REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

Impact of Salicylic Acid on Plant Growth and Metabolism

Shireesha Somineni[1*]

[1*]Department of Botany, Telangana Social Welfare Residential Degree College, Armoor, Telangana, 503224, India

***Corresponding Author:** Shireesha Somineni
*Email: bunnishireesha@gmail.com

ABSTRACT
Plants' growth and development, stomatal closure, photosynthesis, respiration, nutrient uptake, nitrogen metabolism, flowering, yield, and senescence are just a few of the many physiological processes that have been found to be impacted by SA that is supplied from outside the plant. Treatment with low doses of SA often induces these activities, whereas high quantities block them, indicating that SA controls these processes in a concentration-dependent way. We may characterize the phytohormone SA as a multi-functional regulator of plant development in response to (a)biotic stress, according to the existing literature. Plants may be protected from biotic stress and have their growth responses and productivity modulated by the exogenous application of SA under abiotic stress circumstances. There is a wide range of variability in SA concentrations between species, plants, organs, developmental stages, and environmental factors. This precludes the possibility of providing a recommended SA concentration for external application to any particular crop.

Key Words; Phytohormone, Salicylic Acid, Biotic Stress, Abiotic Stress.

INTRODUCTION
Numerous plants contain the phenolic chemical salicylic acid, also known as ortho-hydroxy benzoic acid (SA) (Yang et al. 2021). In both healthy and unhealthy plant environments, SA and its derivatives (Fig. 1) regulate a wide range of physiological and developmental activities, including defense responses. Photosynthesis, stomatal movement, enzyme activity, nutrient absorption, legume nodulation, and general plant development (seed germination, vegetative growth, blooming, and senescence) are all physiological processes that SA controls in plants.

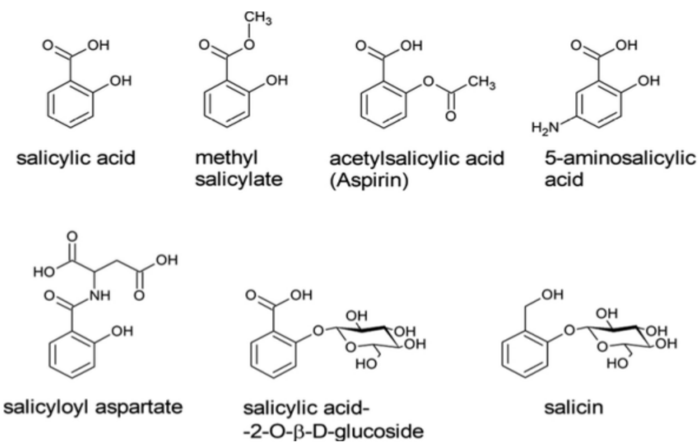

Fig 1 : Structures of salicylic acid and derivatives (Arif, Sami et al. 2020)

A saturated water solution of free SA has a pH of 2.4, making it extremely soluble in polar organic solvents but very insoluble in water. Several plants have been shown to have SA due to its ability to glow at 412 nm when activated at 301 nm. The role of SA, a phytohormone (a small organic compound found in plants in extremely low concentrations), in the activation and regulation of various responses to biotic and abiotic stresses, such as ozone, ultraviolet radiation, heat, cold, drought, heavy metal toxicity, and salinity/osmotic stresses, has been demonstrated in numerous studies (Aviles-Baltazar et al. 2019). Furthermore, SA has been shown to influence other aspects of plant development, including as seed germination, vegetative growth, and overall plant health.
The regulation of various physiological processes in plants, including photosynthesis, stomatal closure, respiration, glycolysis, and the Krebs cycle, as well as their interaction with other organisms, is influenced by senescence, flowering, and other factors (Hayat et al. 2010). Different plant species, different organs of different plants, different developmental phases of different plants, and different environmental variables all contribute to different SA concentrations. According to Rivas-San Vicente and Plasencia (2011), one study found that Arabidopsis thaliana naturally has SA concentrations

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

ranging from 0.250 µg to 1 µg g-1 fresh weight (FW). Tobacco leaves (*Nicotiana tabacum*) have very tiny amounts of SA, in comparison.
Endogenous SA plays a crucial role in plant immunity and resistance, as it is first accumulated in infected tissue and then distributed throughout the plant to induce systemic acquired resistance (SAR) in healthy parts of the plant. Researchers have shown that SA helps shape the populations of microbes that live around plant roots (Yao et al. 2020).

METHODOLOGY, DISCUSSION

SYNTHESIS AND METABOLISM OF SA

Research in genetics and biochemistry has revealed two separate pathways that can produce SA. One in the plastids called the isochorismate (IC) pathway and another in the cytosol called the phenylalanine-ammonia lyase (PAL) pathway (Dempsey and Klessig 2017). Chorismic acid, a byproduct of shikimic acid production, is the starting point for both routes. The conversion of shikimic acid to chorismic acid and subsequently to phenylalanine by chorismic mutase occurs in the cytosol as part of the PAL pathway. Benzaldehyde and ortho-coumaric acid are byproducts of the process that begins with PAL using phenylalanine to generate trans-cinnamic acid. Figure 2. Benzoic acid (BA) is produced when aldehyde oxidase (AAO) converts benzaldehyde. When benzoic acid hydroxylase (BA2H) is activated, it converts BA to SA. In the chloroplast, an enzyme called isochorismate synthase (ICS) converts chorismic acid to isochorismate, which is then turned into SA in the cytosol by an enzyme called isochorismate pyruvate lyase. This process is known as the IC route. Every plant genome that has been sequenced has both the ICS and PAL genes. Both routes contribute to SA levels in plants, although their relative contributions vary greatly between species (Shine, Yang et al. 2016). Tobacco plants infected with tobacco mosaic virus (TMV) showed a significant increase in PAL enzymatic activity but little ICS activity, indicating that PAL is the primary mechanism for SA production (Ogawa, Nakajima et al. 2006). In contrast, SA helps rice plants resist insects and is generated via the PAL pathway. It was shown in soybean that pathogen-induced SA biosynthesis involves both the ICS and PAL pathways (Peng, Yang et al. 2021). It has been shown that plants whose ICS and PAL pathways are both mutated become more susceptible to various infections, suggesting that both pathways are necessary for SA accumulation and their function in response to biotic stressors. Nonetheless, the ICS route is mostly responsible for pathogen-induced SA production. In contrast, ozone treatments and ultraviolet (UV-C) radiation are examples of abiotic stressors that might stimulate SA synthesis via any of these channels. Other metabolic pathways have strong ties to both of these.

SIGNALLING AND PERCEPTION

A crucial regulator of the SA signaling system has been found by genetic screening as the NPR1 gene (Nonexpresser of PR genes 1) . This opens the door for NPR1 to reach the nucleus, where it binds to certain transcription factors encoded by TGAs, triggering the production of genes associated with defense mechanisms promoted by SA.
While NPR1 is unable to bind SA, NPR3 and NPR4, which are homologs of NPR1, are able to bind SA and act as receptors for SA. To fully induct target genes and create SA-induced responses, NPR1 turnover is necessary (Dempsey and Klessig 2017). It also guarantees proper defense activation. When SA levels are low in uninfected cells, NPR4 is thought to keep NPR1 levels low. Nevertheless, NPR4 and NPR1 are able to interact normally before infection, but this breaks down when SA levels rise, leading to the buildup of NPR1. According to Dempsey and Klessig (2017), NPR1 is degraded when NPR3 attaches to it, which occurs at very high SA levels. One way to store SA once it has been produced or delivered into the cytosol is to convert it into SAG or SGE. Certain transporters regulate the intracellular levels of SA and its inactive variants. This means that SAG may be converted to SA at the apoplast and then transported into the vacuole in a number of plant species, including tobacco and soybean (Peng, Yang et al. 2021). Tobacco and Ricinus communis seedlings have been shown to undergo SA translocation in the phloem and xylem (Ohashi, Murakami et al. 2004). Systemic Acquired involves SA as a crucial long-distance inducer.

EFFECTS OF SALICYLIC ACID ON PLANT GROWTH AND DEVELOPMENT

Crucial stages in the life cycle of a crop include seed germination, blooming, and senescence. Significant consequences for these activities are shown to result from SA production and metabolism.

Germination

One of the most important steps in a plant's life cycle is seed germination. According to Rivas-San Vicente and Plasencia (2011), this process is controlled by interactions and crosstalk between several plant hormones, including SA, ABA, JA, GA, ET, BR, AUX, and CK. By stimulating the production of germination-critical proteins and the release or breakdown of mature seed proteins, SA can enhance seed germination. In general, SA's function in seed germination is conditional on the experimental conditions, plant genotype, and SA concentration. According to Hayat et al. (2010), plants benefit from SA when applied externally, whether it's by seed priming (soaking seeds before planting), hydroponic solution addition, or spraying plants with SA solution. Priming (by spraying with SA) boosted germination, growth rate and production in barley (Pancheva, Popova et al. 1996). Soaking grains in 10-5 M SA sig-nificantly improved the leaf number, fresh and dry mass of wheat seedlings.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

Belghazi et al. (2006) both highlight the significant impact that SA plays in improving seed germination in the presence of abiotic stress. Application of SA to soybean seedlings increased seed germination and helped develop heavy metal resistance (Li, Ma et al. 2014). In the presence of saline stress, priming tomato seeds with SA (150 mg L−1) enhanced germination, accelerated germination, and strengthened seed vigor (Ghoohestani, Gheisary et al. 2019). found that when exposed to salt stress, Vicia faba germinated better when exposed to varying amounts of SA applied topically (0.25, 0.5, 1 mM). According to Lee and Park (2010), when Arabidopsis were exposed to salt stress, SA (100 µM) improved seed germination via controlling antioxidant activity and decreasing oxidative damage.

Vegetative growth

A major regulator of plant growth and productivity, SA is known to impact a wide range of physiological and biochemical processes. Possible hormonal alterations (Shakirova, Sakhabutdinova et al., 2003) or enhancements to photosynthesis, transpiration, and stomatal conductance (Stevens, Senaratna et al., 2006) are associated with SA's growth-promoting effects. Species, stage of development, and amounts of exogenous SA all play a role in how this compound affects vegetative growth. Research has shown that SA may stimulate plant growth in several crops, including soybeans, wheat (Shakirova, Sakhabutdinova et al. 2003), and maize (Khodary 2004): After 7 days of treatment with SA (10 nM, 100 mM, 10 mM), the shoot growth in soybean plants rose by around 20% and the root growth by about 45%. According to a study by Shakirova, Sakhabutdinova,et, al.,in 2003, ear size increased in wheat seedlings exposed to 0.05 mM SA. Several wheat grain yield indices, including plant height, leaf and tiller counts, and SA concentration (0.2 mM and 0.4 mM applied foliarly) were shown to be enhanced (Ziasmin, Islam et al. 2017). Once again, according to Ziasmin, Islam et al. (2017), SA applied externally to wheat at concentrations of 50, 100, and 150 mg L-1 increased grain production and 1000 kernel weight. According to Khodary (2004), when SA was sprayed over maize, the plant's growth, pigment content, photosynthetic rate, and carbohydrate content were all significantly enhanced. Several mechanisms operate together to control flowering. Although combining SA with GA has been shown to have a greater impact on flowering than other hormone combinations (Kumar, Dube et al. 1999), additional studies are required to clarify SA's interactions with other hormones and the specific mechanism by which it induces flowering (Fig. 2; Rivas-San Vicente and Plasencia 2011). Flowering and pod development were both improved when SA was applied foliarly to soybeans (Kumar, Dube et al. 1999). According to Hayat et al. (2010), plants grown in cucumber and tomato were shown to produce far more fruit when sprayed with lower SA concentrations.

Senesence

As plants age, their antioxidant capacity declines, leading to an increase in reactive oxygen species (ROS) levels and a decrease in photosynthetic activity. These occurrences are likely due to the buildup of SA. At the mid-senescent stage, the SA level in Arabidopsis senescing leaves increased fourfold. In line with these results, SA biosynthesis was impacted. For instance, in a study conducted by Morris, Mackerness et al. (2000), it was shown that Arabidopsis mutants with a defective SA signaling system, such NPR1, exhibited different senescence patterns, such as delayed yellowing and decreased necrosis, when compared to wildtype plants. It is well-known that SA plays a significant role in the alterations in gene expression that accompany senescence. In Arabidopsis plants lacking SA, transcripts of several SAGs are either significantly decreased or not detectable (Morris, Mackerness et al. 2000). Although their roles in the advancement of senescence are still unclear, the majority of SAGs that rely on the SA pathway encode kinases, transferases, and hydrolases. Additional investigation is needed to ascertain the potential roles of SA throughout the aging process and its interrelationships with other phytohormones that either accelerate (ABA, JA, and an ET) or postpone (CKs and GAs) this process.(Fig. 4)

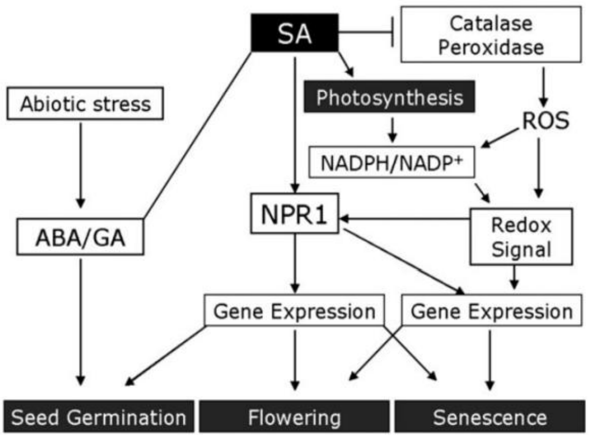

Figure 2: Descriptive model of salicylic acid function in plant growth and development

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

Salicylic Acid's Impact on Crop Production and Quality There is evidence that SA, when introduced externally, can enhance plant root mass and mineral absorption (Dong, Liu et al. 2020). These factors have been linked to increased yields and improved grain quality (Tab. 1), lending credence to SA's role as a regulator of plant growth. One study found that spraying maize cultivars' canopies with SA (1µM) during vegetative development significantly increased root/shoot DW, plant height, and grain output (Tucuch-Haas, Dzib-Ek et al. 2021). Increases in micronutrient and nitrogen, phosphorus, and potassium levels as well as overall grain quality were further evidence that SA enhanced grain quality. Results showed that SA had a beneficial influence on root growth, which enhanced nutrient absorption and accumulation, which in turn improved grain quality (Tucuch-Haas, Dzib-Ek et al. 2021).

EFFECTS OF SALICYLIC ACID ON PLANT METABOLISM

Photosynthesis

The primary activity in plants is photosynthesis, which entails the conversion of inorganic carbon dioxide (CO_2) into organic molecules like carbs and amino acids through the enzymes RUBISCO (ribulose-1,5-bisphosphate carboxylase/oxygenase in C3 plants) or PEP carboxylase (in C4 plants). Tabs. 2 show that SA is critical for normal and stressed environmental photosynthetic regulation and modulation. Based on its effects on stomatal closure, chloroplast and leaf structure, chlorophyll and carotenoid contents, and the activity of RUBISCO and carbonic anhydrase, SA is thought to be a key regulator of photosynthesis, according to recent evidence. (Fichman Y et al 2021) Leaf anatomy was altered (i.e., the epidermis and mesophyll tissue were narrower) by exposure to high doses of exogenous SA. Within cells, there has been shown an increase in chloroplast volume, swelling of grana thylakoids, and coagulation of the stroma. Reductions in light-induced reactions and photosynthetic activity have also been noted. Concentration and plant species determine the specific exogenous SA effects on photosynthesis.The photosynthetic CO_2 absorption in Brassica juncea seedlings was enhanced by a lower concentration of SA (10 µM). The activities of carbonic anhydrase and nitrate reductase were elevated in response to increases in photosynthetic rates and chlorophyll concentrations (Fariduddin, Hayat et al. 2003). At doses of 10^{-3} M or 10^{-4} M, SA showed inhibitory effects. It was hypothesized that this modest dosage of SA would have favorable benefits. For instance, several studies have shown that plants including barley, cowpea, wheat, and Arabidopsis have lower chlorophyll levels when exposed to high concentrations of SA (1-5 mM) (Arif, Sami et al. 2020). Various phytohormones regulate stomatal closure via guard cells, an essential component of photosynthesis. When pathogens attack, stomatal closure is facilitated by endogenous SA concentrations. Stomatal closure was elicited in Arabidopsis within 2 hours by 0.4 mM of exogenously administered SA (Mateo, Funck et al. 2006). because SA inhibits auxin oxidation, which is important since nitrate reductase activity rises with increasing auxin levels. Another research showed that SA applied topically to soybean plants increased their transpiration rate, internal CO_2 content, and water usage efficiency (Kumar, Dube et al. 1999).

Table 2: Response of photosynthesis to SA application.

Plant	Exogenous SA application	Response
Glycine max	500 µM	Overall increase in photosynthetic rate
Solanum tuberosum	0.5 mmol L^{-1}	Upregulation of photosynthesis, WUE and sub-stomatal CO_2
Phaseolus vulgaris	1 mM	Elevated chlorophyll index and net photosynthesis
Hordeum vulgare	1 mM	Inhibited PSII and Hill reaction activity
Triticum aestivum	0.75 mM	Upregulation of photosynthesis and chlorophyll a/b ratio
Brassica juncea	10-5 M	Increased photosynthesis, chlorophyll content
Glycine max	10–5 mol L^{-1}	Enhanced photosynthesis and stomatal conductance
Triticum aestivum	1000 µM	Enhanced photosynthesis

Nitrogen metabolism

Crop development, growth, yield, and quality are all affected by nitrogen metabolism. Soybean plants treated with SA showed an upregulation of nitrate reductase (NR) activity, leading to an increase in total protein content (Kumar, Dube et al. 1999). Plants grown from wheat grains soaked in a lower concentration (10^{-5} M) of SA showed a notable rise in NR activity in both their roots and leaves (Hayat, Hayat et al. 2010). Research has shown that SA influences the first phases of the symbiosis between rhizobium and legumes. This, in turn, reduced nitrogen fixation and eventually stunted plant growth. Soybean, *Lotus japonicus*, and *P. vulgaris* plants did not show any inhibition of nodulation when sprayed with the same dosage of SA. As the invading rhizobia responded to flavonoids generated by the legume, they produced nod factors, which altered the host plant's endogenous SA concentration during the early phases of nodulation (Sharma 2014). By postponing nodule formation and reducing the number of nodules per plant, exogenous SA reduced rhizobial development and nod factor synthesis (Sharma 2014). When administered after inoculation, SA had no effect on the growth of nodules that followed.

Table 3: Response of plants to SA in the presence of mineral nutrients under abiotic stress

Plant	Stress	SA conc.	Response
Cucumis sativus	Salt	1.0 mM	Increased the uptake of N, P, K, Ca, and Mg
Arabidopsis	Salt	0.5 mM	SA increased S assimilation and alleviated decrease in photosynthesis
Solanum lycop.	Salt	10^{-4} M	SA inhibited K uptake and increased Na uptake
Zea mays	Salt	0.5 mM	SA maintained higher K^+/Na^+ & Ca^{2+}/Na^+ ratios; improved growth & yield
Zea mays	Drought	0.5 mM	Stimulated mineral nutrient concentrations P, K, Mg, and Mn
Triticum aestivum	Drought	1-3 mM	SA interacts with N assimilation to influence Pro metabolism & CO_2 fix.
Triticum aestivum	Drought	1.0 mM	SA increased the rate of Ca, Mg, and K and reduced drought stress

Protective substances The production of reactive oxygen species (ROS) such superoxide radicals (O2 -), hydrogen peroxide (H2O2), and hydroxyl radicals (OH-) during oxidation processes in plants leads to cell death by damaging membranes, lipids, and nucleic acids. Responsive antioxidant systems incorporating antioxidant-enzymes such superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), peroxidase (POX), and glutathione reductase (GR) have evolved in plants to decrease ROS generation and the reactions linked to it. Research has consistently shown that SA may help lower ROS levels (Siddiqui, Mir et al. 2021).

The role of SA under abiotic stress

Abiotic stress tolerance induced by SA works by regulating hormone pathways, increasing scavenging of reactive oxygen species, increasing synthesis of secondary metabolites (terpenes, phenolics, alkaloids, glutathione, glucosinolates), and SA-mediated accumulation of osmolytes (glycinebetaine, proline, soluble sugars, and amines), which aids in maintaining osmotic homeostasis (Heo et al. 2020).

Salinity

One of the main pressures that plants experience is salinity, which inhibits their development and output. As per Siddiqui, Mir et al. (2021), it messes with ionic balance, photosynthesis, energy and lipid metabolism, and protein synthesis. Exogenous SA treatment has been shown to improve photosynthesis, antioxidant enzyme activity, and nitrate metabolism (Tab. 3), hence mitigating some of the negative effects of salinity on many plants, that SA enhanced the development of sorghum plants by reducing their intake of Na and Cl and improving their uptake of critical nutrients, even when subjected to salt stress. By reducing ROS production and enhancing mineral ion absorption, SA treatment significantly mitigated the harmful effects of salt stress in *Vigna angularis* (Ahanger, Aziz et al. 2019). By reducing sodium concentration, proline, and lipid peroxidation and by upregulating antioxidant activity, secondary metabolites, and sugars under varied degrees of salinity, Brassica nigra's salt tolerance was increased by the exogenous application of 1 mM SA.

Drought

Reduced turgor, growth, photosynthesis, stomatal conductance, and cellular compartmentation are among the significant physiological and biochemical dysfunctions caused by water stress in plants. Through its modulation of several growth indices in response to drought stress, SA is crucial in regulating this stress (Sami et al. 2020). By synthesizing osmolytes (soluble sugars and proline), SA applied topically to plants might mitigate the harmful effects of oxidative stress caused by drought and keep their water status stable. In addition to reducing lipid peroxidation, lipoxygenase activity, and H2O2 generation, SA may enhance the activity of antioxidant enzymes (POX, SOD, CAT).

According to Lee and Park (2010), SA caused Arabidopsis to initiate sucrose phloem-loading, which in turn assisted to preserve leaf turgor, osmotic potential, and postpone senescence in the face of water deficiencies. By increasing the activity of antioxidant enzymes, SA, when applied externally to rice plants, conferred drought resistance (Tahjib-UlArif et al. 2020). Under drought stress, SA treatment improved wheat's antioxidant system and nitrogen mobilization (Sharma, Gupta et al. 2017). Evidence in the literature that SA helps plants tolerate drought by regulating important physiological processes like photosynthesis, nitrogen metabolism, proline metabolism, glycine betaine production, and antioxidant defense system maintenance.

Heavy metal stress

Because they leach into the soil, heavy metals (such as Cd, Ni, and Pb) are a major issue for farmers all over the globe. These substances are easily absorbed by plants and cause significant changes in their metabolism and visible symptoms, such as chlorosis, stunted growth, reduced nutrient uptake and photosynthesis, stomatal opening inhibition, altered nitrogen metabolism, and ATPase activity disruption (Hayat, Hayat et al. 2010). Tab. 3 provide several instances of how

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

SA supplied from outside the body regulates respiration and photosynthesis, as well as how it activates defense mechanisms in response to heavy metal exposure (Salem, Saleh et al. 2021). In response to Cd stress, for instance, studies in barley, maize (Krantev, Yordanova et al., 2008) found that administering SA externally at a concentration of 0.5 mM enhanced photosynthesis, leading to greater shoot and root development. The toxicity caused by Al in stressed *Hordeum vulgare* might be reduced by inhibiting Al absorption and activating the antioxidant enzyme system when 10 µM SA was either pre- or co-treated.

Temperature stress

There are specific temperature requirements for each stage of crop development. When temperatures are too high or too low throughout these phases of development, they cause oxidative stress, membrane disruptions, and metabolic changes, all of which disturb the plant's growth and development. According to several studies (Arif, Sami et al., 2020), SA protects cells from oxidative damage by activating antioxidative enzymes, which helps them to tolerate both high- and low-temperature stress. As an illustration, in Festuca arundinacea, the negative impacts of heat stress were mitigated by increasing photosynthetic pigment levels, proline accumulation, and non-enzyme and enzymatic antioxidant activities. Additionally, forage yield and heat tolerance were improved with the application of SA (1 mM). The use of SA enhanced the heat tolerance of potatoes (López-Delgado et al. 2021). Cold tolerance was improved in both tolerant and sensitive barley cultivars by modifying the metabolism of reactive oxygen species (ROS) and antioxidative enzymes when 0.1 mM SA was constantly supplemented for 7 days found that wheat plants subjected to chilling stress had an increase in antioxidants and photosynthetic activity after receiving exogenous SA treatment. Several developmental processes under heat stress are controlled by crosstalk between the chemical signaling pathways of different phytohormones; SA's participation in this regulation has recently come to light.

CONCLUSION

Under order to reduce production losses under certain environmental situations, farmers have turned to agricultural practices including crop rotation, mixed cropping systems, and enhanced fertilization methods. Biostimulants have seen a surge in usage in the agricultural sector throughout the last few decades. An alternate strategy for increasing agricultural yields in the face of changing climatic circumstances may include the exogenous administration of different signaling molecules and plant growth regulators (Janda, Pál et al. 2017). Seed priming, which involves soaking seeds in SA before planting, adding SA to hydroponic solutions, and irrigating or spraying plants with SA solutions are some of the ways that SA may be used to help plants withstand different types of abiotic stress. On the other hand, not all of these application techniques work in the field, particularly when it comes to cereals cultivated on huge plots of land, which might be costly. Only in greenhouses are hydroponic cultures able to thrive.

There is hope for increasing agricultural yields via priming seeds before planting. Soaking seeds in the right chemical solution before processing them may provide a number of benefits over other methods. Compared to spraying plants, it requires fewer chemicals, is less expensive, and allows for greater control over the applied dosage. Szalai, Pál et al. (2016) found that SA was most effective when applied to seeds sown in early spring in Hungary, a region where chilling damage are more likely due to continental climatic conditions. Before any naturally occurring biologically active material, including SA, can be responsibly recommended for practical use, particularly in field settings, a number of questions need to be addressed, regardless of the amount of experiments conducted in controlled or uncontrolled environments. Possible areas of investigation at the most fundamental scientific level include: The mechanism of action of exogenously applied phytohormones as growth regulators is well understood. Clarification is required about their transport and absorption processes, signaling pathway control, and the intricate interplay between these processes. To uncover the connections between several environmental elements and the primary stressors, experiments must be carefully planned in a controlled context. It is possible, for instance, to investigate how varying amounts of nutrients affect the efficacy of physiologically active chemicals in improving stress tolerance, taking into account the impact of genotypic variance. The optimal genotype-management combinations for improving crop water and nutrient usage efficiency should be better determined in this way (Janda, Pál et al. 2017). There has been little study on the connections between SA and numerous (a)biotic stress episodes and distinct forms of stress, while SA's effects have been studied in model or crop plants under varied stress situations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 4 (2023)
http://www.veterinaria.org
Article Received: 14/11/2023 Revised: 23/11/2023 Accepted: 03/12/2023:

REFERENCES

1. Ahanger, M. A., U. Aziz, A. A. Alsahli, M. N. Alyemeni and P. Ahmad, 2019: Influence of Exogenous Salicylic Acid and Nitric Oxide on Growth, Photosynthesis, and Ascorbate-Glutathione Cycle in Salt Stressed Vigna angularis. Biomolecules 10.
2. Arif, Y., F. Sami, H. Siddiqui, A. Bajguz and S. Hayat, 2020: Salicylic acid in relation to other phytohormones in plant: A study towards physiology and signal transduction under challenging environment. Environmental and Experimental Botany 175
3. Aviles-Baltazar Alhoshan, M., M. Zahedi, A. A. Ramin and M. R. Sabzalian, 2019: Exogenous Application of Salicylic Acid and Glycine Betaine as Tools to Enhance Biomass and Tolerance of Potato Cultivars. Gesunde Pflanzen 71, 25-35.
4. Belgagi, R. N., T. K. Bose, B. N. Roy and A. Mukhopadhyay, 2006: Auxin Synergists in Rooting of Cuttings. Physiologia Plantarum 22, 649-652.
5. Dempsey, D. A. and D. F. Klessig, 2017: How does the multifaceted plant hormone salicylic acid combat disease in plants and are similar mechanisms utilized in humans? BMC Biol 15, 23
6. Dong, C.-J., X.-Y. Liu, L.-L. Xie, L.-L. Wang and Q.-M. Shang, 2020: Salicylic acid regulates adventitious root formation via competitive inhibition of the auxin conjugation enzyme CsGH3.5 in cucumber hypocotyls. Planta 252.
7. Fariduddin, Q., S. Hayat and A. Ahmad, 2003: Salicylic acid influences net photosynthetic rate, carboxylation efficiency, nitrate reductase activity, and seed yield in Brassica juncea. Photosynthetica 41, 281-284.
8. Fichman Y, Mittler R (2021) A systemic whole-plant change in re dox levels accompanies the rapid systemic response to wounding. Plant Physiol 186: 4–8
9. Ghoohestani, A., H. Gheisary, S. M. Zahedi and A. Dolatkhahi, 2019: Effect of Seed Priming of Tomato with Salicylic Acid, Ascorbic Acid and Hydrogen Peroxideon Germination and Plantlet Growth in Saline Conditions. International Journal of Agronomy and Plant Production. 3, 700-704.
10. Haeo, J., Y. Liu, D. Yuan, M. Duan, Y. Liu, Z. Shen, C. Yang, Z. Qiu, D. Liu, P. Wen, J. Huang, D. Fan, S. Xiao, Y. Xin, X. Chen, L. Jiang, H. Wang, L. Yuan and J. Wan, 2020: An R2R3 MYB transcription factor confers brown planthopper resistance by regulating the phenylalanine ammonia-lyase pathway in rice. Proc Natl Acad Sci U S A 117, 271-277.
11. Hayat, Q., S. Hayat, M. Irfan and A. Ahmad, 2010: Effect of exogenous salicylic acid under changing environment: A review. Environmental and Experimental Botany 68, 14-25.
12. Hayat, Q., S. Hayat, M. Irfan and A. Ahmad, 2010: Effect of exogenous salicylic acid under changing environment: A review. Environmental and Experimental Botany 68, 14-25
13. Janda, T., M. Pál, É. Darkó and G. Szalai, 2017: Use of Salicylic Acid and Related Compounds to Improve the Abiotic Stress Tolerance of Plants: Practical Aspects. In: R. Nazar, N. Iqbal and N. A. Khan eds. Salicylic Acid: A Multifaceted Hormone. pp. 35-46.
14. Khodary, S. E. A., 2004: Effect of Salicylic Acid on the Growth, Photosynthesis and Carbohydrate Metabolism in Salt Stressed Maize Plants. International Journal of Agriculture & Biology 6, 5-8.
15. Khodary, S. E. A., 2004: Effect of Salicylic Acid on the Growth, Photosynthesis and Carbohydrate Metabolism in Salt Stressed Maize Plants. International Journal of Agriculture & Biology 6, 5-8.
16. Krantev, A., R. Yordanova, T. Janda, G. Szalai and L. Popova, 2008: Treatment with salicylic acid decreases the effect of cadmium on photosynthesis in maize plants. Journal of Plant Physiology 165, 920-931.
17. Kumar, P., S. D. Dube and V. S. Chauhan, 1999: Effect of salicylic acid on growth, development and some biochemical aspects of soybean (Glycine max. merrill). lndian Journal of Plant Physiology 4, 327-330.
18. Kumar, P., S. D. Dube and V. S. Chauhan, 1999: Effect of salicylic acid on growth, development and some biochemical aspects of soybean (Glycine max. merrill). lndian Journal of Plant Physiology 4, 327-330.
19. Li Ma S. and C. M. Park, 2010: Modulation of reactive oxygen species by salicylic acid in Arabidopsis seed germination under high salinity. Plant Signal Behav 5, 1534-1536.
20. López-Delgado, H. A., D. R. Ruiz-Saénz, D. D. Ayala-Hernández and M. Aguilar-Camacho, 2021: Potato Virus Elimination as Short and Long-Term Effect of Salicylic Acid Is Mediated by Oxidative Stress and Induction of Tolerance to Thermotherapy or Cryotherapy. In: S. Hayat, H. Siddiqui and C. A. Damalas eds. Salicylic Acid - A Versatile Plant Growth Regulator. pp. 265-286.
21. Mateo, A., D. Funck, P. Muhlenbock, B. Kular, P. M. Mullineaux and S. Karpinski, 2006: Controlled levels of salicylic acid are required for optimal photosynthesis and redox homeostasis. Journal of Experimental Botany 57, 1795-1807
22. Morris, K., S. A. H. Mackerness, T. Page, C. F. John, A. M. Murphy, J. P. Carr and V. Buchanan-Wollaston, 2000: Salicylic acid has a role in regulating gene expression during leaf senescence. The Plant Journal 23, 677-685.
23. Ogawa, D., N. Nakajima, S. Seo, I. Mitsuhara, H. Kamada and Y. Ohashi, 2006: The phenylalanine pathway is the main route of salicylic acid biosynthesis in Tobacco mosaic virus-infected tobacco leaves. Plant Biotechnology 23, 395–398
24. Ohashi, Y., T. Murakami, I. Mitsuhara and S. Shigemi, 2004: Rapid Down and UpWard TransIOCation of Salicylic Acid in Tobacco Plants. Plant Biotechnology 21, 95-101.

25. Pancheva, T. V., L. P. Popova and A. N. Uzunova, 1996: Effects of salicylic acid on growth and photosynthesis in barley plants. Journal of Plant Physiology 149, 57-63.
26. Peng, Y. J., J. F. Yang, X. Li and Y. L. Zhang, 2021: Salicylic Acid: Biosynthesis and Signaling. In: S. S. Merchant ed. Annual Review of Plant Biology, Vol 72, 2021. Series; Annual Review of Plant Biology, pp. 761-791
27. Rivas-San Vicente, M. and J. Plasencia, 2011: Salicylic acid beyond defence: its role in plant growth and development. Journal of Experimental Botany 62, 3321-3338.
28. Salem, K. F. M., M. M. Saleh, F. F. B. Abu-Ellail, L. Aldahak and Y. A. Alkuddsi, 2021: The Role of Salicylic Acid in Crops to Tolerate Abiotic Stresses. In: S. Hayat, H. Siddiqui and C. A. Damalas eds. Salicylic Acid - A Versatile Plant Growth Regulator. pp. 93-152
29. Sami, K. F. M., M. M. Saleh, F. F. B. Abu-Ellail, L. Aldahak and Y. A. Alkuddsi, 2021: The Role of Salicylic Acid in Crops to Tolerate Abiotic Stresses. Salicylic Acid - A Versatile Plant Growth Regulator. pp. 93-152.
30. Shakirova, F. M., A. R. Sakhabutdinova, M. V. Bezrukova, R. A. Fatkhutdinova and D. R. Fatkhutdinova, 2003: Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. Plant Science 164, 317-322.
31. Sharma, M., S. K. Gupta, B. Majumder, V. K. Maurya, F. Deeba, A. Alam and V. Pandey, 2017: Salicylic acid mediated growth, physiological and proteomic responses in two wheat varieties under drought stress. Journal of Proteomics 163, 28-51.
32. Sharma, P., 2014: Salicylic Acid: A Novel Plant Growth Regulator - Role in Physiological Processes and Abiotic Stresses Under Changing Environments. In: N. Tuteja and S. S. Gill eds. Climate Change and Plant Abiotic Stress Tolerance. pp. 939-989. Wiley-VCH Verlag GmbH & Co. KGaA.
33. Siddiqui, H., A. R. Mir, F. Sami, K. B. M. Ahmed and S. Hayat, 2021: Biosynthetic Convergence of Salicylic Acid and Melatonin, and their Role in Plant Stress Tolerance. In: S. Hayat, H. Siddiqui and C. A. Damalas eds. Salicylic Acid - A Versatile Plant Growth Regulator. pp. 193-217
34. Szalai, G., M. Pál, T. Árendás and T. Janda, 2016: Priming seed with salicylic acid increases grain yield and modifies polyamine levels in maize. Cereal Research Communications 44, 537-548.
35. Tucuch-Haas, C. J., M. A. Dzib-Ek, S. Vergara-Yoisura and A. Larqué-Saavedra, 2021: Salicylic Acid Increases Root Size That Favours the Absorption and Accumulation of Macro and Micronutrients That Contribute to Biomass Production. In: S. Hayat, H. Siddiqui and C. A. Damalas eds. Salicylic Acid - A Versatile Plant Growth Regulator. pp. 17-33.
36. Yanng Y., C. Pan, Y. Du, D. Li and W. Liu, 2021: Exogenous salicylic acid regulates reactive oxygen species metabolism and ascorbate-glutathione cycle in Nitraria tangutorum Bobr. under salinity stress. Physiol Mol Biol Plants 24, 577-589.
37. Yao, R. and L. Popova, 2020: Effect of exogenous treatment with salicylic acid on photosynthetic activity and antioxidant capacity of chilled wheat plants. Gen. Appl. Plant Physiology 33, 155-170
38. Ziasmin, M. M. Islam, K. U. Ahmed, S. Islam and S. Parvin, 2017: Response of Wheat to Salicylic Acid. International Journal of Scientific and Research Publications 7, 738-742.