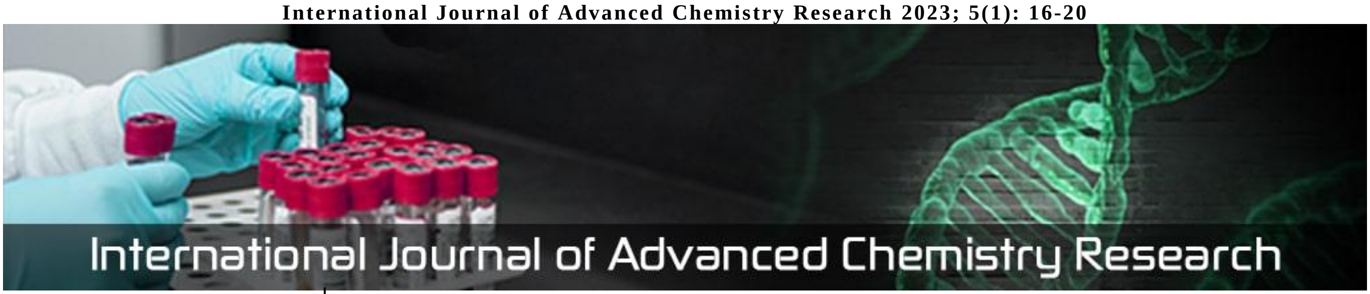
International Journal of Advanced Chemistry Research 2023; 5(1): 16-20




**ISSN Print:** 2664-6781
**ISSN Online:** 2664-679X
IJACR 2023; 5(1): 16-20
www.chemistryjournals.net
Received: 25-10-2022
Accepted: 27-12-2022

**Neeraj Nath Parihar**
Ph.D. Research Scholar, Seed Science and Technology, MPKV, Rahuri, Maharashtra, India

**Dr. VR Shelar**
Seed Research Officer, STRU, MPKV, Rahuri, Maharashtra, India

**Corresponding Author:**
**Neeraj Nath Parihar**
Ph.D. Research Scholar, Seed Science and Technology, MPKV, Rahuri, Maharashtra, India

# Miracle molecule: Salicylic acid

**Neeraj Nath Parihar and VR Shelar**

**DOI:** https://doi.org/10.33545/26646781.2023.v5.i1a.138

**Abstract**
Salicylic acid, a naturally occurring plant hormone acting as an important signalling 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 signalling to trigger plant defense against pathogens. This positive effect of SA could be attributed to an increased $CO_2$ 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 plants 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. Salicylic acid (SA) plays many roles in plant physiology. Besides pathogenesis-related resistance, SA is involved in the response to abiotic stress. However, the effects of SA on plant resistance to abiotic stress were found in contra dictionary, and the actual role of SA in abiotic stress remains unresolved. Generally, a deficiency of SA or a very high level of SA increases the plant susceptibility to abiotic stress. The optimal levels for the highest stress tolerance range from 0.1 mm to 0.5 mm for most plants. But the role of SA at a certain level in moderate and severe abiotic stress may be different. This can be attributed to redox regulations in plant cells. In this paper, we discuss the relationship between reactive oxygen species (ROS) and SA, and propose a subsequent intracellular signal transduction network of SA and ROS under abiotic stress. Anti-stress substances besides antioxidant enzymes induced by SA are also summarized.

**Keywords:** Salicylic acid (SA), Miracle molecule, Salicylic acid, reactive oxygen species (ROS)

## Introduction
Salicylic acid (SA) is a common plant-produced phenolic compound. Compounds in this group can function as plant growth regulators (Arberg 1981) [5]. Exogenous application of SA may influence a range of diverse processes in plants, including stomatal closure (Larque-Saaverda 1979) [40], ion uptake and transport (Harper and Balke 1981) [28], ethylene synthesis (Leslie and Romani 1986) [42], seed germination, fruit yield, glycolysis (Cutt and Klessig 1992) [12] and the growth-inhibitory effect of abscisic acid (ABA) (Rai *et al.* 1986) [47]. SA is also involved in induction of an alternative respiratory pathway (Ethlon *et al.* 1989) [18] and expression of a nuclear gene encoding the alter.

## Miracle effects of salicylic acid
SA is involved in induction of an alternative respiratory pathway (Ethlon *et al.* 1989) [18] and expression of a nuclear gene encoding the alternative oxidase protein in Suaromantum gut Tatum (Rhoads and McIntosh 1991) [52]. Salicylic acid has been shown to play a role in plant thermogenicity (Raskin *et al.* 1987) [50]. It has also been shown that SA may play a part in the flowering of cocklebur plants, since its concentration increased in the phloem when they were induced to flower by manipulating day length (Cleland and Ajami 1974) [11]. Acetylsalicylic acid (ASA, 2-acetyloxy-benzoic acid; an artificial analogue of SA) and resorcylic acid (2, 6 dihydroxy benzoic acid) have shown thermo genic activity comparable to SA (Raskin *et al.* 1989) [51]. Flowering in these plants can also be stimulated by benzoic acid (Raskin 1992) [49]. The involvement of SA in the induction of systemic acquired resistance (SAR) is a topic of intense research (Sticher *et al.* 1997) [63]. ASA has been used in preference to SA in in vitro germplasm programs, as a component of culture media, in order to retard growth and induce tuberization or shoot organogenesis in potato micro plants (Lopez-Delgado and Carrillo Castaneda 1996) [43].

Gentisic acid (GTA, 2, 5-dihydroxybenzoic acid) occurs in a wide range of plant species (Griffith 1959) [24] and has been demonstrated to have antifungal activity in vitro. Benzoic acid and SA are normally converted into gentisic acid, where SA is the immediate precursor of GTA (Belles, *et al.*1999) [8].

Under pathogen attack conditions the metabolism of phenolic compounds and the functioning of the photosynthetic apparatus play key roles (Prokharchik and Marshakova 1985) [46]. Previous experiments conducted in our laboratory have shown that the chronic injection (Zhou and Smith 1996) [70] of SA (10-2 mol/L from shortly after tasseling until physiological maturity) increases the photosynthetic rate of corn plants (Zhou *et al.* 1999) [69].

Plants are the major source of reduced carbon compounds directly or indirectly used by all animals and thus any possible increase in the photosynthetic activity will be beneficial and requires particular attention, especially if it can be enhanced by the simple application of exogenous chemicals. The known effects of SA on stomatal function, chlorophyll content, transpiration rate, and respiratory pathways indicate that SA and related phenolic compounds may be involved in the regulation of some photosynthetic reactions. The objective of this work was to test the possibility that the exogenous foliar application of SA and related phenolic compounds affect metabolic processes related to gas exchange and growth by plants. We investigated the effects of exogenous application of SA and related compounds on net photosynthetic rate, stomatal conductance, and transpiration rate in two diverse crop plants, corn ($C_4$) and soybean ($C_3$), following exogenous application of salicylic acid and related compounds. Plant growth regulators can improve the physiological efficiency including photosynthetic ability and thereby helping in effective flower formation, fruit and seed development, and ultimately enhance productivity of the crops (Solamani *et al.* 2001) [61].

Foliar feeding of plants can effectively supplement soil fertilization. It has been found that element foliar application is more influential compared to soil application (Kazemi 2013) [35].

Salicylic acid (SA) is an endogenous plant growth of phenolic nature that possesses an aromatic ring with a hydroxyl group or its hormone plays a vital role in plant growth, ion uptake, and transport (Hayat *et al.* 2010) [22]. Enhanced germination and seedling growth were recorded in wheat when the grains were subjected to pre-sowing seed-soaking treatment in salicylic acid (Shakirova 2007) [58]. In cucumber and tomato, the fruit yield enhanced significantly when the plants were sprayed with lower concentrations of salicylic acid (Larque-Saavedra and Martin-Mex 2007) [38].

Salicylic acid was also found to enhance the activities of antioxidant enzymes such as peroxidase (POD), super oxidase dismutase (SOD), and catalase (CAT), when sprayed exogenously to the drought-stressed plants of tomato (Hayat *et al.* 2008) [29] or to the salinity stressed plants (Szepesi *et al.* 2008; Yusuf *et al.* 2008) [64, 68]. The exogenous SA application also enhanced the growth and photosynthetic rate in wheat (Hussein *et al.* 2007) [34] under water stress. However, numerous studies have demonstrated that the effect of exogenous SA depends on various factors, including the species and developmental stage, the mode of application and the concentration of SA used (Vanacker *et al.* 2001; Horvth *et al.* 2007) [66, 32].

Fariduddin *et al.* (2003) [19] also reported that the dry matter accumulation was significantly increased in *Brassica juncea*, when lower concentrations of salicylic acid were sprayed. However, higher concentrations of salicylic acid had an inhibitory effect. Khodary (2004) [37] observed a significant increase in growth characteristic, pigment contents, and photosynthetic rate in maize, sprayed with salicylic acid. Eraslan *et al.*, (2007) [17] also reported that exogenous application of salicylic acid, enhanced growth, physiological process, and antioxidant activity of carrot plants grown under salinity stress.

Soybean (*Glycine max* (L.) Merrill) is an important grain legume due to its high protein (35%), oil content (21%), and nitrogen-fixing ability (17-24 kg/ha/yr.). Increasing plant productivity is one the main targets in Indian Agricultural policy, which could be achieved through fertilization and plant growth regulators. However, very little is known about the effect of SA applied to foliage on plant growth and development and especially about the effect of SA on influencing the activities of antioxidative enzymes at different growth stages. Keeping in view the diverse physiological roles played by SA, the present research was undertaken to improve our understanding of the effect of the various concentrations of SA applied as foliar spray on the pigment and protein content, lipid peroxidation, and activities of antioxidative enzymes in soybean at different growth stages.

Exogenous application of plant growth regulators is considered effective technique for improving the plant productivity. Salicylic acid has been found to induce significant effects on various biological aspects in plants. Our results state that SA have stimulatory effects on the vegetative growth parameters of the Soybean plant. Application of SA leads to increase in a number of branching and leaves per plant along with increase in the dry weight also. Regarding foliar application of SA, obtained results are similar to those described by Salarizdah *et al.* (2012) [55] on canola,

Dawood *et al.* (2012) [13] on sunflowers and Ali and Mahmoud (2012) [3] on mungbean. In the present study, SA showed elevated effects and leads to a manifold increase in the level of biochemical and antioxidant enzymes. The chlorophyll content of Soybean leaves was increased due to foliar application of SA (Khan *et al.* 2003) [36]. Lower SA concentration was generally more effective in enhancing photosynthetic rate and biochemical parameters. Application of lower concentration of SA might leads to synthesis of more carbohydrates in treated plants. Chlorophyll pigments play a key role in light capturing for photosynthesis whose content forced a direct impact on the intensity of photosynthesis. The stimulatory effects of SA are in agreement with those of Barakat (2011) [7] on wheat and Saeidnejad *et al.* (2012) [54] on maize. However, a declined in chlorophyll content under influence of SA in certain crops like *Vigna mungo* has been reported by Anandhi and Ramanujam, (1997) [4].

The reduction of total chlorophyll content occurs due to increased in activity of the enzyme chlrophyllase. The Role of SA deficiency is associated with reduced damage to the photosynthetic apparatus as well as chlorophyll level. MDA content was estimated to determinate the extent of lipid peroxidation. The data showed that increased level of MDA

content was achieved from 45 to 60 DAS over that of control. It has been postulated that low level of the induced leakiness of membrane is caused by lipid peroxidation resulting from uncontrolled ROS increase (Rodriques-Rosales *et al.* 1999) [53].
Delvari *et al.* (2010) [14] showed that pre-treatment will decrease the level of lipid peroxidation induced by oxidative stress in basil plants. Agarwal *et al.* (2005) [2] also showed that SA treatment of wheat leaves under water stress conditions resulted in less production of MDA. So, the lipid peroxidation induced by drought stress was ameliorated by SA treatments. Antioxidant enzymes of soybeans were increased in response to different concentrations of SA. Oxidative stress generated in the plants can be removed with the help of antioxidative enzymes. It was found that application of low concentration of SA increased the activity of antioxidant enzymes like CAT, APOX, GPOX, and SOD. This increase in the activity of antioxidant enzymes might be due to the regulatory role of SA at the level of transcription/Translation. Foliar spray of SA to soybean plants leads to a significant increase in SOD and CAT activity. Among the enzymes measured here, CAT and SOD are most effective in preventing cellular damage by converting superoxide anion to $H_2O_2$ and $H_2O_2$ to $H_2O$ (Scan-Dalios 1993) [57]. It was found that increased SOD activity was accompanied by an increase in CAT and POD because of high demands of $H_2O_2$ quenching. It was cleared that increment in SOD and POD simultaneously affect each other. First line of defense was provided by SOD against the cellular due to environmental stress along with its major superoxide scavenger. Catalase seems to be a key enzyme in SA-induced stress tolerance.
Tenhakan and Rubel (1998) [65] and Rao *et al.* (1999) [48] have reported that SA caused hypersensitive reactions or enhanced $H_2O_2$ produced leading to cell death was not associated with the inhibition of these $H_2O_2$ scavenging enzymes, similarly, there was no inhibition of GPOX activity by SA thus confirming the results reported by Durner and Klessing (1995) [15]. So these antioxidant enzymes protect plant cell from oxidative damage by being scavenging of ROS. So from the above discussion, it was observed that foliar application of SA increased antioxidant enzymes activity (SOD, GPOX, CAT) which was further related to a decrease in oxidative stress ($H_2O_2$). From the above results, it was observed that foliar feeding of soybean (*Glycine max* L. Merrill) varieties Pusa-9612 with SA at lower concentration can stimulate the growth through increasing in the activities of antioxidant enzymes, preventing protein loss and enhancing photosynthetic pigment thereby increasing overall growth parameter of the plant. Thus SA at 10-6 M concentration can positively affect the growth of the Soybean plant as compared to 10-5 or 10-4 M application.

## Conclusion

Salicylic Acid (SA) is a vital phenolic compound in plants, influencing numerous physiological processes. Our study demonstrates that the exogenous application of SA significantly enhances growth parameters, including branching, leaf count, and dry weight in soybean plants. Lower concentrations of SA improve photosynthetic rate, biochemical parameters, and antioxidant enzyme activities. These findings suggest that foliar feeding with SA, particularly at lower concentrations, can boost plant productivity by enhancing physiological efficiency and mitigating oxidative stress. Thus, SA application emerges as a promising strategy for improving crop yield and resilience under various stress conditions.

## References

1. Aebi H. Catalase *in vitro*. Methods in Enzymology. 1984;105:121-126.
2. Agarwal S, Sairam RK, Srivastava GC, Meena RC. Changes in antioxidant enzymes activity and oxidative stress by abscisic acid and salicylic acid in wheat genotypes. Biologia Plantarum. 2005 Dec;49(4):541-550.
3. Ali EA, Mahmoud Adil M. Effect of foliar spray by different salicylic acid and zinc concentrations on seed yield and yield component of mungbean in sandy soils. Asian Journal of Crop Science. 2012;5(1):33-40.
4. Anandhi S, Ramanujam MP. Effect of salicylic acid on black gram (*Vigna mungo*) cultivars. Indian Journal of Plant Physiology. 1997;2(2):178-181.
5. Arberg B. Plant growth regulators. XLI. Mono-substituted benzoic acid. Swedish Agricultural Research. 1981;11:93-105.
6. Arnon DI. Copper enzymes in isolated chloroplasts: polyphenol oxidase in *Beta vulgaris*. Journal of Plant Physiology. 1949 Jan;24(1):115.
7. Barakat Nasser AM. Oxidative stress markers and antioxidant potential of wheat treated with phytohormones under salinity stress. Journal of Stress Physiology and Biochemistry. 2011;7(4):250-267.
8. Belles JM, Garro R, Fayos J, Pilar N, Primo J, Conejero V. Gentisic acid as a pathogen-inducible signal, additional to salicylic acid for activation of plant defenses in tomato. Molecular Plant-Microbe Interactions. 1999 Mar;12(3):227-235.
9. Bradford MM. A rapid and sensitive method for quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analytical Biochemistry. 1976 May 7;72(1-2):248-254.
10. Chandra A, Bhatt RK. Biochemical physiological response to salicylic acid in relation to systemic acquired resistance. Photosynthetica. 1998 Jul;35(2):255-258.
11. Cleland CF, Ajami A. Identification of the flower-inducing factor isolated from aphid honeydew as being salicylic acid. Plant Physiology. 1974 Dec 1;54(6):904-906.
12. Cutt JR, Klessig DF. Salicylic acid in plants: A changing perspective. Pharmaceutical Technology. 1992;16(3):25-34.
13. Dawood MG, Sadak MS, El-Hazek A. Physiological role of salicylic acid in improving performance, yield, and some biochemical aspects of sunflower plant grown under newly reclaimed sandy soil. Australian Journal of Basic and Applied Sciences. 2012;6(4):82-89.
14. Delavari PM, Baghizadeh A, Enteshari SH, Kalantari KHM, Yazdanpanah A, Mousavi EA. The effects of salicylic acid on some biochemical and morphological characteristics of *Ocimum basilicum* under salinity stress. Australian Journal of Basic and Applied Sciences. 2010;4(10):4832-4845.
15. Durner J, Klessig DF. Inhibition of ascorbate peroxidase by salicylic acid and 2, 6-dichloroisonicotinic acid, two inducers of plant defense

responses. Proceedings of the National Academy of Sciences, USA. 1995;92(24):11312-11316.
16. Dwyer LM, Tollenaar M, Houwing L. A non-destructive method to monitor leaf greenness in corn. Canadian Journal of Plant Science. 1991;71(2):505-509.
17. Eraslan F, Inal A, Gunes A, Alpaslan M. Impact of exogenous salicylic acid on growth, antioxidant activity, and physiology of carrot plants subjected to combined salinity and boron toxicity. Scientia Horticulturae. 2007;113(2):120-128.
18. Ethlon TE, Nickels RL, McIntosh L. Mitochondrial events during the development of thermogenesis in *Sauromatum guttatum* (Schott). Planta. 1989;180:82-89.
19. Fariduddin Q, Hayat S, Ahmad A. Salicylic acid influences the net photosynthetic rate, carboxylation efficiency, nitrate reductase activity, and seed yield in *Brassica juncea*. Photosynthetica. 2003;41(2):281-284.
20. Fehr WR, Caviness CE. Stages of soybean development. Special Report, Agriculture and Home Economics Experiment Station, Iowa State University. 1977;80:11.
21. Giannopolitis CN, Ries SK. Superoxide dismutase I. Occurrence in higher plants. Plant Physiology. 1977;59:309-314.
22. Hayat Q, Hayat S, Irfan M, Ahmad A. Effect of exogenous salicylic acid under changing environment: A review. Environmental and Experimental Botany. 2010;68(1):14-25.
23. Glass ADM, Dunlop J. Influence of phenolic acids onion uptake: IV. Depolarization of membrane potentials. Plant Physiology. 1974 Dec;54(6):855-858.
24. Griffith LA. On the distribution of gentisic acid in green plants. Journal of Experimental Botany. 1959;10(3):437-442.
25. Gross D, Parthier B. Novel natural substances acting in plant growth regulation. Journal of Plant Growth Regulation. 1994 Jun;13:93-114.
26. Coronado GMA, López TC, Saavedra LA. Effect of salicylic acid on the growth of roots and shoots in soybean. Plant Physiology and Biochemistry. 1998;36(8):563-565.
27. Hampton RE, Oosterhuis DM. Application of phenolic acids to manipulate boll distribution in cotton. Arkansas Farm Research. 1990;39(2):11.
28. Harper JR, Balke NE. Characterization of the inhibition of K+ absorption in oat roots by salicylic acid. Plant Physiology. 1981;68(6):1349-1353.
29. Hayat S, Hasan SA, Fariduddin Q, Ahmad A. Growth of tomato (*Lycopersicon esculentum*) in response to salicylic acid under water stress. Journal of Plant Interactions. 2008;3(4):297-304.
30. Heath RL, Packer L. Photo peroxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. Archives of Biochemistry and Biophysics. 1968;125(1):180-198.
31. Holden M. Chemistry and biochemistry of Plant Pigment. In: Goodwin, TW, editor. Academic Press, New York; c1965. p. 462-468.
32. Horváth E, Szalai G, Janda T. Induction of abiotic stress tolerance by salicylic acid signalling. Journal of Plant Growth Regulation. 2007 Sep;26:290-300.
33. Huang YF, Chen CT, Kao CH. Salicylic acid inhibits the biosynthesis of ethylene in detached rice leaves. Journal of Plant Growth Regulation. 1993 Jan;12:79-82.
34. Hussein MM, Balbaa LK, Gaballah MS. Salicylic acid and salinity effects on growth of maize plants. Research Journal of Agriculture and Biological Sciences. 2007 Jan 1;3(4):321-328.
35. Kazemi, Mohsen. Effect of foliar application with SA and methyl Jasmonate on growth, flowering, yield, and fruit quality Tomato. Bulletin of Environmental Pharmacology and Life Sciences. 2013;3(2):154-158.
36. Khan W, Prithviraj B, Smith DL. Photosynthetic responses of corn and soybean to foliar application of salicylates. Journal of Plant Physiology. 2003 Jan 1;160(5):485-492.
37. Khodary SEA. Effect of salicylic acid on the growth, photosynthesis and carbohydrate metabolism in salt-stressed maize plants. Journal of Agriculture and Biology. 2004 Jun 16;6(1):5-8.
38. Saavedra LA, Mex MR. Effect of salicylic acid on the bio-productivity of plants. In: Hayat S, Ahmad A, Editors. Salicylic Acid: A Plant Hormone. Springer Publishers, Dordrecht, The Netherlands; c2007.
39. Saavedra LA. The antitranspirant effect of acetylsalicylic acid on *Phaseolus vulgaris* L. Physiologia Plantarum. 1978 Jun;43(2):126-128.
40. Saavedra LA. Stomatal closure in response to acetylsalicylic acid treatment. Zeitschrift für Pflanzenphysiologie. 1979 Jul 1;93(4):371-375.
41. Lennon AM, Neuenschwander UH, Carbo RM, Giles L, Ryals JA, Siedow JN. The effects of salicylic acid and tobacco mosaic virus infection on the alternative oxidase of tobacco. Plant Physiology. 1997 Oct 1;115(2):783-791.
42. Leslie CA, Romani RJ. Salicylic acid: A new inhibitor of ethylene biosynthesis. Plant Cell Reports. 1986 Apr;5:144-146.
43. Delgado LH, Castañeda CG. Acetylsalicylic acid: Its effects on a highly expressed phosphatase from *Solanum cardiophyllum*. Biotecnologia Aplicada. 1996;13(3):186-189.
44. Maehly AC. Determination of peroxidase activity. In: Glick D, Editor. Methods of Biochemical Analysis. Inter Science Publishers, INC: New York. 1954;1:385-386.
45. Mex MR, Couoh VE, Campos HT, Saavedra LA. Positive effect of salicylates on the flowering of African violet. Scientia Horticulturae. 2005 Feb 10;103(4):499-502.
46. Prokharchik RA, Marshkova ML. Effect of phenolic compounds on the Hill reaction in relation to structural state of chloroplasts. Vyestsi Akademii Navuk BSSR Seriya Biyalagichnykh Navuk. 1985;5:25-37.
47. Rai VK, Sharma SS, Sharma S. Reversal of ABA-induced stomatal closure by phenolic compounds. Journal of Experimental Botany. 1986 Jan 1;37(1):129-134.
48. Rao MV, Davis KR. Ozone-induced cell death occurs via two distinct mechanisms in *Arabidopsis*: The role of salicylic acid. Plant Journal. 1999 Mar;17(6):603-614.
49. Raskin I. Role of salicylic acid in plants. Annual Review of Plant Physiology and Plant Molecular Biology. 1992 Jun;43(1):439-463.
50. Raskin I, Ehmann A, Melander WR, Meeuse BJDI. Salicylic acid: A natural inducer of heat production in Arum lilies. Science. 1987 Sep 25;237(4822):1601-1602.

51. Raskin I, Turner IM, Melander WR. Regulation of heat production in the inflorescences of an Arum lily by endogenous salicylic acid. Proceedings of the National Academy of Sciences of the United States of America. 1987;86(7):2214-2218.
52. Rhoads DM, McIntosh L. Isolation and characterization of a cDNA clone encoding an alternative oxidase protein of *Sauromatum guttatum* (Schott). Proceedings of the National Academy of Sciences of the United States of America. 1991;88(6):2122-2126.
53. Rodriquez-Rosales MP, Kerkeb L, Bueno B, Donaire JP. Changes induced by NaCl in lipid content and composition, lipoxygenase, plasma membrane H+-ATPase and antioxidant enzyme activities of tomato (*Lycopersicum esculentum* Mill) calli. Plant Science. 1999;143(2):143-150.
54. Saeidnejad AH, Mardani H, Naghibolghora M. Protective effects of salicylic acid on physiological parameters and antioxidants response in maize seedlings under salinity stress. Journal of Applied Environmental and Biological Sciences. 2012;2(8):364-373.
55. Salarizdah M, Baghizadeh A, Forogh Abasi, Mozaferi H. Response of *Brassica napus* L. Grains to the interactive effect of salinity and salicylic acid. Journal of Stress Physiology & Biochemistry. 2012;8(2):159-166.
56. SAS Institute Inc. SAS Users Guide, Version 6, Carry, USA; c1989, p. 1673.
57. Scandalios JG. Oxygen stress and superoxide dismutase. Plant Physiology. 1993;101:7-12.
58. Shakirova FM. Role of hormonal system in the manifestation of growth promoting and anti-stress action of salicylic acid. In: Hayat S, Ahmad A, Editors. Salicylic acid, a plant hormone. Springer, Dordrecht, Netherlands; c2007. p. 69-89.
59. Singh G, Kaur M. Effect of growth regulators on podding and yield of mung bean (*Vigna radiata* (L.) Wilczek). Indian Journal of Plant Physiology. 1980;23:366-370.
60. Singh SP. Effect of non-auxinic chemicals on root formation in some ornamental plant cuttings. Advances in Horticulture and Forestry. 1993;3:207-210.
61. Solamani A, Sivakumar C, Anbumani S, Suresh T, Arumugam K. Role of plant growth regulators on rice production: A review. Agricultural Reviews. 2001;22(1):33-40.
62. Steel RGD, Torrie JH. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Co., New York; c1980.
63. Sticher L, Mani MB, Métraux JP. Systemic acquired resistance. Annual Review of Phytopathology. 1997 Sep;35(1):235-270.
64. Szepesi C, Poor P, Gemes K, Horvath E, Tari I. Influence of exogenous salicylic acid on antioxidant enzyme activities in the roots of salt-stressed tomato plants. Acta Biologica Szegediensis. 2008 Jan 1;52(1):199-200.
65. Tenhaken R, Rubel C. Induction of alkalization and an oxidative burst by low doses of cyclohemide in soybean cells. Planta. 1998 Oct;206:666-672.
66. Vanacker H, Lu H, Rate DN, Greenberg JT. A role for salicylic acid and NPR1 in regulating cell growth in *Arabidopsis*. The Plant Journal. 2001 Oct;28(2):209-216.
67. Wang LJ, Fan L, Loescher W, Duan W, Liu GJ, Cheng JS. Salicylic acid alleviates decreases in photosynthesis under heat stress and accelerates recovery in grapevine leaves. BMC Plant Biology. 2010 Dec;10:34-40.
68. Yusuf M, Hasan SA, Ali B, Hayat S, Fariduddin Q, Ahmad A. Effect of salicylic acid on salinity-induced changes in *Brassica juncea*. Journal of Integrative Plant Biology. 2008 Sep;50(9):1-4.
69. Zhou XM, Mackenzie AF, Madramootoo CA, Smith DL. Effects of stem-injected plant growth regulators, with or without sucrose, on grain production, biomass and photosynthetic activity of field-grown corn plants. Journal of Agronomy and Crop Science. 1999 Sep;183(2):103-110.
70. Zhou XM, Smith DL. A new technique for continuous injection into stems of field-grown corn plants. Crop Science. 1996 Mar;36(2):452-456.