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Review article

EFFECT OF SALICYLIC ACID IN AGRICULTURE

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ABSTRACT

Salicylic acid, a naturally occurring plant hormone acting as an important signaling molecule adds to tolerance against abiotic stresses. It plays a vital role in plant growth, ion uptake and transport. Salicylic acid is also involved in endogenous signaling to trigger plant defense against pathogens. This positive effect of SA could be attributed to an increased CO2 assimilation and photosynthetic rate and increased mineral uptake by the stressed plant under SA treatment. The application of salicylic acid, acetylsalicylic acid or other analogues of SA, to leaves of corn and soybean accelerated their leaf area and dry mass production, but plant height and root length remained unaffected. SA reduced the Na uptake of plants and/or increased the uptake of N, P, K, Ca, Mg and the other minerals as compared to control treatment under salt stress.

INTRODUCTION

Plants tend to adapt to drought by accumulation of cyto-compatible organic osmolytes [53] such as polyols, proline and betaines. Seed treatment or foliar application of chemicals like glycinebetaine, kinetin, salicylic acid [25, 36] may increase yield of different crops due to reduction in stress induced inhibition of plant growth [19], enhanced photosynthetic rates, leaf area and plant dry matter production [40]. Salicylic acid, a naturally occurring plant hormone acting as an important signaling molecule adds to tolerance against abiotic stresses. It plays a vital role in plant growth, ion uptake and transport. Salicylic acid is also involved in endogenous signaling to trigger plant defense against pathogens [40]. Salicylic acid is an endogenous growth regulator of phenolic nature and acts as potential non-enzymatic antioxidant which participates in the regulation of many physiological processes in plants, such as stomatal closure, photosynthesis, ion uptake, inhibition of ethylene biosynthesis, transpiration and stress tolerance [3, 40]. Salicylic acid is a tool to increase plant tolerance against the adverse effect of biotic and abiotic stresses [13] either by foliar application or seed treatment. Since, it has a regulatory effect on activating biochemical pathways associated with tolerance mechanisms in plants [47]. The promotive effect of salicylic acid could be attributed to its bio regulator effects on physiological and biochemical processes in plants such as ion uptake, cell elongation, cell division, cell differentiation, sink/source regulation, enzymatic activities, protein synthesis and photosynthetic activity as well as increase the antioxidant capacity of plants [10, 18, 51]. SA is an effective inhibitor of ethylene biosynthesis, the effect being pH-dependent. Salicylic acid is a natural phenolic compound that involved in plant processes such as fruit maturity, senescence [66], rooting of poplar (*Populus alba* L. and P. *canescens Sm*) [11], grape (*Vitis vinifera* L.) [5] and olive (*Olea europaea* L.) [31] and resistance to abiotic stresses in carrot and tall fescue seedlings [20, 30]. This effect has been demonstrated with apple disks [53]. With 10 μM SA maximal inhibition (90%) was achieved in 3 hours. Results with applied SA to pear cell suspension cultures suggest that both compounds acted by blocking the conversion of 1-aminocyclopropane-1-carboxylic acid to ethylene [29]. Authors described SA as an effective, non-toxic and reversible inhibitor of ethylene biosynthesis at concentrations comparable to those found in some plant tissues. A survey of literature indicates that SA could affect antioxidant enzyme activities and then cause a moderate increase in the content of reactive oxygen species (ROS) such as hydrogen peroxide (H_2O_2) [2, 15, 28, 43], which acts as a second messenger in regulating plant defense responses [17, 29, 33].

In recent years, effects of SA on terpenoids secondary metabolism also have received attentions gradually. Ali et al. [2] and Shabani et al. [55] showed that SA induced the accumulation of triterpenoids, ginsenosides in ginseng and glycyrrhizin in licorice, respectively. Production of sesquiterpenoids, such as bilobalide in ginkgo [34], crepidiaside, deoxylactucin and sonchuside in chicory [44], and artemisinin in Artemisia annua [1, 50] could also be stimulated by SA.

Chlorophyll content

The increase in chlorophyll content with SA confirmed the reports of El-Tayeb [18] for barley, Gunes *et al* [25] for maize and Yildirim *et al*. [61] for cucumber. These results are in agreement with Moharekar *et al*. (2003) for wheat, Yildirim *et al*. (2008) for cucumber. Salicylic acid activated the synthesis of carotenoids, xanthophylls and the rate of de-epoxidation but decreased the level of chlorophyll pigments, both in wheat and moong plants also the ratio of chlorophyll a/b, in wheat plantlets [46]; SA also increased the chlorophyll and carotenoid content in maize plant [41]. Enhancing effect of SA on photosynthetic capacity can be attributed to its stimulatory effects on Rubisco activity and pigment contents. Sinha et al [57] pointed out that chlorophyll and carotenoid contents of maize leaves were increased upon treatement with SA by lead stress. The metabolic aspect of plants supplied with SA or its derivates shifted to a varied degree depending on the plant type and the mode of application of SA. The application of SA (20 mg/ml) to the foliage of the plants of Brassica napus, improved the chlorophyll contents [22].

Photosynthetic rate

This positive effect of SA could be attributed to an increased CO2 assimilation and photosynthetic rate and increased mineral uptake by the stressed plant under SA treatment [21, 40, 59]. In soybean plants, treatment with salicylic acid, increased pigments content as well as the rate of photosynthesis pointed out that chlorophyll and carotenoid contents of maize leaves were increased upon treatment with SA [57, 67]. This enhanced photosynthetic activity increased sap production in the leaf lamella which resulted in maintenance of relative water content in leaf and better growth. L-TRP it is an endogenous hormone which stimulates plant growth and is associated with increased amount of water content in the cell [29]. Similar findings have also been reported by other investigators [21, 62]. Foliar application of SA is also involved in stomatal regulation thereby controlling photosynthetic rate [40]. However, the beneficial effect of SA application depends on genotype [7]. Moreover, salicylic acid acts as one of antioxidant substances concentrated in the chloroplast and protect the photosynthetic apparatus when a plant is subjected to stress, by scavenging the excessively reactive oxygen species known as free radicals. Such effects might be due to protecting the endogenous anti-oxidant systems often correlated with increased resistance to oxidative stress and/or controlling the level of free radicals within plant tissues [58].

Leaf area and Plant height

The application of salicylic acid, acetylsalicylic acid or other analogues of SA, to leaves of corn and soybean accelerated their leaf area and dry mass production, but plant height and root length remained unaffected. However the leaves of corn and soybean applied with acetylsalicylic acid (ASA) or gentisic acid (GTA) exhibited no change in their chlorophyll contents [40]. The promoting effect of SA on the leaf area was attributed to its important roles on activating cell division and the biosynthesis of organic foods. In addition, Raskin [51] mentioned that enhancing effect of SA on the availability and movement of nutrients could result in stimulating different nutrients in the leaves. Foliar application of salicylic acid increased the leaf area of sugarcane [68].

Leaf Relative Water Content (LRWC)

Increases in LRWC of strawberry plants treated with SA were also reported for other crops grown under salt stress including barley [18], tomato and cucumber [62]. This phenomenon may be attributed to the fact that foliar SA application can increase the leaf diffusive resistance and lower Tran [59, 60] spiration rates.

Membrane functions and antioxidant responses

These results of Yildirim [62] for cucumber, who determined that SA facilitated the maintenance membrane functions. This facilitation could be attributed to the induction of antioxidant responses and elevated Ca uptake that protects the plant from the oxidative damage by SA [18]. Application of SA increases the accumulation of Ca^{+2} which can maintain membrane integrity [39].

Minerals

SA reduced the Na uptake of plants and/or increased the uptake of N, P, K, Ca, Mg and the other minerals as compared to control treatment under salt stress. The reports of El-Tayeb [18] for barley, Gunes et al. [25] for maize, Szepsi et al., [59] for tomato and Yildirim et al. [62] for cucumber. Application of 100 ppm SA to the plants subjected to drought may help maintain higher leaf K and avoiding drought induced damage to photosynthesis. These results are in line with many other researchers who reported an increased amount of almost all elements in roots and shoot with application of SA and L-TRP [36, 64].

Physiological processes

Salicylic Acid (SA) is a growth regulator which participates in the regulation of physiological processes in plants. It stimulates flowering in a range of plants, increases flower life, controls ion uptake by roots and stomatal conductivity [9]. Previous studies have demonstrated that a wide range of responses might appear after exogenous SA application as follows: height plant increases, fruit weight and fruits per plant [18, 41]. Application of SA also significantly increased dry weights of root and top part of barley and soybeans [26]. The mechanism of salicylic acid was reported by Oata [48] and Pieterse and Muller [49] who concluded that salicylic acid induced flowering by acting as a chelating agent. This view was supported by Raskin et al., [52] who confirmed that salicylic acid functioned as endogenous growth regulators of flowering and florigenic effects. It is well known that salicylic acid induces flowering, increases flower life, retard senescence and increases cell metabolic rate. In addition, salicylic acid may be a prerequisite for synthesis of auxin and /or cytokinin [23, 45]. Flowering is another important parameter that is directly related to yield and productivity of plants. Salicylic acid has been reported to induce flowering in a number of plants. Different plant species including ornamental plant Sinningia speciosa flowered much earlier as compared to the untreated control, when they received an exogenous foliar spray of salicylic acid [13] In cucumber and tomato, the fruit yield enhanced significantly when the plants were sprayed with lower concentrations of salicylic acid [4]. It was reported that the foliar application of salicylic acid to soybean also enhanced the flowering and pod formation [42].

Total flavonoids (TF), Total soluble solid (TSS) and Titratable acidity (TA)

It was reported that the foliar application of salicylic acid on soybean also enhanced the flowering and pod formation [42]. Sayyari et al., [54] has shown that the amount of acidity and TSS was influenced by SA treatment in pomegranate. Chandra et al., [14] reported that application of salicylic acid increased total soluble sugar and soluble protein of cowpea plants. Vitamin C, pH, TSS and titratable acidity (TA) of fruits treated with higher 5-SSA concentrations was higher than those of control fruits. It has been suggested that TA decreases in fruits in result of breakup of acids to sugars during respiration [4]. Han and Li [27] have also reported that apple fruits treated with SA had increased TA content at the end of storage. Our results showed that SA had significant effect on maintaining higher content of vitamin C in peach fruits. Kazemi et al., [37] have also reported that fruits treated with SA were observed with maximum vitamin C content. Ghasemnezhad et al., [24] reported that the decrease of total phenolic levels might be due to breakdown of cell structure in order to senescence phenomena during the storage period. SA application might activate the metabolic consumption of soluble sugars to form new cell constituents as a mechanism to stimulate the growth of sunflower plants. Moreover, SA treatment might also be assumed to inhibit polysaccharide-hydrolyzing enzyme system on one hand and/or accelerate the incorporation of soluble sugars into polysaccharides. Our assumption could be supported by the result that SA increased polysaccharide level on the sake of soluble sugars and activate the consumption of soluble sugar metabolism by increasing osmotic pressure [65]. Chandra et al. [14] reported that application of salicylic acid increased total soluble sugar and soluble protein of cowpea plants.

Salicylic acid and abiotic stress

SA treatment ameliorates the impact of abiotic stress through improving antioxidant system necessary to reduce oxidative damage and ion leakage from membranes [63]. The soaking of wheat (*Triticum aestivum* L.) seeds in 0.05m SA also reduced the damaging effects of salinity on seedlings growth and accelerated the growth processes [56]. Salicylic acid pre-treatment also provided protection against salinity in tomato plants, probably due to the increased activation of aldose reductase and apx enzymes and the accumulation of osmolytes, such as sugar, sugar alcohol or proline [59, 60]. Soaking seed with salicylic acid have been shown to enhance stand establishment in non-saline areas [38] and have potential in saline areas as well [6]. Salicylic acid as anti-stress substance may enhance the plant tolerance to environmental stresses [58]. The mode of action of salicylic acid is not fully understood, but it apparently interferes with the control of cellular oxidation. Janda et al., [32] reported that treating maize plants with SA induced the production of antioxidant enzymes, which increase chilling and salt tolerance. It is now clear that SA provides protection against a number of abiotic stresses such as heat stress in mustard seedlings [16], chilling damage in different plants [35], heavy metal stress in barley seedlings [45] and drought stress in wheat plants [7]. SA potentiated the generation of reactive oxygen species (ROS) in photosynthetic tissues of Arabidopsis during osmotic stress, thus participating in the development of stress symptoms. It has been shown that SA alleviates the adverse effect of salinity by increasing growth hormones such as IAA and cytokinins [56], reducing the uptake and accumulation of toxic ions and maintaining the cellular membrane integrity [12].

MATHERIALS AND METHODS

This paper is a review of the literature search on ISI, Scopus and the Information Center of Jahad and MAGIRAN and SID is also abundant. Search library collection of books, reports, proceedings of the Congress was also performed. All efforts have been made to review articles and abstracts related to internal and external validity.

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