzymes and production of reactive oxygen species (ROS), which cause oxidative damage to membrane and organelles. Reproductive growth of rice is more sensitive to drought than vegetative growth. Drought causes a decrease in the number of tillers per plant, seeds per plant, 1000 seed weight and seed yield by influencing a number of morphological and physiological traits. Adverse effects of drought can be minimized by different management practices like planting methods, foliar application of plant

growth regulators, nutrients, compatible solutes and various breeding programmes for drought tolerance in rice. So, there is a need to adopt the various management techniques in order to combat the problem of drought. Drought tolerance evaluated as amplify cell membrane stability under water shortage conditions. The root system is the main plant organ for adaptation of drought stress conditions. The main basis of variation appears to be constitutive, therefore, root system architecture that allows reserve of more water quantity are the most important tool for drought tolerance. Drought stress alone inhibited plant growth in term of reducing shoot length and fresh weight of the hypocotyls. The drought, tolerant plants initiate defence mechanisms against water deficit, plants use different mechanisms of drought tolerance at different levels of aridity. Some of this is morphological mechanism such as escape from drought, drought avoidance and phenotypic flexibility. Also, there are physiological mechanisms to avoid negative effects of drought on the plant growth. Drought, salinity, temperature stresses are decreased germination percent. Stresses of high severity in addition germination reduction are decreased germination rate, seedling emersion and vigor. Drought is one of the serious abiotic stresses in most countries of the world.

A complex network of hormonal signals has been known to regulate the plant's response to abiotic stress. (Bartsch & Bednarek, 2010; Lumba *et al.*, 2010) [6, 22]. The Gibberellic acid (GA), Salicylic acid (SA), Potassium nitrate (PN) and Jasmonic acid (JA) are plant growth regulators with a well-documented plant response to abiotic stress (Grobkinsky *et al.*, 2016) [11].

Effect of growth regulators on rice under drought

Among the abiotic stresses, drought causes severe damage to plants in various ways, reducing growth by disrupting photosynthesis and other physiological functions, which ultimately reduce yield. Production of reactive oxygen species (ROS) is one of the most important biochemical responses of plants to drought stress. Oxygen plays an important role in normal metabolism and in cell signalling, but during drought stress, ROS (e.g., singlet oxygen 1O_2 , superoxide anion $O_2^{\bullet-}$, hydrogen peroxide H_2O_2 , or hydroxyl radical OH^{\bullet}) are overproduced which are very dangerous for plants. Reactive oxygen species levels increase drastically resulting in oxidative damage to proteins, DNA, and lipids, and cause damage to plants by increasing lipid peroxidation, protein degradation, DNA fragmentation, and ultimately leading to cell death. (Hasanuzzaman *et al.*, 2012) [1, 5, 12]. Under drought stress, stomata close and CO_2 concentrations inside the leaf are reduced. Carbon fixation is therefore disrupted, and excessive excitation energy is produced in chloroplasts. Under severe stress conditions, excited pigments in the thylakoid membranes may interact with O_2 and form $O_2^{\bullet-}$ or 1O_2 , and more downstream reactions produce other ROS, such as H_2O_2 and OH^{\bullet} .

Gibberellic acid, well-known natural substances which modulate plant growth by improving its tolerance under stress. Potassium nitrate induced chilling tolerance in rice seedlings and improved overall growth and total biomass accumulation under low temperature conditions. Calcium silicate act as a plant growth regulator due to release of Ca^{2+} ions that act as a ubiquitous secondary messenger that mediates plant growth and development under stress conditions. Moreover, humic substances have also been reported to regulate plant growth under abiotic stress conditions. For example, foliar application of GA (1.5 mg/L)

substantially ameliorated the adversities of drought by enhanced levels of antioxidant enzymes (superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) activities and proline). Furthermore, salicylic acid is considered as an endogenous regulator, has long been known as a signal molecule in the induction of defense mechanisms in plants and plays an important role in defending biotic and abiotic stresses in plants, because it has been qualified as a plant hormone due to its physiological and biological roles.

Role of gibberellic acid under drought stress

Gibberellic acid (GA) is a tetracyclic di-terpenoid compound is, a plant hormone that promotes plant growth and development. The phytohormone gibberellic acid (GA; also referred to as gibberellin) governs almost all plant development and growth processes, including seed development and germination, stem and root growth, cell division, and flowering time. GAs stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, determines sex expression and grain development along with an interaction of different environmental factors *viz.*, light, temperature and water. Stamens that influence male flower production and pedicel growth are the major sites of bioactive GA. While it is thought that GAs often behave like paracrine signals do, it is still a mystery to understand the biosynthesis of GA and its motion. The appropriate bioactive GA site in plants or tissues targeted by bioactive GAs have not yet been confirmed to initiate their action. It is certainly a key challenge for the scientific community to understand the appropriate mechanism for GA movement in plant growth, floral development, sex expression, grain development and seed germination.

Gibberellic acid is a hormone that is found in both plants and fungi. It is used mainly for stimulating plant growth but it also works as a protectant under stress conditions. Various plant growth regulators have the potential to regulate water balance, stomatal closure, and are also responsible for activating secondary metabolism under drought stress (Khan *et al.*, 2018) [14, 17, 29, 30]. Gibberellic acid is able to scavenge ROS and under drought stress, it assists plants with their more negative water potential and so maintaining photochemical efficiency of PSII. It is also thought that GA assists plants under nutrient stress by increasing nutrient uptake as well as nitrogen use efficiency. Pan *et al.*, 2013 [33] showed that different growth hormones, including GA, play a similar role as antioxidant enzymes in deleting ROS. These authors also stated that GA helps to decrease lipid peroxidation and increase SOD and POD activity. Various plant growth regulators including GA improve photosynthetic ability, decrease leaf senescence, and aid in increasing seed-set under drought stress (Li *et al.*, 2010) [15, 16]. Gibberellic acid is known to increase the chlorophyll content of leaves and mineral nutrients uptake under abiotic stress (Kang *et al.*, 2014) [14, 15, 16] as well as mitigating the adverse effects of drought and thus improve plant growth (Hasanuzzaman *et al.*, 2018) [1, 5, 12].

Role of salicylic acid under drought stress

Salicylic acid (SA) plays a vital role in many physiological routes of plants, and several studies stated the use of SA in stress mitigation (Maruri-López *et al.* 2019) [26]. Likewise, H_2O_2 acts as a signaling molecule at mild levels which operates versatile functions in plants. It also regulates plant metabolism by cooperating with other hormones and

signaling molecules and confers stress tolerance (Smirnov and Arnaud 2019) [31]. The latest studies showed that the exogenous H₂O₂ augmented abiotic stress tolerance of different plants (Banerjee and Roychoudhury 2019, Latef *et al.* 2019) [5, 20]. Salicylic acid (SA) is a phenolic compound involved in the regulation of growth and development of plants, and their responses to biotic and abiotic stress factors (Miura and Tada, 2014) [28]. SA is involved in the regulation of important plant physiological processes such as photosynthesis, nitrogen metabolism, proline (Pro) metabolism, production of glycine betaine (GB), antioxidant defence system, and plant-water relations under stress conditions and thereby provides protection in plants against abiotic stresses (Nazar *et al.*, 2011; Miura and Tada, 2014) [28, 29, 30]. Apart from its involvement in the induction of defense-related genes and stress resistance in biotic stressed plants (Kumar, 2014) [19], SA has been shown to improve plant tolerance to major abiotic stresses such as metal (Zhang *et al.*, 2015), salinity (Nazar *et al.*, 2015) [29, 30], osmotic (Alavi *et al.*, 2014), drought (Fayez and Bazaid, 2014), and heat stress. Exogenously applied SA was reported to improve growth and photosynthetic traits in several crop plants including lead [Pb-(0.05, 0.15, 0.25 mmol L⁻¹)] exposed *Oryza sativa*, Cd (10, 15, and 25 µM)-exposed *Zea mays*, and Cu (0.05, 0.10, 0.15, and 0.20 mM)-exposed *Phaseolus vulgaris* (Zengin, 2014). Applied SA was evidenced to modulate antioxidant system-components and significantly decrease membrane lipid peroxidation in Cu-exposed *P. vulgaris* (Zengin, 2014) and Pb-exposed *O. sativa*. Recent evidences also suggested that SA is an important regulator of photosynthesis, photosystem II (PSII), photosynthetic pigments, and the activity of enzymes such as Rubisco and carbonic anhydrase under metal stress (Al-Whaibi *et al.*, 2012; Noriega *et al.*, 2012; Zhang *et al.*, 2015) [21, 38, 42, 44]. Exogenous SA (3.0 mM) enhanced *OsWRKY45* gene expression and increased endogenous content of SA. It has been shown that increased endogenous SA level prevented membrane damage by lowering H₂O₂ content in Cd-exposed *O. sativa* (Chao *et al.*, 2010) [7]. Involvement of SA (0.5 mM) in the phytochelatin (PCs)-mediated protection of *Z. mays* was evidenced against Cd-toxicity (Szalai *et al.*, 2013) [39]. SA can also significantly inhibit Fe-deficiency-caused chlorosis in plants (Kong *et al.*, 2014) [18]. Exogenously applied SA can modulate important enzymatic (including monodehydroascorbate reductase, MDHAR; dehydroascorbate reductase, DHAR; GR; GSH peroxidase, GPX) and non-enzymatic (including GSH) components of AsA-GSH pathway, and also glyoxalase system (Gly I and Gly II) and decrease oxidative stress in drought-exposed plants (Alam *et al.*, 2013) [1]. Foliar application of SA (1.0 µM) strengthened antioxidant defense system in drought-tolerant *Z. mays* cultivar to a great extent (vs. drought-sensitive cultivar; Saruhan *et al.*, 2012) [37]. Low membrane lipid peroxidation but increased plant height and dry mass, and less wilting of leaves were reported in drought-exposed and SA (0.5 mM)-supplemented *T. aestivum* Kang *et al.* (2012) [14, 15, 16]. The authors correlated the gene-expression-responses to SA with signaling pathway in plants under drought stress condition. SA (0.5 mM)-mediated significantly improved growth in drought-exposed *T. aestivum* seedlings was argued as a result of SA-mediated enhancements in the transcription of GST1, GST2, GR, MDHAR genes (Kang *et al.*, 2013) [14, 15, 16]. SA-accumulating mutants (cpr5 and acd6) exhibited stomatal closure and improved drought tolerance in *A. thaliana* by SA-mediated induced expression of PR genes (PR1, PR2, and PR5; Liu *et*

al., 2013) [15, 18]. SA was reported to inhibit valine and sucrose uptake in a concentration-dependent manner (10–200 µM). Improved plant health can also be achieved with increased contents of polysaccharides and soluble sugars, respectively, with 100 µmol L⁻¹ (Yuan *et al.*, 2014) [42], and 0.5 and 1.0 mM SA (Luo *et al.*, 2014) [23]. Salicylic acid can be involved in the regulation of uptake of several plant-beneficial elements such as Mn, Ca, Cu, Fe, P, and Zn and thereby minimize oxidative stress under Pb stress.

Role of potassium nitrate (KNO₃) under drought stress

K is an essential nutrient and is also the most abundant cation in plants. The concentration of K⁺ in the cytoplasm has consistently been found to be between 100 and 200 mM and apoplasmic K⁺ concentration may vary between 10 and 200 or even reach up to 500 mM (White *et al.*, 2010) [40]. K plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance. Increased evidence has shown that crop production is significantly restricted by biotic stresses. These numbers reflect the total attainable production for eight major crops (wheat, rice, maize, barley, potatoes, soybeans, sugar beets and cotton). K is essential to the performance of multiple plant enzyme functions, and it regulates the metabolite pattern of higher plants, ultimately changing metabolite concentrations. In a K-sufficient plant, the synthesis of high-molecular-weight compounds (such as proteins, starches and cellulose) was markedly increased, thereby depressing the concentrations of low-molecular-weight compounds, such as soluble sugars organic acids, amino acids and amides, in the plant tissues. These low-molecular-weight compounds are important for the development of infections and insect infestations, so lower concentrations, thereby, leave plants less vulnerable to disease and pest attacks in K-sufficient plants. Adequate K increases phenol concentrations, which play a critical role in plant resistance.

The major limitation for plant growth and crop production in arid and semi-arid regions is soil water availability. Plants that are continuously exposed to drought stress can form ROS, which leads to leaf damage and, ultimately, decreases crop yield. During drought stress, root growth and the rates of K⁺ diffusion in the soil towards the roots were both restricted, thus limiting K acquisition. The resulting lower K concentrations can further depress the plant resistance to drought stress, as well as K absorption. Maintaining adequate plant K is, therefore, critical for plant drought resistance. A close relationship between K nutritional status and plant drought resistance has been demonstrated. The roles of K in physiological and molecular mechanisms of plant drought resistance have been explored.

Deeper rooting could be achieved by deep placement of K fertilizer that is associated with other mineral nutrients, such as P and N, which both have root signalling functions. Adequate amounts of K can enhance the total dry mass accumulation of crop plants under drought stress in comparison to lower K concentrations. This finding might be attributable to stomatal regulation by K⁺ and corresponding higher rates of photosynthesis. Furthermore, K is also essential for the translocation of photo assimilates in root growth (Romheld and Kirkby, 2010) [35]. Root growth promotion by increased appropriate K supply under K-deficient soil was found to increase the root surface that was exposed to soil as a result of increased root water uptake (Romheld and Kirkby, 2010) [35].

Increased evidence shows that the maintenance of membrane integrity and stability under drought stress is also essential for plant drought tolerance. Cell membrane stability was significantly declined under drought stress. This improvement was mainly attributed to the role of K in improving cell membrane stability and osmotic adjustment ability. An adequate K supply is essential to enhancing drought resistance by increasing root elongation and maintaining cell membrane stability.

During water stress, roots regulated their water and ion uptake capacities by modifying *PIPs* (plasma membrane intrinsic proteins) and K^+ channel at the transcription level to cope with the water deficiency. Transcription expression levels of the *PIPs* and K^+ channel-encoding genes was induced by K^+ starvation and could be down regulated by a polyethylene glycol (PEG)-mediated water deficit in rice, which may result in a reduction in the membrane water permeability and then promote cellular water conservation during drought stress. However, it should be mentioned that the expression level of some other water channels, such as OsPIP1;1, OsPIP1;2, AtPIP1;4 and AtPIP2;5, could be induced by a relative long-term water-deficit treatment, which should result in greater osmotic water permeability and facilitated water flux. Recently, Kanai *et al.* 2011 [13] also observed close coupling between aquaporin activities and K -channel transporters. The initial response of K deficiency was perceived in the form of a change in K -channel activity, which altered root hydraulic conductance, and transduction of the follow up signal resulted in a shift of aquaporin activity. They found that aquaporin activities might have been suppressed by K deficiency and result in a reduction of root hydraulic conductance and water supply to the growing stem for diameter expansion and the leaf for transpiration.

The maintenance of a favorable water status is critical for plant survival under drought stress. Osmotic adjustment is a major trait that is associated with maintaining high cellular turgor potential and water retention in response to drought stress. Many studies have shown that osmotic adjustment of leaves is positively correlated with drought tolerance in various plant species. As one of the most prominent inorganic osmotica in plants, K^+ plays a key role in formation of the osmotic adjustment ability, even under drought conditions. Cell turgor recovery in osmotically-generated stress was regulated by increasing K^+ , Cl^- and Na^+ uptake by root cells, which was partly mediated by voltage-gated K^+ transporters at the cellular plasma membrane. Furthermore, sufficient K induces solute accumulation, thus lowering osmotic potential and helping to maintain plant cell turgor under osmotic stress. In summary, an adequate K status may facilitate osmotic adjustment, which maintains higher turgor pressure, relative water content and lower osmotic potential, thus improving the ability of plants to tolerate drought stress.

Drought stress-induced ROS production can additionally be enhanced in K -deficient plants. Under drought stress, photosynthetic CO_2 fixation in K -deficient plants is substantially limited by impairment in stomata regulation, conversion of light energy into chemical energy and phloem export of photosynthates from source leaves into sink organs. As the impairment in photosynthetic CO_2 fixation occurs, molecular O_2 is activated, leading to extensive generation of ROS and, thereby, oxidative degradation of chlorophyll and membranes. The maintenance of adequate K nutrition is critical for mitigating or preventing damage by drought stress and controlling the water balance. An adaptive K requirement for drought-stressed plants could be related to the role of K in

enhancing photosynthetic CO_2 fixation and transport of photosynthates into sink organs and inhibiting the transfer of photosynthetic electrons to O_2 , thus reducing ROS production.

Role of calcium silicate (CaSi) under drought stress

Silicon (Si) being considered as a non-essential element for plant growth and development finds its role in providing several benefits to the plant, especially under stress conditions. Thus, Si can be regarded as “multi-talented” quasi-essential element. It is the most abundant element present in the earth’s crust after oxygen predominantly as a silicon dioxide (SiO_2), a form plants cannot utilize. Plants take up Si into their root from the soil in the plant-available forms (PAF) such as silicic acid or mono silicic acid [$Si(OH)_4$ or H_4SiO_4]. (Sajad Majeed Zargar *et al.*, 2019) [36].

Si application during drought stress provides tolerance to plant via different mechanisms. Application of Si under drought stress might up regulates aquaporin gene (PIP; Plasma membrane Intrinsic Protein) and mitigates ROS-induced aquaporin activity inhibition in plants. Under drought stress, Si supply affected the osmo-regulation by increasing the accumulation of soluble sugars and/or amino acids in the xylem sap which increases osmotic driving force or by activating the K^+ translocation to xylem sap by via SKOR (Stelar K^+ Outward Rectifier) gene. Si application can improve the root hydraulic conductance by modifying the root growth and increase root/shoot ratio along with elevating aquaporin activity and osmotic driving force. Higher root hydraulic conductance results in increasing the uptake and transport of water which helps to maintain a higher photosynthetic rate and improve plant resistance to water deficiency (Luyckx *et al.* 2017; Chen *et al.* 2018) [7, 8, 21, 24, 38, 44]. Si application can also reduce drought stress via increasing uptake of mineral nutrients by plants, altering gas exchange attributes in plants (Rizwan *et al.* 2015) [34]. Under drought stress, exogenous application of Si has improved seed germination, biochemical processes and protects the seedling from oxidative stress by enhancing antioxidant defense. In the maize plant, calcium silicate application in the soil increases seed germination under drought stress (Zargar and Agnihotri 2013) [36, 43]. Silicon application increases the photosynthetic rate, leaf and root water and osmotic potential, water use efficiency (WUE), while decreases transpiration rate, membrane permeability under water-deficit conditions in different crop species *viz.*, Kentucky bluegrass (*Poa pratensis* L.) (Saud *et al.* 2014) [10, 38], maize (Amin *et al.* 2014) [4, 22], wheat (Gong and Chen 2012; Maghsoudi *et al.* 2016) [7, 8, 21, 38, 44]. In this regard, Si application in soil has been reported to increase the uptake of macronutrients (P, K, Ca and Mg) and micronutrients (Fe, Cu and Mn) in crop under water deficit stress. An increase in level of K and total P in rice straw of Si-treated plants compared to control under drought conditions has been reported (Emam *et al.* 2014) [9, 25]. Si supply has been widely reported to decrease oxidative damage through enhancing the antioxidant enzyme (SOD, APX, CAT and POD) activities under drought stress in wheat plants, sunflower and chickpea. Si pretreatment was demonstrated to up-regulated the expression of both ring domain containing protein *OsRDCPI* gene and drought-specific genes, *OsCMO* coding rice choline monooxygenase and dehydrin *OsRAB16b*, in drought-stressed rice plants as compared to control.

Despite its abundance in the soil, silicon fails to meet the universally adopted definition of essentiality for higher plants.

However, Si has been demonstrated to be beneficial for the healthy growth and development of many plant species, and severe deficiency in Si can cause abnormalities in growth, development or reproduction in many higher plants, particularly rice (*Oryza sativa* L.) and sugarcane (*Saccharum officinarum* L.) in the Poaceae family. In rice, Si has been found to enhance growth and yield. Beneficial effects of Si supplementation for other plants are usually slight under optimized growth conditions, but more pronounced under stress conditions. Silicon has been demonstrated to alleviate drought stress in many crops, such as wheat, sorghum, maize, potato, sunflower and rice (Chen *et al.*, 2011) [7, 8, 21, 38, 44]. Commonly evaluated sources of Si in these studies include reagent-grade silicic acid and potassium/sodium/calcium silicate, which are not usually practical for field-scale delivery. Calcium silicate slag, which is a by-product from the refining of phosphate rocks for phosphorus fertilizers, is a potential liming material and a source of Si. Rice and sugarcane grown on organic soils in Florida had greater yield and were less susceptible to disease following pre-plant application of calcium silicate slag. Few studies have evaluated calcium silicate slag as a source of Si to reduce drought stress in rice.

Calcium silicate slag could benefit rice production by improving Si availability and reducing drought stress during the early growth phase of rice. Use of this material provides a mechanism to reduce waste generated from phosphorus mining. Future studies should address the impact on the reproductive phase of rice culture and its effect on grain production. (Yang *et al.*, 2019) [41, 44].

Conclusion

Rice can perceive environmental stimuli and adapt to various environments. However, the degree of adaptability and tolerance to different stresses environmental varies from species to species. The process of adaptation to stress involves most of the prometabolic processes of plants, but generally is considers that plant hormones play a key role, and among these, the most important are Salicylic acid (SA). The levels of this hormone significantly increase under stress and changes in endogenous SA levels stimulate a series of metabolic and physiological events leading the acquisition of tolerance. However, in many situations of stress play a primary role of other hormones, such as GA₃, Potassium nitrate and calcium silicate whose biosynthesis can be considered a real the plant health status indicator. These plant growth regulators can interact in either cooperative or antagonistic way, depending on the stressor. Regarding stimuli such as environmental stress and disease stress, plants regulate the concentration of each plant hormone at the cell/tissue level and think that it can exert various physiological actions by the fluctuation of the balance of the plant hormone as a result. The selection of the most appropriate answer to each of these stimuli is determined in part by the interaction, positive or negative, that is established between these hormones and their signalling pathways. The SA has importance as a regulatory mechanism in defense of the plant not only to abiotic stress situations but also against the attack of pathogens. As part of a strategy in the development of tolerant plants under these kinds of stress, it is important to know specific mechanisms that allow tolerance, as well as resistance. The application of plant growth regulators would enable horizontal as well as vertical plant production. However, it is necessary to have the detailed knowledge of the impacts of these compounds on the

physiological processes that regulate the development of plants in relation in terms of stress tolerance.

Reference

1. Alam MM, Hasanuzzaman M, Nahar K, Fujita M. Exogenous salicylic acid ameliorates short-term drought stress in mustard (*Brassica juncea* L.) seedlings by up-regulating the antioxidant defense and glyoxalase system. *Aust. J Crop Sci* 2013;7:1053–1063.
2. Alavi SMN, Arvin MJ, Kalantari KM. Salicylic acid and nitric oxide alleviate osmotic stress in wheat (*Triticum aestivum* L.) seedlings. *J Plant Interac* 2014;9:683–688. doi: 10.1080/17429145.2014.900120 Cross Ref Full Text | Google Scholar
3. Al-Wahaibi MH, Siddiqui MH, Basalah MO. Salicylic acid and calcium-induced protection of wheat against salinity. *Protoplasma* 2012;249:769–778. doi: 10.1007/s00709-011-0322-1 PubMed Abstract | CrossRef Full Text | Google Scholar
4. Amin M, Ahmad R, Basra SM, Murtaza G. Silicon induced improvement in morpho-physiological traits of maize (*Zea mays* L.) under water deficit. *Pak J Agric Sci* 2014;51:187–196. [Google Scholar]
5. Banerjee A, Roychoudhury A. Abiotic stress tolerance in plants by priming and pre-treatment with hydrogen peroxide. In: Hasanuzzaman M., Fotopoulos V. (eds.): *Priming and Pre-treatment of Seeds and Seedlings*. Singapore, Springer 2019, P417–426.
6. Bartsch M, Bednarek P, Vivancos PD, Schneider B, Von Roepenack-Lahaye E, Foyer CH, Parker JE. Accumulation of isochlorogenic acid-derived 2, 3-dihydroxybenzoic 3-O-β-D-xyloside in Arabidopsis resistance to pathogens and aging of leaves. *Journal of Biological Chemistry* 2010;285(33):25654–25665.
7. Chao YY, Chen CY, Huang WD, Kao CH. Salicylic acid-mediated hydrogen peroxide accumulation and protection against Cd toxicity in rice leaves. *Plant Soil* 2010;329:327–337. doi: 10.1007/s11104-009-0161-4 Cross Ref Full Text | Google Scholar
8. Chen D, Wang S, Yin L, Deng X. How does silicon mediate plant water uptake and loss under water deficiency? *Front Plant Sci* 2018;9:281. doi: 10.3389/fpls.2018.00281. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
9. Emam MM, Khattab HE, Helal NM, Deraz AE. Effect of selenium and silicon on yield quality of rice plant grown under drought stress. *Aust J Crop Sci* 2014;8(4):596. [Google Scholar]
10. Fayez KA, Bazaid SA. Improving drought and salinity tolerance in barley by application of salicylic acid and potassium nitrate. *J Saudi Soc. Agri. Sci* 2014;13:45–55. doi: 10.1016/j.jssas.2013.01.001 CrossRef Full Text | Google Scholar
11. Grobkinsky DK, Van Der Graaff E, Roitsch T. Regulation of Abiotic and Biotic Stress Responses by Plant Hormones. *Plant Pathogen Resistance Biotechnology* 2016, P131.
12. Hasanuzzaman M, Hossain MA, Texeira da Silva JA, Fujita M. Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. In: Venkateswarlu B, Shanker AK, Shanker C, Maheswari M, editors. *Crop stress and its management: perspectives and strategies*. Dordrecht: Springer 2012, P261–316. https://doi.org/10.1007/978-94-007-2220-0_8

13. Kanai S, Moghaieb RE, El-Shemy HA, Panigrahi R, Mohapatra PK, Ito J *et al.* Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in green house tomato prior to its effects on source activity. *Plant Sci* 2011;180:368–374. [PubMed] [Google Scholar]
14. Kang SM, Radhakrishnan R, Khan AL, Kim MJ, Park JM, Kim BR. Gibberellin secreting rhizobacterium, *Pseudomonas putida* H-2-3 modulates the hormonal and stress physiology of plant growth under saline and drought conditions. *Plant Physiol Biochem* 2014;84:115–124. <https://doi.org/10.1016/j.plaphy.2014.09.001>
15. Kang GZ, Li GZ, Liu GQ, Xu W, Peng XQ, Wang CY. Exogenous salicylic acid enhances wheat drought tolerance by influence on the expression of genes related to ascorbate-glutathione cycle. *Biol. Plant* 2013;57:718–724. doi: 10.1007/s10535-013-0335-z CrossRef Full Text | Google Scholar
16. Kang G, Li G, Xu W, Peng X, Han Q, Zhu Y. Proteomics reveals the effects of salicylic acid on growth and tolerance to subsequent drought stress in wheat. *J Proteome Res* 2012;11:6066–6079. doi: 10.1021/pr300728y PubMed Abstract | CrossRef Full Text | Google Scholar
17. Khan N, Bano A, Zandi P. Effects of exogenously applied plant growth regulators in combination with PGPR on the physiology and root growth of chickpea (*Cicer arietinum*) and their role in drought tolerance. *J Plant Interact* 2018;13(1):239–247. <https://doi.org/10.1080/17429145.2018.1471527>
18. Kong J, Dong Y, Xu L, Liu S, Bai X. Effects of foliar application of salicylic acid and nitric oxide in alleviating iron deficiency induced chlorosis of *Arachis hypogaea* L. *Bot. Stud* 2014;55:9. doi: 10.1186/1999-3110-55-9 CrossRef Full Text | Google Scholar
19. Kumar D. Salicylic acid signaling in disease resistance. *Plant Sci* 2014;228:127–124. doi: 10.1016/j.plantsci.2014.04.014 PubMed Abstract | CrossRef Full Text | Google Scholar
20. Latef A, Hamed AA, Kordrostami M, Zakir A, Zaki H, Saleh OM. Eustress with H₂O₂ facilitates plant growth by improving tolerance to salt stress in two wheat cultivars. *Plants (Basel)* 2019;8:303.
21. Li Z, Lu GY, Zhang XK, Zou CS, Cheng Y, Zheng PY. Improving drought tolerance of germinating seeds by exogenous application of gibberellic acid (GA₃) in rapeseed (*Brassica napus* L.). *Seed Science and Technology* 2010;38:432–440. <https://doi.org/10.15258/sst.2010.38.2.16>
22. Lumba S, Cutler S, McCourt P. Plant nuclear hormone receptors: a role for small molecules in protein-protein interactions. *Annual review of cell and developmental biology* 2010;26:445–469.
23. Luo YL, Su ZL, Bi TJ, Cui XL, Lan QY. Salicylic acid improves chilling tolerance by affecting antioxidant enzymes and osmoregulators in sacha inchi (*Plukenetia volubilis*). *Braz. J Bot* 2014;37:357–363. doi: 10.1007/s40415-014-0067-0 CrossRef Full Text | Google Scholar
24. Luyckx M, Hausman JF, Lutts S, Guerriero G. Silicon and plants: current knowledge and technological perspectives. *Front Plant Sci* 2017;8:411. doi: 10.3389/fpls.2017.0041. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
25. Maghsoudi K, Emam Y, Ashraf M. Foliar application of silicon at different growth stages alters growth and yield of selected wheat cultivars. *J Plant Nutr* 2016;39(8):1194–1203. [Google Scholar]
26. Maruri-López I, Aviles-Baltazar NY, Buchala A, Serrano M. Intra and extracellular journey of the phytohormone salicylic acid. *Frontiers in Plant Science* 2019, P10.
27. Ming DF, Pei ZF, Naeem MS, Gong HJ, Zhou WJ. Silicon alleviates PEG-induced water-deficit stress in upland rice seedlings by enhancing osmotic adjustment. *J Agron Crop Sci* 2012;198:14–26. [Google Scholar]
28. Miura K, Tada Y. Regulation of water, salinity, and cold stress responses by salicylic acid. *Front. Plant Sci* 2014;5:4. doi: 10.3389/fpls.2014.00004 PubMed Abstract | CrossRef Full Text | Google Scholar
29. Nazar R, Iqbal N, Syeed S, Khan NA. Salicylic acid alleviates decreases in photosynthesis under salt stress by enhancing nitrogen and sulfur assimilation and antioxidant metabolism differentially in two mungbean cultivars. *J Plant Physiol* 2011;168:807–815. doi: 10.1016/j.jplph.2010.11.001
30. Nazar R, Umar S, Khan NA. Exogenous salicylic acid improves photosynthesis and growth through increase in ascorbate-glutathione metabolism and S assimilation in mustard under salt stress. *Plant Signal. Behav* 2015;10:e1003751. doi: 10.1080/15592324.2014.1003751 PubMed Abstract | CrossRef Full Text | Google Scholar
31. Nicholas Smirnoff, Dominique Arnaud. Hydrogen peroxide metabolism and functions in plants. *New Phytologist* 2019. <https://doi.org/10.1111/nph.15488>.
32. Noriega G, Caggiano E, Lecube ML, Cruz DS, Batlle A, Tomaro M. The role of salicylic acid in the prevention of oxidative stress elicited by cadmium in soybean plants. *Biometals* 2012;25:1155–1165. doi: 10.1007/s10534-012-9577 PubMed Abstract | CrossRef Full Text | Google Scholar
33. Pan S, Rasul F, Li W, Tian H, Mo Z, Duan M. Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (*Oryza sativa* L.). *Rice* 2013;6:9. <https://doi.org/10.1186/1939-8433-6-9>
34. RaskinRizwan M, Ali S, Ibrahim M, Farid M, Adrees M, Bharwana SA. Mechanisms of silicon-mediated alleviation of drought and salt stress in plants: a review. *Environ Sci Pollut Res* 2015;22:15416–15431. doi: 10.1007/s11356-015-5305-x. [PubMed] [CrossRef] [Google Scholar]
35. Romheld V, Kirkby EA. Research on potassium in agriculture: Needs and prospects. *Plant Soil.* 2010;335:155–180. [Google Scholar]
36. Sajad Majeed Zargar, Reetika Mahajan, Javaid A. Bhat, Muslima Nazir and Rupesh Deshmukh. *Biotech* 2019;9(3).
37. Saruhan N, Saglam A, Kadioglu A. Salicylic acid pretreatment induces drought tolerance and delays leaf rolling by inducing antioxidant systems in maize genotypes. *Acta Physiol Plant* 2012;34:97–106. doi: 10.1007/s11738-011-0808-7 CrossRef Full Text | Google Scholar
38. Saud S, Li X, Chen Y, Zhang L, Fahad S, Hussain S, Chen Y. Silicon application increases drought tolerance of Kentucky bluegrass by improving plant water relations and morphophysiological functions. *Sci World J* 2014.

- doi: 10.1155/2014/368694. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
39. Szalai G, Krantev A, Yordanova R, Popova LP, Janda T. Influence of salicylic acid on phytochelatin synthesis in *Zea mays* during Cd stress. *Turk. J Bot* 2013;37:708–714.
40. White P, Karley A. Potassium. In: Hell R., Mendel R.R., editors. *Cell Biology of Metals and Nutrients*. Springer; Berlin/Heidelberg, Germany: 2010 P199–224. [Google Scholar]
41. Yang R, Howe JA, Golden BR. Calcium silicate slag reduces drought stress in rice (*Oryza sativa* L.). *J Agro Crop Sci* 2019;205:353–361. <https://doi.org/10.1111/jac.12327>
42. Yuan Z, Cong G, Zhang J. Effects of exogenous salicylic acid on polysaccharides production of *Dendrobium officinale*. *South Afr. J Bot* 2014;95:78–84. doi: 10.1016/j.sajb.2014.08.007 CrossRef Full Text | Google Scholar
43. Zargar SM, Agnihotri A. Impact of silicon on various agromorphological and physiological parameters in maize and revealing its role in enhancing water stress tolerance. *Emir J Food Agric* 2013;25:138–141. [Google Scholar]
44. Zhang Y, Xu S, Yang S, Chen Y. Salicylic acid alleviates cadmium-induced inhibition of growth and photosynthesis through upregulating antioxidant defense system in two melon cultivars (*Cucumis melo* L.). *Protoplasma* 2015;252:911–924. doi: 10.1007/s00709-014-0732-y PubMed Abstract | Cross Ref Full Text | Google Scholar
45. Zengin F. Exogenous treatment with salicylic acid alleviating copper toxicity in bean seedlings. *Proc. Natl. Acad. Sci. India Sec. B Biol. Sci* 2014;84:749–755. doi: 10.1007/s40011-013-0285-4 CrossRef Full Text | Google Scholar