SKUAST Journal of Research 25(1): 1-12; (2023)
(*DOI No: 10.5958/2349-297X.2023.00001.6*); NAAS rating: 4.17

Review Paper

Physiological modulation of plants by salicylic acid under drought stress - a review

Zaffar Mahdi Dar[1*], Farooq Ahmad Khan[1], Malik Asif Aziz[2], Mushtaq Ahamd Malik[2], Amjad Masood[3] and Fida Rafiq Wani[1]

[1]Division of Basic Sciences and Humanities, Faculty of Horticulture; [2]Division of Basic Sciences, Faculty of Agriculture; [3]Division of Agronomy Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, 190 025, Jammu and Kashmir (India)
*e-mail: *zaffar_123@yahoo.com*

(Received January 24, 2023; accepted February 09, 2023)

ABSTRACT

Abiotic stresses are well known to harm crop performance worldwide. Drought stress is widely considered to be one of the most dangerous stresses, the intensity of which is likely to increase owing to alarming change in the climate. Change in plant water relations, stomatal conductance, photosynthetic rate, generation of active oxygen species, and imbalance in hormonal concentration are many few of the changes which are inclusively acceptable to be responsible for the reduction in crop performance. To enhance crop productivity under drought conditions several strategies have been proposed and espoused so far, one among them being the priming or spraying with phytohormones. As far as the literature is concerned salicylic acid (SA) seems to be one of the best remedial phytohormones under drought conditions with promising results like up-regulation in the synthesis of osmoprotectants and antioxidants and leading to improvement in the activity/content of most of the physiological, biochemical and molecular aspects. Keeping in view the beneficial role of SA, this review is being outlined to prepare a report which enlightens some of the physiological roles of SA among its diverse activities related to drought tolerance that in turn would be helpful for the researchers to enhance the drought resilience in plants.

Keywords: Abiotic, drought, phytohormones, plants, salicylic acid

Drought is considered the most devastating and a chief restricting factor to agricultural production of all the abiotic stresses and is projected to worsen further because of the persistent climate change (Zaffar *et al*., 2018). Drought is continued soil moisture deficiency resulting in severe implications on plant growth, development, and reproduction when soil moisture levels fall below the required amount for a prolonged period. The effects of drought turn out to be very chronic in regions with irregular rainfall during the plant's life cycle (Rosegrant and Cline, 2003). Historically, the occurrence of drought has facilitated important famines and posed a threat to the world food supply in the near future (Okorie *et al*., 2019). The plant undergoes several modifications as a result of drought stress. Reduced leaf and stem growth, root spread, and altered water relations in the plant are just a few of the symptoms Muhammad *et al*. (2009). Furthermore, agricultural output losses by drought have been linked to the closure of stomata, change in cell membrane properties, and declined enzyme functioning particularly those associated with CO_2 fixation and ATP generation. Stomatal closure and increased metabolic flux caused by photorespiration lead to the formation of free radicals in the plant cells, which in turn degrade macromolecules and promote cell death (Agurla and Raghavendra, 2016). The changes responsible for the reduction in crop yield by drought stress have been summarised in the following flow diagram (Fig.1)

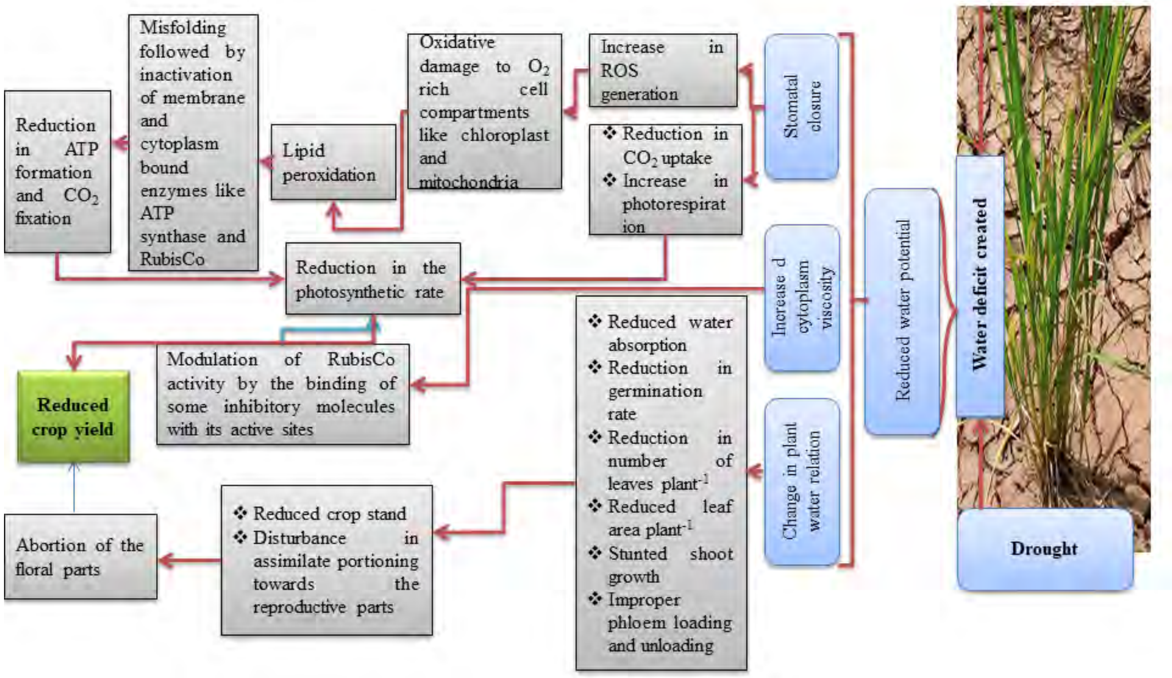

Fig. 1: General response displayed by plants under drought stress

In light of drought-related negative impacts, as well as increased food demand it seems imperative to develop strategies or technologies that can enhance plant drought tolerance with minimum impact on plant productivity. To improve plant stress tolerance, researchers have used a variety of strategies such as seed priming, osmoprotectant treatment, nutrient application, nano-technological instruments, and metabolic engineering (Mahmoud *et al*., 2021). Growth hormones are now being researched as a long-term solution for reducing the negative impacts of water scarcity on crops. Over the past few years, SA has gained greater prominence as a way to regulate key plant metabolic processes (Khan *et al*., 2000; Rahat *et al*., 201; Miura and Tada, 2014). SA is a phenolic molecule that, in addition to drought stress, protects plants from a variety of other abiotic stresses besides regulating plant growth and development (Raskin, 1992; Miura and Tada, 2014; Zhang *et al*., 2015). The activity of SA has been reported to depend on its concentration, time, and application method (Kováčik *et al*., 2009; Shi *et al*., 2009; Miura and Tada, 2014) as shown in table-1. To enhance the overall performance of cultivated plants under changing climatic conditions, it seems sensible to use existing knowledge on SA to alleviate drought resistance in cultivated plants. Therefore, this review was framed with an aim to collect the knowledge and some possible roles of SA concerning drought stress, which in turn could be useful for researchers to develop the ideotypes with the highest resistance to drought.

<u>Plant water relations in response to SA under drought conditions:</u> The absolute need for water is an outstanding element for sustaining plant survival (Onwugbuta-enyi Jane 2004). During plant growth, drought affects the plant moisture level, hence strongly disrupting its entire metabolism contingent on the strength, time, and span of the stress. (Sharma *et al.,* 2020; Osakabe *et al.,* 2014). Cell desiccation developed under deficient soil moisture content is reflected in terms of essential modifications brought about in plant biochemical and physiological processes, cell membrane properties, and structure of different cell organelles (Tuba *et al.,* 1996; Sarafis 1998; Yordanov *et al.,*2003). At the morphological level the first visible change developing in the plants owing to the lack of soil moisture is the change in the plant canopy architecture because of the reduced total leaf area hence plants are encountered with so many problems including a reduction in the gaseous exchange, growth and development of vegetative and reproductive parts (Rahmati *et al.,* 2018) and hence affecting the crop yield. Besides so many reasons like variation in hormonal balance, plant nutrition and carbon balance the change in plant water status is a significant factor contributing to a reduction in the crop yield under drought stress (Munns *et al.,* 1982). Appraisal of plant water status is extraordinarily vital to measure the resistance of plants to water deficit as it gives a useful sign of the potential of crop species to keep up their physiology under drought (White *et al.,* 2000). Parameters regularly used as indicators of the degree of water stress include relative water content (RWC) and leaf water potential (LWP) (Omae *et al*., 2007; Luis and Marco, 2001; Nayyar *et al*., 2005).

Table-1 Response of plants to different concentrations of SA used through different methods at different growth stages and soil moisture level

Name of Crop	Stage of drought imposition	Moisture level	Concentration of SA used	Method of SA application	Modification brought about by SA	References
Winter Wheat	Before tillering to flowering	30% of field capacity (FC)	0.5 mM	Foliar spray a week after germination	➢ Induction of stress proteins ➢ Enhancement in the activity of antioxidants followed by increase in membrane stability. ➢ Improvement in the photosynthetic rate.	Masoumeh *et al.* (2021)
Wheat	At three leaf stage for the next 15 days	10% of FC	1mM	Foliar spray after two weeks of germination	➢ Increased leaf water status, Chl a, Chl b and carotenoid content ➢ Enhancement in the activity of antioxidants	Ammar *et al.* (2020)
Rice	At four leaf stage	50% of FC	100 ppm	Foliar spray at five leaf stage	➢ Maintenance of tissue water potential by accumulation of compatible solutes ➢ Enhanced potency of antioxidant system	Muhammad *et al.* (2009)
Maize	From the 14th leaf stage until blister growth stages	50% of FC	140 ppm	Foliar spray at 16th leaf and 18th leaf stages	➢ Increase in antioxidant enzymes activity ➢ Accumulation of compatible solutes like proline and soluble sugars	Ramadan *et al.* (2021)
Mustard	10 days after germination	10% and 20% PEG	50 µM	Foliar spray 10 days after germination	➢ Enhancement in antioxidant defence mechanism ➢ Increase in the activity of glyoxalase systems	Md. Mahabub *et al.* (2013)
Sunflower	At three leaf stage	10% of FC	25ml/pot	Foliar spray at three leaf stage	➢ Increase in sugar, chlorophyll, protein, carotenoid and phenolic contents	Naeem *et al.* (2018)
Barley	After germination	One irrigation at the time of sowing	0.5mM	Foliar spray 21 days after sowing	➢ Increase in chlorophyll concentration and relative water content ➢ Increase in the activity of antioxidant enzymes	Khaled *et al.* (2020)
Tomato	After 30 days of seedling emergence	Withholding water for 10 days	10^{-5} M	Foliar spray after 45 days of seedling emergence	➢ Increase in leaf water potential, nitrate reductase and carbonic anhydrase activity, chlorophyll content and photosynthetic parameters. ➢ Increase in the antioxidant content and membrane stability index ➢ Accumulation of proline	Shamsul *et al.* (2008)
Chickpea	From vegetative to reproductive stages	Vegetative to reproductive stages	200 ppm	Foliar spray	➢ Accumulation of proline	Siamak *et al.* (2014)

Drought in the long run outcomes in the development of a water deficit in the leaf cells with perceptible abatements in LWP and RWC with a simultaneous increase in leaf temperature (Siddique *et al*., 2000). Drought altered the plant water relations in soybean (Chowdhury *et al*., 2017), snap bean (Omae *et al*., 2007), rice (Cruz *et al*., 1986) wheat (Siddique *et al*., 2000), etc. The decrease in RWC in stressed plants might be due to a decrease in plant vigor (Techawongstin *et al*., 1993) and lower stomatal index in the adaxial surface or to a higher capability for soil extraction under drought stress (Rosales-Serna *et al* 2004). Halder and Burrage (2003) reported that drought stress is accompanied by the accumulation of solutes in the root zone that drastically reduce the root permeability hence resulting in restricted moisture uptake from the soil in turn facilitating the reduced LWP. Under reduced soil moisture levels following response is displayed by the roots.

1. Approaching the zone of suberization towards the root tip diminishes the root growth and length of root absorption zone.
2. Reduction in the gradient in root water potential and the medium water potential which in turn critically reduces the root permeability as well as the water supply towards the root (Raper and Kramer, 1983; Turner and Kramer, 1980).

Chopard (2004) proposed that other than the fluctuations achieved in the root qualities, its density and distribution could be considered as a critical component for water take-up by a plant in the soil the two of which altogether decline under dry spell consequently influencing the plant water relations. Transpiration can be regarded as the dominant process in plant-water relations. Many plants limit transpiration by stomatal closure at low negative LWP originated during the drought period (Fisher *et al*., 2008) as indicated by reduced RWC (Heshmat *et al*., 2012).

SA showed promising results to help plants with drought stress. It is also involved in the regulation of so many plant processes including plant water relations hence protecting the plants against environmental stresses (Miura and Tada 2014; Hayat *et al*., 2010) by reducing the negative effects of drought (Hussain *et al*., 2009). An increase in RWC by SA application has been reported in drought-stressed chrysanthemum (Vahdati *et al*., 2012), strawberry (Ali *et al*., 2017), maize (Kiran *et al*., 2015), wheat (Bhupinder and Usha, 2003), and shara (Jalal Ud-Din *et al*., 2012). Proline (2-oxopropanoic acid), glycine betaine (3-hydroxy-N,N-dimethylglycine) and soluble carbohydrate might act as compatible osmolytes in plants, by acting largely at the early stages of drought-induced senescence of root tissue leading to an increase in RWC by SA as reported by Demiralay *et al* (2013). Scientific data have found that drought-stressed plants show an increase in sugar levels when they are treated with SA. Another study described SA treatment helping to resist drought because of its function in enzyme protection along with the maintenance of osmoregulation, membrane stabilization, and protection against hydroxyl radicals (Shao *et al*., 2006.) Sugars, which are often associated with this increase in plant root length by SA, help to minimize the effect of drought stress by exploiting the soil moisture in the deeper layers (Tas and Tas, 2007) as has been reported in maize (Kiran *et al*., 2015) and wheat (Heshmat *et al*., 2018). Increased root length, which is found in some strains that have been treated with SA, has been shown to be linked to increased cell division under one form of drought stress (Zafar *et al*., 2021; Brito *et al*., 2018 and Sakhabutdinova 2003).

Chlorophyll retention by SA under drought stress: In terms of physiological and biochemical disturbances caused by drought, diminution in leaf chlorophyll (Chl) content is considered as the most severe issue affecting plant growth and yield (Rahdari *et al*., 2012; Ommen *et al*., 1999). The Chl concentration is commonly used as a measure of the activity of the source tissues (Zobayed *et al*., 2005), therefore it is reasonable to look at its decrease as one of the non-stomatal limiting factors under water deficit conditions. Decrease in Chl content under drought stress stands confirmed in maize (Majid and Roza, 2011; Majid, 2012), rice (Shamima *et al*., 2020), tomato (Sivakumar *et al*., 2017), paddy (Syamsia *et al*., 2018), peanuts (Xing *et al*., 2018) and so many other agricultural and horticultural crops of economic importance contingent upon the span and magnitude of dry spell (Kpyoarissis *et al*., 1995). Other than harming the chloroplast structure extreme dry spell represses the photosynthetic capacity of plants by lessening the biosynthesis of Chl as well as its components which include glutamate-1-semialdehyde, 5-aminolevulinic acid, Mg-protoporphyrin IX monomethyl ester, and protochlorophyllide (Iturbe-Ormaetxe *et al*., 1998; Vijay and Baishnab, 2012). Drought slows down the chlorophyll formation in plants, leading to a reduction in their Chl content. This has been connected to the reduction in the levels of various porphyrin components that contribute to chlorophyll biosynthesis, such as protoporphyrin IX, protochlorophyllide, magnesium-protoporphyrin IX, and its methyl ester on account of the down-regulation of most enzymes involved in their biosynthesis, particularly in the Chl branch (Thu-ha *et al*., 2011). Jain *et al* (2013) reported that a major drop in aminolevulinic acid content (ALA) and aminolevulinic acid dehydratase (ALAD) activity is linked with a substantial reduction in Chl synthesis. During drought stress, down-regulation of the key enzymes of Chl biosynthesis which include GlutamyltRNA reductase 1 (HemA) and magnesium-chelatase subunit (ChlH) contribute to inhibition of Chl biosynthesis (Hortensteiner and Krautler 2011). Xing *et al* (2018) proposed that inhibition of Chl biosynthesis is brought about by a sharp reduction in the expression of an enzyme encoded by AhPORA gene. PORA, PORB, and PORC, three structurally related NADPH: protochlorophyllide oxidoreductases (PORs), have been discovered to play a key role in catalysing the light-dependent reduction of protochlorophyllide a to chlorophyllide a, which is then converted to Chl during photomorphogenesis (Masuda and Takamiya 2004; Michal *et al*., 2015). There is a piece of strong evidence that drought can cause Chl levels to decrease by inducing chloroplast destruction, instability of the Chl proteins (Khan *et al*., 2015), photo-oxidation and dissolution of pigment molecules (Shakeel *et al*., 2011) and excessive production of active oxygen species (AOS) (Smirnoff, 1995; Majid and Roza, 2011).

SA (SA) has been discovered to play a crucial role in plant growth, development, and protection responses by functioning as a buffer against biotic and abiotic stresses. During drought stress, increased growth and yield enhancement with SA preconditioning is seen as an outward signal of a shift in metabolism within plant cells. Various mechanisms have been suggested to assist the plant in achieving tolerance by SA amongst which Chl retention is a key parameter (Mutlu *et al*., 2009). Among the several physiological characteristics induced by exogenous SA infusions, increases in Chl a, Chl b, and total Chl have been reported to promote pant drought resistance (Mutlu *et al*., 2009; Rao *et al*., 2012). Application of SA improved the pigment content in mustard (Alam *et al*., 2013), wheat (Heshmat *et al*., 2012), soyabean (Nasrin *et al*., 2017; Leslie and Romani, 1988), chickpea (Taibi *et al*., 2016), and peppermint plants (Abeer, 2019) under stress conditions. Researchers have verified that the effect of SA reduces Chl degradation in plants under water stress via inflicting a build-up of photosynthetic pigments (Ma *et al*., 2017). SA counterparts the immortality of leaves of water-stressed plants through the preservation in their pigment content by retarding ethylene synthesis, inhibiting membrane depolarization, and reduced membrane permeability thus preventing the leaves from senescence (Leslie and Romani, 1988). The activation of protein kinase synthesis, which is vital for cell division and development at various stages, is another high-quality action of SA (El-Tayeb, 2005). SA reduces the consumption of oxygen through enhancement rate in epoxidase and de-epoxidase reactions, thus protecting the thylakoid membranes from oxidative damage (David, 2002). Damage to the cell membrane, photosynthetic machinery, and Chl molecules caused by excess electrons and AOS has also been reported to decrease via an increase in the xanthophylls and carotene cycle (Jagtap and Bhargara, 1995; Costa *et al*., 2005) by SA pre-conditioning. It has been discovered that it regulates Chl, protein synthesis, transpiration, photosynthesis, and protective enzymes including superoxide dismutase (SOD) and peroxidase (POD), all of which promote plant tolerance to environmental challenges (Mutlu *et al*., 2009).

Photosynthetic rate as effected by SA under drought: Water availability is a vital element affecting plant growth and yield in arid and semi-arid areas, where plants are often subjected to intervals of drought (Manuela *et al*., 2003) which turns to be persistent in locations with low water availability or abnormal precipitation in the course of the plant's cycle and therefore reducing its growth and yield through its effect on plant photosynthetic rate (Pr) (Zaffar *et al*., 2021) on account of the decrease in leaf growth, impaired photosynthetic equipment, untimely leaf senescence and associated reduction in food production (Wahid and Rasul, 2005). The reduction in Pr under drought has been reported in apple (Zhibo *et al*., 2018), soyabean (Wensen *et al*., 2018), bean (Zlatko and Ivan, 2004), rice (Halder and Burrage, 2003), wheat (Parisa and Nayer, 2016), potatos (Moorby *et al*., 1975) and so many agricultural and horticultural crops of economic importance. Whilst evaluating the stomatal and non-stomatal reasons for the reduction in photosynthesis, the impact of the previous appears to be very least suggesting that besides reduction in the CO_2 uptake by the plant, there is mutilation inside the other plant physiological strategies additionally. Stomatal closure is taken into consideration as the first line of defense towards the drought (Cornic and Massacci, 1996) which alternatively acts as the principal determinant for reduced photosynthesis below mild to mild drought (Cornic and Massacci, 1996; Yokota *et al*. 2002). Dearth in the CO_2 level and its assimilation inside the leaf mesophyll cells brings about a disparity between the excited electrons and their usage in the carbon reaction ensuing inside the production of AOS, commonly superoxide (O_2•−) and hydrogen peroxide (H_2O_2) (Reddy *et al*. 2004) which bog down the synthesis of the core D_1 protein of PS_{II} system (Shunichi and Norio, 2008). Reviews regarding the impact of oxidative stress on plant growth and development directly propose harm to lipids, nucleic acids, and proteins (Hasan *et al*., 2018), resulting in inhibition of biosynthetic pathways for PS_{II}, PS_I, light-harvesting Chl-proteins, chaperones, and Chla-b binding proteins (Vijay and Baishnab, 2018; Hasan *et al*., 2018) which in turn are enormously important for shielding of integrity and inner structure of photosynthetic organs such as chloroplasts and its components (Fengxia *et al*., 2013). Tezara *et al*. (1999) pronounced that, even under slight drought situations photosynthetic electron transport chain down-regulates ensuing in a decreased rate of photophosphorylation and formation of assimilatory powers required for CO_2 fixation due to reduction in D_1 synthesis. Related to this disorganization and damage to chloroplast structure and retarded activity of the enzymes involved in carbon assimilation and ATP synthesis also contribute to reduced Pr (Ali and Ashraf, 2011; Golldack *et al*., 2011). Reports on the activity of RubisCO suggest that under severe drought the decreased Pr is not only because of the intense reduction of RuBISCo activity (Bota *et al*., 2004) but also by its reduced biosynthesis (Joseph *et al*., 1999) and its tight binding with some inhibitor molecules, as seen in cotton (Parry *et al*., 2002). Furthermore, elevations in solute concentration in the cell cytoplasm are hazardous to the contents of the cell, particularly to enzymes engaged in the photosynthetic apparatus (Hoekstra *et al*., 2001). Under drought conditions, the activity of enzymes such as RubisCo, phosphoenolpyruvate carboxylase, nicotinamide adenine dinucleotide phosphatemalic enzyme, and fructose-1, 6-bisphosphatase has been reported to be reduced by 2-4 times, with a 9.1-fold reduction in the activity of pyruvate orthophosphate dikinase compared to unstressed plants (Hoekstra *et al*., 2001).

According to Rahat *et al*. (2015), SA is a phytohormone and a potential molecule that might lower plant sensitivity to environmental challenges by regulating a variety of physiological functions, including Pr. According to Adisa and Erna (2018), an increase in photosynthetic rate caused by SA treatment during drought stress is due to a rise in plant pigment content, including Chl a, b, total Chl, and carotenoids, as well

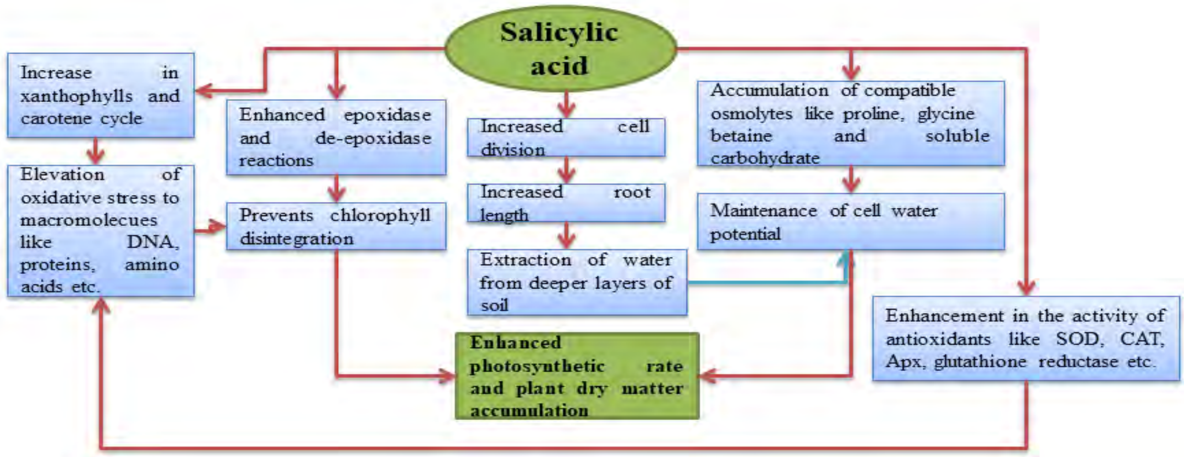

Fig. 2: Role of salicylic acid in enhancing drought stress tolerance

as the prevention of Chl degradation (Ma *et al*., 2017). Apart from that, SA helps to maintain the integrity of the light-harvesting apparatus (Rahat *et al*., 2015), a process that may be responsible for increased photosynthesis during drought stress. SA pre-treatment has been shown to increase photosynthetic pigment concentration in Zea mays (Khodary, 2004), barely (El Tayeb, 2005), wheat (Sarika *et al*., 2005), and Brassica napus (Navita *et al*., 2002). Changes in protein kinase and Rubis Co activity, as well as an increase in Chl content, have been reported in response to drought stress (Sun *et al*., 2009); Kang *et al*., 2014; Rahat *et al*., 2015), as evidenced by an increase in protein spots such as ribulose-1, 5-bisphosphate carboxylase activase, two Rubisco large subunit-binding proteins and carbonic anhydrase (Azooz *et al*., 2011). The production of abiotic stress response genes (Li *et al*., 2013), biosynthetic enzymes, and proteins in plants by SA have been shown to protect chloroplast against oxidative damage during drought (Rahat *et al*., 2015; Wang *et al*., 2019). Signal transduction, photosynthesis, glucose metabolism, energy production, protein metabolism, stress defense proteins including dehydrins, chaperones, and heat shock proteins are all involved in metabolic processes according to findings from SA's protein expression pattern analysis (Kang *et al*., 2012).

CONCLUSION

The results gained in recent years clearly suggest that SA is a highly promising molecule for reducing crop abiotic stress sensitivity since it has been proven to attenuate the detrimental effects of numerous stress elements in plants. SA is a promising compound to increase plant tolerance to drought stress, and is involved in the regulation of important plant physiological processes including plant water relations by promoting the accumulation of compatible osmolytes like proline, glycine betaine, and soluble carbohydrate in plants subjected to drought stress. An increase in photosynthetic rate caused by SA treatment during drought stress is due to a rise in plant pigment content, including chlorophyll a, b, total chlorophylls, and carotenoids, as well as the prevention of chlorophyll degradation.

REFERENCE

Abeer, H. E. 2019 Impact of SA application on growth, photosynthetic pigments, and organic osmolytes response in menthe arvensis under drought. *Journal of Biological Sciences,* **19**: 372-380.

Adisa, P. and Erna K. 2018. The Effect of SA on Response to water deficit in basil. *Genetics and Applications* **2**: 42-48.

Agurla, S. and Raghavendra, A.S. 2016. Convergence and divergence of signalling events in guard cells during stomatal closure by plant hormones or microbial elicitors. *Frontiers in Plant Sciences* **7**:13-32. https://doi.org/10.3389/fpls.2016.01332

Alam, M.M., Hasanuzzaman, M., Nahar, K. and Fujita, M. 2013. Exogenous SA ameliorates short-term drought stress in mustard (*Brassica juncea* L.) seedlings by up-regulating the antioxidant defense and glyoxalase system. *Australian Journal of Crop Sciences* **7**: 1053–1063.

Ali, Q. and Ashraf, M. 2011. Induction of drought tolerance in maize due to exogenous application of threolose: growth, photosynthesis, water relation and oxidative defence mechanism. *Agronomy of Crop Sciences* **1**: 1-14.

Ali, T., Huang, J., Wang, J. and and Xie, W. 2017. Global footprints of water and land resources through China's food trade. *Global Food Security-Agriculture Policy Economics and Environment* **12**: 139-145.

Ammar, A., Humaira, Y., Muhammad, N.H., Asia, N., Rabia, N., Muhammad, S., Noshin, I. and Malik, N. A. 2020. Co-application of bio-fertilizer and SA improves growth, photosynthetic pigments and stress tolerance in wheat under drought stress. *The journal of life and environmental Sciences* **27** 8:e9960.doi: 10.7717/peerj.9960. eCollection 2020.

Azooz, M.M., Youssef, A.M. and Ahmad, P. 2011. Evaluation of SA application on growth, osmotic solutes and antioxidant enzyme activities on broad bean seedlings grown under diluted seawater. *International Journal of plant Physiology and Biochemistry* **3**:253–264.

Bhupinder, S. and Usha, K. 2003. SA induced physiological and biochemical changes in wheat seedlings under water stress. *Plant Growth Regulation* **39**:137-141.

Bota, J., Medrano, H.- and Flexas, J. 2004. Is photosynthesis limited by decreased Rubisco activity and RuBP content under progressive water stress? *New Phytologist* **162**: 671–681.

Brito, C., Dinis, L., Ferreira, H., Moutinho-Pereira, J. and Correia, C. 2018. The role of night time water balance on *Olea europaea* plants subjected to contrasting water regimes. *Journal of Plant Physiology* **226**: 56–63.

Chopard, J. 2004. 3D modelling of water transfers in soil and roots systems. In Proc. 4th Int. Workshop on Functional-Structural Plant (Montpellier)

Chowdhury, A., Karim, M.A., Khaliq, Q.A., Ahmed, A.U. and Mondol, A.T.M.A.I. 2017. Effect of drought stress on water relation traits of four soybean genotypes. *SAARC Journal of Agriculture* **15** (2): 163-175.

Cornic, G. and Massacci, A. 1996. Leaf photosynthesis under drought stress. In: Baker NR, ed. *Photosynthesis and the Environment*. The Netherlands: Kluwer Academic Publishers.

Costa, M., Civell, P.M., Chaves, A.R. and Martinez, G.A. 2005. Effects of ethephon and 6-benzylaminopurine on chlorophyll degrading enzymes and a peroxidase-linked chlorophyll bleaching during post-harvest senescence of broccoli at 20ºC. *Post-harvest Biology and Technology* **35**: 191-199.

Cruz, R.T., Toole, J.C., Dingkuhn, M., Yambao, E.B., Thangaraj, M. and DeDatta, S.K. 1986. Shoot and root responses to water deficit in rainfed rice. *Australian Journal of Plant Physiology* **13**: 567–575.

David, W.L. 2002. Limitation of photosynthesis in water-stressed leaves: Stomata Vs. metabolism and the role of ATP. *Annals of Botany* **89**: 871-885.

Demiralay, M., Saglam, A., and Kadioglu, A. 2013. SA delays leaf rolling by inducing antioxidant enzymes and modulating osmoprotectant content in ctenanthe setosa under osmotic stress. *Turkish Journal of Biology* **37**: 1205-1216.

El-Tayeb, M. A. 2005. Response of barley grains to the interactive effect of salinity and salicylic acid. *Plant Growth Regulation* **45**: 215–224.

Fengxia, T., Jiangfeng, G., Jin, Z., Meng, Z., Guokun, W., Aixiu, L. and Wei, W. 2013. Enhanced stability of thylakoid membrane proteins and antioxidant competence contribute to drought stress resistance in the *tasg1* wheat stay-green mutant. *Journal of Experimental Botany* **64**: 1509–1520

Fisher, J.B., Tu, K. and Baldocchi, D.D. 2008. Global estimates of the land atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at FLUXENT sites. *Remote Sensing and Environment* **112**: 901-919.

Golldack, D., Lüking, I. and Yang, O. 2011. Plant tolerance to drought and salinity: stress regulating transcription factors and their functional significance in the cellular transcriptional network. *Plant Cell Reports* **30**: 1383–1391.

Halder, K.P, Burrage, S. W. (2003): Drought stress effects on water relations of rice growth in nutrient film technique. *Pakistan journal Biological Sciences* 6: 441-444.

Hasan, M.M.U., Ma, F., Prodhan, Z.H., Li, F., Shen, H., Chen, Y. and Wang, X. 2018. Molecular and physio-biochemical characterization of cotton species for assessing drought stress tolerance. *International Journal of Molecular Sciences* **19**:26-36. https://doi.org/10.3390/ijms19092636

Hayat, R., Ali, S., Amara, U., Khalid, R. and Ahmed, I. 2010. Soil beneficial bacteria and their role in plant growth promotion: a review. *Annals of Microbiology* **60**:579–598.

Heshmat, S.A., Farag, L.I. and Hanan, E.G. 2018. Comparative effects of SA and/or trehalose on osmotic adjustment and solutes allocation of two droughted wheat (*Triticum aestivum* L.) Cultivars. *Advances in Agricultural Technology and Plant Sciences* **1:** 180001.

Heshmat, S.A., Samy, A. Abo, H., Mohmed, A.A. and Abeer, E. 2012. Role of glycine betaine and SA in improving growth vigour and physiological aspects of droughted wheat cultivars. *Journal of Stress Physiology & Biochemistry* **8**:149-171.

Hoekstra, F. A., Golovina, E. A., Buitink, J. (2001): Mechanisms of plant desiccation tolerance. Trends in Plant Science 6: 431–438.

Hortensteiner, S. and Kräutler, B. 2011. Chlorophyll breakdown in higher plants. *Biochimica et Biophysica Acta* **1807**: 977–988.

Hussain, M., Malik, M.A., Farooq, M., Khan, M.B., Akram, M. and Saleem, M.F. 2009. Exogenous glycine betaine and SA application improves water relations, allometry and quality of hybrid sunflower under water deficit conditions. *Journal of Agronomy Crop Science* **195**: 98–109.

Iturbe-Ormaetxe, I., Pedro, R., Escuredo, Cesar, A. I. and Mauel, B. 1998. Oxidative damage in pea plants exposed to water deficit or paraquat. *Plant Physiology* **116**: 173–181.

Jagtap, V. and Bhargava, S. 1995. Variation in the antioxidant metabolism of drought tolerant and drought susceptible varieties of *Sorghum bicolor* L.exposed to high light, low water and high temperature stress. *Journal of Plant Physiology* **145**: 195-197.

Jain, M., Mittal, M. and Gadre, R. 2013. Effect of PEG-6000 Imposed water deficit on chlorophyll metabolism in maize leaves. *Journal of Stress Physiology & Biochemistry* **9**: 262-271.

Jalal-Ud-Din, D., Sami, U.K., Ali and R.G. 2012. Physiological and biochemical constituents as predictive appreciation for selection of drought tolerant cultivars in wheat (*Triticum aestivum* L.). *Journal-Chemical Society of Pakistan* **34**:151-155.

Joseph, C.V.V., Russ, W.G., Hartwell, A. Jr., Kenneth, J.B. and George, B. 1999. CO_2 enrichment delays a rapid, drought-induced decrease in Rubisco small subunit transcript abundance. *Journal of Plant Physiology* **155**: 139–142.

Kang, G., Li, G. and Guo, T. 2014. Molecular mechanism of SA-induced abiotic stress tolerance in higher plants. *Acta Physiologiae Plantarum* **36**: 2287–2297.

Kang, G., Li, G., Xu, W., Peng, X., Han, Q., Zhu, Y., Guo, T. 2012. Proteomics reveals the effects of SA on growth and tolerance to subsequent drought stress in wheat. *Journal of Proteome Research* **11**: 6066–6079.

Khaled, A.A.A., Kotb, A.A., Salman, F.A., Mohamed, M. El., Afry, A., Ghazy, Dalia, S.T., Abdullah, A.A., El, Sayed, E, Abdel, ghafar, M.A. and Yaser, M.H. 2020. Exogenous application of proline and SA can mitigate the injurious impacts of drought stress on barley plants associated with physiological and histological characters. *Sustainability* **12**: 17-36.

Khan, M.A., Ungar, I.A. and Showalter, A.M. 2000. Effects of sodium chloride treatments on growth and ion accumulation of the halophyte Haloxylon recurvum. *Communications in Soil Science and Plant Analysis* 31: 2763–2774.

Khan, M.B., Hussain, M., Raza, A., Farooq, S. and Jabran, K. 2015. Seed priming with CaCl2 and ridge planting for improved drought resistance in maize. *Turkish Journal of Agriculture and Forestry* **39**: 193–203.

Khodary, S.E.A. 2004. Effect of SA on the growth, photosynthesis and carbohydrate metabolism in salt stressed maize plants. *International journal of agricultural biology* **6**: 5–8.

Kiran, M., Noshin, I., Nazima, B., Bashir, A. and Muhammad, A. 2015. Effect of SA on the growth and physiological characteristics of maize under stress conditions. Journal of Chemical Society of Pakistan **37**: 588-593.

Kovacik, J., Grúz, J., Baekor, M., Strnad, M. and Repcák, M. 2009. SA-induced changes to growth and phenolic metabolism in *Matricaria chamomilla* plants. *Plant Cell Report,* **28**: 135–143.

Kpyoarissis, A., Petropoulou, Y. and Manetas, Y 1995. Summer survival of leaves in a soft-leaved shrub (*Phlomis fruticosa* L. *Labiatae*) under Mediterranean field conditions: avoidance of photo inhibitory damage through decreased chlorophyll contents. *Journal of Experimental Botany,* **46**: 1825–1831.

Leslie, C. A. and Romani, R.J. 1988. Inhibition of ethylene biosynthesis by SA. *Plant Physiology,* **88**:833-837.

Li, G., Peng, X., Wei, L. and Kang, G. 2013: SA increases the contents of glutathione and ascorbate and temporally regulates the related gene expression in salt-stressed wheat seedlings. *Genetics,* **529**:321–325.

Luis, G. and Marco, G. 2001. Determination of relative water content. Handbook of plant ecophysiology techniques kluwer academic publishers, Netherlands pp. 207-212.

Ma, Y., Rajkumar, M., Moreno, A., Zhang, C. and Freitas, H. 2017. Serpentine endophytic bacterium *Pseudomonas azotoformans* ASS1 accelerates phytoremediation of soil metals under drought stress. *Chemosphere,* **185**: 75–85.

Mahmoud, M.E., Ibrahim, G.A.A. and Abdelwahab, M.S. 2021. Manganese dioxide nanoparticles decorated with chitosan for effective removal of lead and lanthanum ions from water by microwave sorption technique. *Materials Science and Engineering B: Solid-State Materials for Advanced Technology,* 267: (*https://www.sciencedirect.com/science/article/abs/pii/S0921510721000519).*

Majid, K. 2012. The effect of drought stress on leaf chlorophyll content and stress resistance in maize cultivars (*Zea mays*). *African Journal of Microbiology Research* **6**: 2844–2848.

Majid, K. and Roza, G. 2011. The effect of drought stress on leaf chlorophyll content and stress resistance in maize cultivars (Zea mays). *African Journal of Microbiology Research* **6**: 2844-2848.

Manuela, M.C., Joao, P.M. and Joao, S.P. 2003. Understanding plant responses to drought from genes to the whole plant Function. *Plant Biology* **30**: 239-264.

Masoumeh, K., Adel, S., Ebrahim, R. and Sara, K. 2021. SA alleviated the effect of drought stress on photosynthetic characteristics and leaf protein pattern in winter wheat. *Heliyon* **7**:11.

Masuda, T. and Takamiya, K. 2004. Novel insights into the enzymology, regulation and physiological functions of light-dependent protochlorophyllide oxidoreductase in angiosperms. Photosynthesis Research **81**: 1–29.

Md. Mahabub, A., Mirza, H., Kamrun, N. and Masayuki, F. 2013. Exogenous SA ameliorates short-term drought stress in mustard (Brassica juncea L.) seedlings by up-regulating the antioxidant defence and glyoxalase system. *Australian Journal of Crop Science* **7**:1053-1063.

Michal, G., Anna, S., Wojciech, S., Jerzy, K., Kazimierz, S. and Beata, M.K. 2015. Photoactive protochlorophyllide-enzyme complexes reconstituted with PORA, PORB and PORC Proteins of *A. thaliana*: Fluorescence and Catalytic Properties. *Plos One* **10:** e0116990.

Miura, K. and Tada, Y. 2014. Regulation of water, salinity, and cold stress responses by SA. Frontiers in Plant Science **5**:4 10.3389/fpls.2014.00004.

Moorby, J., Munns, R. and Walcott, J. 1975. Effect of water deficit on photosynthesis and tuber metabolism in potatoes. *Australian Journal of Plant Physiology*, **2**: 323-333.

Muhammad, F., Shahzad, B.A.B., Abdul, W., Nora, A. and Basharat, A. S. 2009. Improving the drought tolerance in rice (*Oryza sativa* L.) by Exogenous application of SA. *Journal of Agronomy and Crop Science* **195**:237 – 246.

Munns, R., Greenway, H., Delane, R. and Gibbs, J. 1982. Ion concentration and carbohydrate status of the elongating leaf tissue of *Hordeum vulgare* growing at high external NaCl: II. Cause of the growth reduction. *Journal of experimental botany,* **33**: 574-583.

Mutlu, S., Atici, O. and Nalbantoglu, B. 2009. Effects of SA and salinity on apoplastic antioxidant enzymes in two wheat cultivars differing in salt tolerance. *Biologia Plantarum* **53**: 334-338.

Naeem, K., Eiman, Z., Shahid, A., Asif, M., Muhammad, A.S. and Jianjun, Y. 2018. Impact of SA and PGPR on the drought tolerance and phytoremediation potential of *Helianthus annus*. *Frontiers of Microbiology,* **9**:2507. doi: 10.3389/fmicb.2018.02507

Nasrin, R., Ali, E., Jahanfar, D. and Soodabeh, J. 2017. SA induced changes on antioxidant capacity, pigments and grain yield of soybean genotypes in water deficit condition, *Journal of Plant Interactions,* **12**: 457-464.

Navita, G., Ramesh, C.S. and Neelam, S. 2002. Effects of paclobutrazol and SA on chlorophyll content, hill activity and yield components in Brassica napus L. (CV GSL-1) Phytomorphology. *An International Journal of Plant Morphology,* **52**:83-87.

Nayyar, H., Bains, T. and Kumar, S. 2005. Low temperature induced floral abortion in chickpea: relationship to abscisic acid and cryoprotectants in reproductive organs. *Environmental and Experimental Botany,* **53**:39–47.

Okorie, V.O., Thulisile, N.M. and Samuel, O.A. 2019. Exploring the political economy of water and food security nexus in BRICS. *Africa Insight,* **48**: 21.

Omae, H., Kumar, A., Kashiwaba, K. and Shono, M. 2007. Assessing drought tolerance of snap bean (*Phaseolus vulgaris*) from genotypic differences in leaf water relations, shoot growth and photosynthetic parameters. *Plant Production Science,* **10**: 28–35.

Ommen, O.E., Donnelly, A., Vanhoutvin, S., van, Oijen, M. and Manderscheid, R. 1999. Chlorophyll content of spring wheat flag leaves grown under elevated CO2 concentrations and other environmental stresses within the ESPACE-wheat project. *European Journal of Agronomy,* **10**: 197-203.

Onwugbuta-enyi J. 2004. Water balance and proximate composition in cowpea (*Vigna unguiculata* L. *Walps*) seedlings exposed to drought and flooding Stress. *Journal Applied Sciences and Environment Management,* **8**: 55 – 57.

Osakabe, Y., Osakabe, K., Shinozaki, K. and Tran, L.S.P. 2014. Response of plants to water stress. *Frontiers of Plant Science,* **5**: 1 - 8.

Parisa, S. and Nayer, M. 2016 Effects of drought stress on photosynthesis factors in wheat genotypes during anthesis. *Cereal Research Communication,* **44**: 1-11.

Parry, M.A.J., Androlojc, P.J., Khan, S., Lea, P.J. and Keys, A.J. 2002. Rubisco activity: effects of drought stress. *Annals of Botany,* **89**: 833–839.

Rahat, N., Umar, S. and Nafees, K. 2015. SA supplementation improves photosynthesis and growth in mustard through changes in proline accumulation and ethylene formation under drought stress. *South African journal of Botany,* **98**: 84-94.

Rahat, N., Noushina, I., Shabina, S. and Nafees, A.K. 2011. Salicylic acid alleviates decreases in photosynthesis under salt stress by enhancing nitrogen and sulfur assimilation and antioxidant metabolism differentially in two mungbean cultivars. *Journal of Plant Physiology,* **168**: 807-815

Rahdari, P., Hoseini, S.M. and Tavakoli, S. 2012. The studying effect of drought stress on germination, proline, sugar, lipid, protein and chlorophyll content in Purslane (*Portulaca oleraceae* L.) leaves. *Journal of Medicinal Plant Research,* **6**: 1539-1547.

Rahmati, M., Miras-Avalos, J.M., Valsesia, P., Lescourret, F., Genard, M.M. and Davarynejad, G.H. 2018. Disentagling the effects of water stress on carbon acquisition, vegetative growth and fruit quality of peach trees by means of Qualities mode. *Frontiers in Plant Sciences,* **9**:3. 10.3389/fpls.2018.00003

Ramadan, S., Rui, W., El-Sayed, M.S.G., Hafiz, A.H., Saddam, H., Muhammad, I., Linna, C., Kangping, Z., Sai, Z. and Longchang, W. 2021. Effects of SA, zinc and glycine betaine on morpho-physiological growth and yield of maize under drought stress. *Science Report*, **11:** 3195. (*https://doi.org/10.1038/s41598-021-82264-7)*

Rao, S.R., Qayyum, A., Razzaq, A., Ahmad, M., Mahmood, I. and Sher, A. 2012. Role of foliar application of SA and l-tryptophan in drought tolerance of maize. *The Journal of Animal & Plant Sciences,* **22**: 768-772.

Raper, C.D. and Kramer, P.J 1983. Crop reactions to water and temperature stresses in humid temperate climates. Westview Press, Boulder, Co.

Raskin, I. 1992. Role of SA in plants. *Annual Review of Plant Physiology and Plant Molecular Biology,* **43**: 439–463 (doi: 10.1146/annurev.pp.43.060192.002255).

Reddy A.R., Chaitanya K.V. and Vivekanandan M. 2004. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology*. **161**: 1189–1202

Rosales-Serna, R., Kohashi-Shibata, J., Acosta-Gallegos, J.A., Trejo-Lopez, C., Ortiz-Cereceres, J. and Kelly, J.D. 2004. Biomass distribution, maturity acceleration and yield in drought-stressed common bean cultivars. *Field Crops Research* **85**):203-211.

Rosegrant, M. W., Cline, S. A. 2003. Global food Security : challenges and policies. *Science*, **302**: 1917–1919.

Sakhabutdinova, A.R., Fatkhutdinova, D.R., Bezrukova, M.V. and Shakiova, F.M. 2003. Salicylic acid prevents the damaging action of stress factors on wheat plants. *Bulgarian Journal of Plant Physiology,* **29**: 314–319.

Sarafis, V. 1998. Chloroplasts: a structural approach, *Journal of Plant Physiology,* **152**: 248-264.

Sarika, A., Raj, K.S., Srivastava, G.C. and Ramavatar, M. 2005. Role of ABA, SA, calcium and hydrogen peroxide on antioxidant enzymes induction in wheat seedlings. *Plant Science,* **169**: 559-570.

Shakeel, A.A., Xiao-yu, X., Long-Chang, W., Muhammad, F.S., Chen, M. and Wang, L. 2011. Morphological, physiological and biochemical responses of plants to drought stress. *African Journal of Agricultural Research,* **6**: 2026-2032.

Shamima, N., Shukanta, S., Hasna, H.B. and Rifat, S. 2020. Physiological and biochemical characterisation of drought tolerant rice verities. *Dhaka University Journal of Biological Sciences,* **29**: 117-123.

Shamsul, H., Syed, A.H., Qazi, F. and Aqil, A. 2008. Growth of tomato (*Lycopersicon esculentum*) in response to SA under water stress. *Journal of plant interactions,* **3**: 297-304.

Shao, H.B., Liang, Z.S. and Shao, M.A. 2006. Osmotic regulation of 10 wheat (*Triticum aestivum* L.) genotypes at soil water deficits. *Colloids and Surfaces. B, Biointerfaces,* **47**: 132–139.

Sharma, S., Hamal, K., Khadka, N. and Joshi, B.B. 2020. Dominant pattern of year-to-year variability of summer precipitation in Nepal during 1987–2015. *Theoretical and Applied Climatology*, **142**: 1071– 1084.

Shi, G.R., Cai, Q.S., Liu, Q.Q. and Wu, L. 2009. SA-mediated alleviation of cadmium toxicity in hemp plants in relation to cadmium uptake, photosynthesis, and antioxidant enzymes. *Acta Physiologiae Plantarum,* **31**: 969–977.

Shunichi, T. and Norio, M. 2008. How do environmental stresses accelerate photoinhibition? *Trends of Plant Science,* **13**:178-182.

Siamak, F., Adel, S., Hamdollah, K., Mehrdad, Y. and Asad, R. 2014. Response of chickpea (*Cicer arietinum* L.) to exogenous salicylic acid and ascorbic acid under vegetative and reproductive drought stress conditions. *Journal of Applied Botany and Food Quality,* **87**: 80 – 86.

Siddique, M. R. B., Hamid, A., M. Sirajul, I. 2000. Drought stress effects on water relation of wheat. *Botanical Bulletin- Academia Sinica Taipei,* **41**:35-39.

Sivakumar, R., Nandhitha, G.K., Chandrasekaran, P., Boominathan, P. and Senthilkumar, M. 2017. Impact of pink pigmented facultative methylotroph and PGRs on water status, photosynthesis, proline and NR activity in tomato under drought. *International Journal of Current Microbiology and Applied Science,* **6**: 1640-1651.

Smirnoff, N. 1995. Antioxidant Systems and Plant Response to the Environment. In: Smirnoff, V., Ed., Environment and Plant Metabolism: Flexibility and Acclimation, BIOS Scientific Publishers, Oxford pp. 217-243.

Sun, X., Xi, D.H., Feng, H., Du, J.B., Lei, T., Liang, H.G. and Lin, H.H 2009. The dual effects of SA on dehydrin accumulation in water-stressed barley seedlings. *Russian Journal of Plant Physiology,* **56**: 348–354.

Syamsia, Abubakar, I., Noerfitryani, Marhamah, N., Reta and Muhammad, K. 2018. Paddy chlorophyll concentrations in drought stress condition and endophytic fungi application. *IOP Conference Series: Earth and Environmental Science,* **156**: 12-40

Taibi, K., Taibi, F., Abderrahim, L.A., Ennajah, A., Belkhodja, M. and Mulet, J.M. 2016. Effect of salt stress on growth, chlorophyll content, lipid peroxidation and antioxidant defence systems in *Phaseolus vulgaris* L. *South African Journal of Botany,* **105**: 306–312.

Tas, S. and Tas, B. 2007. Some physiological responses to drought stress in wheat genotypes with different ploidy in Turkey. *World Journal of Agricultural Sciences,* **3**: 178-183.

Techawongstin, S., Nawata, E. and Shingenaga, S., 1993. Recovery in physiological characteristics from sudden and gradual water stress in hot-peppers. Proceedings of an International Symposium, Taiwan, Aug. 13-18, AVRDC, Taiwan, 140-147.

Tezara, W., Mitchell, V.J., Driscoll, S.D. and Lawlor, D.W. 1999. Water stress inhibits plant photosynthesis by decreasing coupling factor and ATP. *Nature* **401**: 914-917.

Thu-Ha, P., Ha-il, J., Joon-Heum, P., Jin-Gil, K., Kyoungwhan, B. and Sunyo, J. 2011. Porphyrin Biosynthesis Control under Water Stress: Sustained Porphyrin Status Correlates with Drought Tolerance in Transgenic Rice. *Plant Physiology* **157**: 1746–1764.

Tuba, Z., Lichtenthalter, H.K., Csintalan, Z.S., Nagy, Z. and Szente, K. 1996. Loss of chlorophylls, cessation of photosynthetic CO2 assimilation and respiration in the poikilochlorophyllous plant *Xerophyta scabrida* during desiccation. *Jornal of plant physiology,* **96**: 383–388.

Turner, N.C. and Kramer P.J. 1980. Adaptations of plants to water and high temperature stress. John Wiley and Sons. New York.

Vahdati, N.M., Tehranifar, A., Bayat, H. and Selahvarzi, Y. 2012. Salicylic and citric acid treatments improve the vase life of cut chrysanthemum flowers. *Journal of Agricultural Science and Technology,* **14**: 879-887.

Vijay, K.D. and Baishnab, C.T. 2012. Modulation of chlorophyll biosynthesis by water stress in rice seedlings during chloroplast biogenesis. *Plant Cell and Environment*, **35**:1685-703.

Vijay, K D. and Baishnab, C.T. 2018. Water-stress induced downsizing of light-harvesting antenna complex protects developing rice seedlings from photo-oxidative damage**.** *Scientific Reports,* **8**: 5955.

Wahid, A. and Rasul, E. 2005. Photosynthesis in leaf, stem, flower and fruit, in: Pessarakli M. (Ed.), Handbook of Photosynthesis, 2nd ed., CRC Press, Florida, 479–497.

Wang, Y.Y., Wang, Y., Li, G.Z. and Hao, L. 2019. SA-altering Arabidopsis plant response to cadmium exposure: underlying mechanisms affecting antioxidation and photosynthesis-related processes. *Ecotoxicology Environmental Safety,* **169**: 645–653.

Wensen, W., Cheng, W., Dayu, P., Yakun, Z., Bin, L. and Jianwei, J. 2018 Effects of drought stress on photosynthesis and chlorophyll fluorescence images of soyabean seedlings. *International journal of Agricultural and Biological Engeenering,* **11:** 196-201.

White, R., Murray, S. and Rohweder, M. 2000. Pilot analysis of global ecosystems (PAGE): grassland ecosystems. Washington, DC: World Resources Institute (WRI).

Xing, L., Limei, L., Meijuan, L., Liangchen, S., Siman, L., Baihong, Z., Xiaoyun, L., Kui, G. and Ling, L. 2018. hGLK1 affects chlorophyll biosynthesis and photosynthesis in peanut leaves during recovery from drought. *Scientific Reports* **8**: 22-50.

Yokota, A., Kawasaki, S., Iwano, M., Nakamura, C., Miyake, C. and Akashi, K. 2002 Citrulline and DRIP-1 protein (ArgE Homologue) in drought tolerance of wild watermelon. *Annals of Botany* **89**: 825–832. doi: 10.1093/aob/mcf074

Yordanov, I.V., Velikova, T. and Tsonev, 2003. Plant responses to drought and stress tolerance. *Bulgarian Journal of Plant Physiology*. Special Issue. 187-206.

Zafar, Z., Rasheed, F., Atif, R.M., Javed, M.A., Maqsood, M. and Gailing, O. 2021. Foliar Application of Salicylic Acid Improves Water Stress Tolerance in Conocarpus erectus L. and Populus deltoides L. Saplings: Evidence from Morphological, Physiological, and Biochemical Changes. *Plants.* **10**: 1242. https ://doi.org/ 10.3390/plants10061242

Zaffar, M.D., Amjad, M., Arshad, H.M., Malik, A. and Mushtaq, A.M. 2018. Review on Drought Tolerance in Plants Induced by Plant Growth Promoting Rhizobacteria. *International Journal of Current Microbiology and Applied Sciences* **7**: 412-422.

Zaffar, M.D., Mushtaq , A.M., Malik, A.A., Amjad, M., Ab. R.D., Shamshir, Ul, H. and Zahoor, A.D. 2021. Role of Selenium in Regulation of Plant Antioxidants, Chlorophyll Retention and Osmotic Adjustment under Drought Conditions: A Review. *International Journal of Plant & Soil Science*, **33**: 52-60.

Zhang, G., Huang, H., Liu, D., Cheng, Y., Liu, X., Zhang, W., Yin, R., Zhang, D., Zhang, P., Liu, J., Li, C., Liu, B., Luo, Y., Zhu, Y., Zhang, N., He, S., He, C., Wang, H. and Chen, D. 2015. N(6)-methyladenine DNA modification in Drosophila. *Cell.* **161**: 893-906.

Zhibo, W., Li G. and Sun, H. 2018. Effects of drought stress on photosynthesis and photosynthetic electron transport chain in young apple tree leaves. *Biology Open* **7**: bio03279.https://doi.org/bio.035279.

Zlatko S., Zlatev A., Ivan T. and Yordanov 2004. Effects of soil drought on photosynthesis and chlorophyll fluorescence in bean plants. *Bulgarian Journal of plant physiology* **30**: 3-18.

Zobayed, S., Afreen, F. and Kozai, T. 2005. Temperature stress can alter the photosynthetic efficiency and secondary metabolite concentrations in St. John's Wort. *Journal of Plant Physiology and Biochemistry,* **43**: 977–984.