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Role of salicylic acid (SA) in plants – A review

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Abstract
The aim of the present investigation was to determine the effect of exogenously application of salicylic acid (SA) in plants. Salicylic acid (SA) act as a potential non-enzymative antioxidant as much as plant growth regulator, playing an important role in regulating a number of plant physiological processes. SA has been identified as a signaling component in numerous plant responses to stress, including UV-B, exposure to ozone and pathogen attack. SA is also involved in activation of the stress induced antioxidant system stimulates flowering in many plants, increase flower life, control ion uptake by roots and stomatal conductivity.

Keywords: Salicylic acid, non-enzymative antioxidant, plant physiological processes

Introduction
Plants are one of the world's richest sources of natural medicines. The use of plants and plant extracts for healing dates back to earliest recorded history. Today plant-derived medicines such as quinine, digitalis, opiates and morphine are widely used, while new natural chemicals such as putatine anti-cancer drug taxol from yew tree bark are being characterized and developed.

Salicylic acid (SA) act as a potential non-enzymative antioxidant as much as plant growth regulator, playing an important role in regulating a number of plant physiological processes (Fariduddin *et al*., 2003; Raskin, 1992) [22, 40]. SA influences the taxol production and isopentenyl pyrophosphate biosynthesis pathways in suspension culture of *Taxus chinnensis* cultures. SA influenced not only biomass but high taxol production also.

The uptake of SA by *Arabidopsis* suspension cultures is driven by proton gradient and extent to which SA accumulates within the cells is dependent upon the (H^+) gradient across the plasma membrane. Substantial evidence that salicylic acid negatively regulates the jasmonate dependent pathway in many plants was shown including *Arabidopsis*.

Present investigation was aimed to evaluate the role of Salicylic acid in plant growth and developments

Salicylic acid in plants
SA is one of numerous phenolic compounds, containing an aromatic ring with a hydroxyl group or its derivatives, found in plants. There has been considerable speculation that phenolies in general function as plant growth regulators (Aberg, 1981) [1]. Exogenously supplied SA was shown to affect a large variety of processes in plants, including stomatal closure, seed germination, fruit yield and glycolysis (Cutt *et al*., 1992) [14]. However, some of these effects were also produced by other phenolic compounds. In addition, some effects of SA may have been caused by the general chemical properties of SA (Raskin, 1992) [40]. Only recently has there been evidence that SA has unique and specific regulatory roles.

Salicylic acid is water soluble antioxidant compound which can also regulate plant growth. It also has a role in abiotic stress tolerance such as, drought tolerance in wheat.

Responses of SA (Salicylic acid) in Plants
Salicylic acid applied on basil and mayoram stimulated the growth and oil yield by enhancing photosynthesis and nutrient uptake. Basil may be a new source of antioxidant phenolics in the diet due to the greater production of eugenol by SA. Salicylic acid treatment enhanced total free aminoacids, prolines, spermidine as well as total polyamines (Fatma Abd E1-Lateef Gharib, 2006) [24].

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In the case of exogenous application of growth regulators, IAA had better rooting effect than IBA in *Pelargonum graveolens* (Kumar *et al*., 1982) [31]. Significant increase in length and width of rhizome, number of rhizome bits and yield of fresh rhizome was observed at 200 ppm of ethrol in ginger (Phogat and Singh, 1987) [39]. Application of GA_3 and KNO_3 promoted the generation of tobacco seeds kept in darkness (Sharma and Phukan, 1981) [48]. NAA at a concentration of 50 ppm was found to be the most effective in improving bulb size, bulb weight and number of cloves per bulb in garlic (Das *et al*., 1996) [15].

Application of growth hormones in crops
The effects of hormones (GA_3 kinetin and IAA) during seed development on the vigour of subsequently formed seeds have been studied in *Pisum sativum* (T 163) and *Vicia faba*. Seeds from hormonal treated pods exhibited enhancement of seedling growth. Number of hormones applied is generally paralleled by the extent of growth enhancement except in *vicia* in which just one application of hormone was found to be sufficient for maximum epicotyl growth. The maximum effective hormone was found to be GA_3 followed by kinetin. IAA on the other hand was found to be least effective (Chhaya Sharma, 1982) [11].

Polyamines (PA) have been implicated in adventitious root formation under *in vitro* and *in vivo* conditions. There is great deal of controversy regarding the exact role played by PAs in adventitious root formation at the base of stem cuttings and its relationship with auxin (Friedman *et al*., 1982; Sankhla and Upadhyaya, 1988) [25, 46]. Application of growth substance like kinetin, triacontanol and GA_3, after 10 days of flowering delayed leaf senescence in rice and eventually increased the panicle weight per tiller (Debata and Murthy, 1981) [17]. Numerous attempts have been made to stimulate the growth and production of crop plants by resorting to the treatment of growth substance adopting different methods, such as, spraying or injecting into the leaves, addition to the soil and preserving seed treatment. The beneficial effects on yield in cereals and other crops have generally been explained on grain yield (Bharadwaj and Rao, 1956) [3]. Exogenous application of auxin (IAA) during growth leads to the enhancement of grain yield in *Triticum aestivum* (Dua and Bharadwaj, 1979) [19]. Brassinosteroid caused significant increase in nitrate reductase activity followed by triacontanol in wheat (Sairam, 1994) [45].

Harper and Balke (1981) [27] found that SA inhibited K^+ absorption in excised oat root tissue. The degree of inhibition was both concentration and pH-dependent. With decreasing pH, the inhibitory effect of SA increased, suggesting hat the protonated form of SA was more active than its charged form. The absorption of SA was also pH dependent. Under proper conditions of pH and concentration, SA could significantly affect mineral absorption by plants in the field (Harper and Balke, 1981) [27]. Reported that SA applied exogenously to barely and oat roots inhibited potassium absorption in a pH and concentration-dependent manner.

SA caused the collapse of the transmembrane electrochemical potential of mitochondria and the ATP-dependent proton gradient of tonoplast-enriched vesicles (Macri *et al*., 1986) [35]. It was found that SA produced in the rhizoshere of some plants played the role of an allelopathic chemical and inhibited the growth of the surrounding plants (Schettel and Balke, 1983) [47]. SA increased the activity of total respiration and the cyanide-resistant pathway in tobacco leaves, leading to an elevation in surface temperature (Van der straeten *et al*., 1995) [53]. The levels of SA increased during heat production of five aroid species and in male cones of four thermogenic cycads (Raskin *et al*., 1990) [42].

Raskin *et al*. (1987) [41] showed that SA was a calorigen and functioned as an endogenous regulator of heat production. It was also shown that both calorigen extract and SA caused the induction of the Alternative Oxidase (AO) gene and the alternative oxidase protein with molecular mass of 38.9 kDa was isolated and characterized (Elthon and Mclntosh, 1987) [21]. The effects of SA on the alternative pathway respiration in slices and isolated mitochondria of dormant and dormancy-breaking potato tubers was compared (Wen and Liang, 1994) [54]. It was found that treatment with 20 μM SA increased the capacity of cyanide-resistant respiration in both model systems. The involvement of the alternative pathway was enhanced by SA to a greater extent in dormancy-breaking potato tubers.

Applying SA to oilseed rape plants increased the concentration of glucosinolates in their leaves. Gluconinolates are a group of thioglucosides found in cruciferous plants. When tissues are damaged, glucosinolates are hydrolysed and release various products which are thought to contribute to the plant's defence against microorganisms and pests. Kiddle *et al*. (1994) [30] demonstrated an increase in secondary metabolite content in response to SA.

SA is an important mediator of the plant defence response to pathogens. The first evidence for this role of SA resulted from the application of an aspirin solution to tobacco leaves (White, 1979) [55]. SA response revealed the appearance of an SA-binding protein, identified as catalase, an H_2O_2-degrading enzyme (Chen and Klessing, 1991) [8]. It was found that 3 hours after treatment of tobacco leaves with 1 mM SA, the amount of H_2O_2 in the leaves had increased, and the levels continued to rise over the 24-h test period. Direct treatment of leaves with H_2O_2 induced PR-la gene expression, which makes possible the suggestion that the pathway from pathogen infection to SA accumulation and to PR gene induction could involve the signal of peroxide accumulation. Several chemical signals have been identified in plant leaves that regulate the response such as oligosaccharides (Bishop *et al*., 1984) [4] or plant growth regulators (Farmer and Ryan, 1992) [23]. Doares *et al*. (1995) [18] indicate that SA inhibited the octadenoid pathway that regulates defence signaling in response to predator attacks. The inhibition of synthesis of proteinase inhibitor synthesis and mRNAs by SA occurs at a step in the signal transduction pathway, after JA synthesis but preceding transcription of the inhibitor genes.

Ray *et al*. (1986) [43] showed that SA antagonized the ABA-induced stomatal closure of *Commelina* epidermal strips. Stomatal behaviour and regulation is a very important factor for photosynthetic ability. Short-term treatment with SA did not affect either the rate of photosynthesis or the capacity of biochemical machinery as compared to untreated control plants. Raskin (1992) [40] reported that the effects of SA in plants are also associated with reduction of disease symptoms.

Jeyakumar *et al*. (2008) [28] reported that application of salicylic acid (125 ppm) increased the dry matter production

as well as seed yield in black gram. and foliar application of SA (100 ppm) on baby corn increased the plant height, leaf area, crop growth rate and told dry matter production. Obvious effects on yield of various crop species have been achieved following exogenous application of salicylic acid an increase in yield and number of pods has been observed in mung bean (Singh & Kaur, 1981) [49].

Different levels of acetyl salicylic acid appeared to function as anti transprint in leaves of *Phaseolus vulgaris* and inhibiting the opening of stomata in epidermal strips of *Commelina communis*. SA was observed to reverse the closure of stomata caused by ABA (Ray *et al*., 1986) [43].

Interfering with membrane depolarization stimulating photosynthetic machinery, increasing the content of chlorophylls as well as blocking wound response in soybeans (Lesile and Romani, 1988; Zhao *et al*., 1995) [34, 56]. The ameliorative effects of SA have been well documented in inducing salt tolerance in many crops (EI-Tayeb, 2005) [20].

Exogenous application of SA induced salt tolerance and water stress tolerance in wheat. Tomato plants raised from the seeds soaked in SA enhanced activation of some enzymes aldose, reductase and ascorbate peroxidase and accumulation of certain osmolites, such as proline.

Exogenous application of SA enhanced the photosynthetic rate and also maintained the stability of membrances, thereby improving the growth of SA stressed barley plants (EI Tayeb, 2005) [20]. SA was observed to reduce leaf area (secondary leaf), root growth, as much as protein and chlorophyll (*a* + *b*) amount parallel to an increase in its concentration in barley plants which were developed from barley seeds germinated in SA solutions (Pancheva *et al*., 1996) [38]. Khan *et al*. (2003) [29] found that spraying ASA (10^{-5} M) on the leaves led to an increase in the overall photosynthetic yield of soybean and corn.

Canakci (2003) [6] reported in a study involving detached leaves from 1 month old bean seedlings that chlorophyll *a* and *b* quantity decreased whereas carotenoid amount remained unaffected. Both fresh weight loss and protein destruction increased parallel to the increase in ASA concentration. Singh *et al*., (2010) [50] showed positive correlation between chlorophyll content and total nitrogen in cucumber cotyledons. Moreover, increase in nitrogen content and chlorophyll content at lower concentration of SA indicates that it plays a regulatory role during the biosynthesis of active photosynthetic pigments.

Phytohormones play an essential role in regulating plant growth and development. Application of growth regulators to restrict the harshly effect of salinity was reported.

Salicylic acid signal molecules in plants
SA has been shown as an important signal molecule for modulating plant responds to environmental stress (Breusegem *et al*., 2001; Rowshan *et al*., 2010) [5, 44]. Salicylic acid is an important signal molecule known to have diverse effect on biotic stress tolerance (Raskin *et al*., 1992; Bergman *et al*., 1994) [40, 2]. Exogenous application of SA may participate in the regulation of physiological processes in plants, such as, stomatal closure, ion uptake and transport in maize (Gunes and Alpasalan *et al*., 2005) [26].

SA induced flowering
The role of SA as an endogenous signaling molecule in flowering was suggested by Cleland *et al*. (1974) [13] found

that honeydew from aphids feeding on *Xanthium strumarium* contained an activity that induced flowering in duck weed (*Lemna gibba*) grown under a non- photo-inductive light cycle. The flower inducing factor could be extracted directly from the *Xantium phloem* and was identified as SA. This was consistant with reports that exogenously applied SA was active in inducing flowering in organogenic tobacco tissue culture (Lee *et al*., 1965) [32].

SA metabolism
Have shown that SA is predominantly synthesized from benzoic acid (BA). The enzyme activity responsible for converting BA to SA, A 2-hydroxylase was induced four-to five-fold upon TMV infection (Leon *et al*., 1993) [33]. BA treatment of tobacco plants also indued BA 2-hydroxylase activity. The results together with the magnitude and timing of BA increase in TMV-infected plants, suggesting an increased BA 2-hydroxylase activity. Thus the rate-limiting step in SA production may be the formation of BA. The glucoside was formed from exogenously supplied radiolabelled SA, within four hours of application.

Mechanism of action of SA
SA is a hormone, particularly in light of the conflicting data concerning its translocation it seems likely that identification of a cellular factors, which directly interacts with SA might shed light on SA's mode of action. This could be a receptor which perceives and transduces the SA signal or a SA regulated cellular target such as an enzyme whose activity is altered by SA binding. Chen *et al*. (1993) [10] have identified and characterized a soluble SA-binding protein (SABP) from tobacco which fits both descriptions of the factor.

The SABP is a 240 - 280 KDa complex which appears to be composed of four 51 kDa subunits. It has a binding affinity for SA which is consistent of SA observed during the induction of defense responses. Only those analogues of SA which are biologically active in the induction of PR genes and disease resistance (eg. acetyl salicylic acid and 2,6-dihydroxybenzoic acid) effectively compete with SA for binding. Inactive analogues, though structurally very similar, are not bound by the SABP (Chen and Klessing, 1991; Chen *et al*., 1993) [8].

Systemic induction of salicylic acid
Recently demonstrated that systemic resistance can be induced in cucumber within 24 h by inoculating leaf with the HR^2-inducing bacterium *Pseudomonas syringae* PV Syringal. Allowing the first leaf to remain on the plant for up to 12 h after inoculation with bacterium resulted in a further increase in the level of systemic resistance as compared to plants that were inoculated and examined after 6 h.

Dean and Kue (1986) [16] provided strong evidence that the systemic signal for induced resistance was generated and mobilized out of the leaves that were initially inoculated with resistance-inducing pathogens. Metraux *et al*. (1990) [36] reported that cucumber plants inoculated with either *Collectotrichum lagenarium* or *Tobacco necrosis* virus on one leaf had higher levels of salicylic acid (Mills and Wood, 1984) [37] and tobacco (While, 1979) [55] in phloem exudates just prior to the expression of induced resistance. Since inoculation with *Pseudmonas syringae* induces resistance in cucumber more rapidly than *C. lagenarium* or *Tobacco*

necrosis virus, it is possible that the time course and production of systemic signals can be monitored more precisely after inoculation with this bacterium.

Conclusion
Salicylic acid which is a secondary plant product performs important actions in the growth and development processes of plant. It is a potent signaling molecule in plants and is involved in eliciting responses to biotic and abiotic stress. Salicylic acid has been studied as the phytohormone, mediating several responses in plants. Among the responses, signaling, pathogen resistance are worth-mentioning. Thus SA behaves as a typical phytohormone for plants.

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