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The Effects of Salicylic Acid On Growth, Productivity and Water Status of Vegetable Plants Under Drought Conditions: A Review

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ABSTRACT

Salicylic acid (SA) is a naturally occurring plant hormone as it affects several physiological and biochemical functions in plants. However, exogenous SA has a positive influence on tolerance to various environmental stresses including drought. Drought seriously affects growth and productivity of the majority of vegetable plants. Moreover, SA is regarded as a relatively safe and an effective tool to improve growth, yield and water status of vegetable plants under drought stress. There is evidence from the previous investigations that SA improves growth, productivity and water status of vegetable plants subjected to drought stress. Such a treatment could be of a great value when dealing with cultivation of vegetable plants in arid zones as shortage of water becomes a limiting factor for production. This review will focus on the effects of SA on growth, productivity and water status of different vegetable plants grown under shortage of water or under drought conditions. The possible roles of SA in such effects will also be discussed.

Keywords: Salicylic acid, water relations, biochemical functions, drought, vegetable.

1. Introduction

Low water availability is a common problem for vegetable production in the new reclaimed lands in the desert areas as vegetable plants are subjected to several environmental stresses including drought stress. Moreover, shortage of water is considered as a limiting factor for plant production in such arid zones. However, finding a practical and simple treatment to improve drought tolerance is highly important to overcome the negatives effects of drought on production and quality of vegetable plants. Salicylic acid (SA) is a phenolic compound which has a pronounced effect on several processes of plants such as plant growth, ion absorption, and substance transport in addition to its effect on plant signaling and increasing plant tolerance to biotic and abiotic stresses.

It has been reported that SA is directly related to yield and productivity of plants as it has the ability to induce flowering in a number of plants (Lakzayi *et al.,* 2014). However, the fruit yield of tomato and cucumber plants is significantly enhanced when the plants were treated as foliar application with lower concentrations of salicylic acid (Larque-Saavedra and Martin-Mex, 2007).

As for the general effects of SA on plants under stress, Song *et al.* (2023) stated that SA as an important signaling molecule, can play a crucial roles in plant tolerance responses to both biotic and abiotic stresses including drought stress and thus help maintaining better plant growth and productivity under stress. Moreover, they indicated that SA is important in regulating the expression of genes responsible in defense signaling pathways and subsequently enhancing plant immunity. They also revealed the effects of SA in mitigating the negative effects of abiotic stresses including drought, as it can act as a signaling molecule to induce the expression of stress-responsive genes and the synthesis of stress-related proteins. Their findings also indicated that SA can act with other signaling molecules including jasmonic acid (JA), auxin, ethylene (ETH) in regulating plant growth and this also help

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improving tolerance under stress and is able to improve certain yield-related photosynthetic indexes and enhancing crop yield under stress.

Salicylic acid can provide a practical solution for enhancing growth and yield of vegetable plants affected by drought stress when grown under arid zones conditions. There is evidence from the previous investigations supporting these effects. For example, Nada and Abd El-Hady (2019) found that foliar application with salicylic acid improved vegetative growth and fruits yield of cucumber grown under shortage irrigation levels. Also, El-Tohamy *et al.* (2020) found that the exogenous application of SA mitigated the effects of drought stress on carrot plants, resulting in improved growth, productivity and quality as well as a better recovery from drought stress. The improvement of tolerance to drought stress in response to SA application is a also proved for several vegetable plants such as tomato (Aires *et al.,* 2022; Dawa *et al.,* 2019), pepper (Khazaei and Estaji, 2021) , cherry tomato (Abdul Qadir *et al.,* 2019), potato plants (Metwaly and El-Shatoury , 2017), common bean (Sadeghipour and Aghaei , 2012) and carrot (Ina *et al.,* 2007).

Moreover, salicylic acid is proved to maintain better water status of vegetable plants under water stress conditions as found by several investigators. Khazaei and Estaji (2021) found that the exogenous application of SA significantly decreased the unfavorable effects of drought stress on pepper plants and thereby increased relative water content (RWC). Similar effects on improved water status of vegetable plants as a results of SA application under water stress conditions were also found in other vegetable plants such as tomato (Aires *et al.,* ,2022), potato (Metwally and El-Shatoury, 2017) and cucumber (Nada and Abd El-Hady, 2019).

This review discusses the responses of several vegetable plants to SA application under drought conditions concerning its roles and the possible effects on their growth, productivity as well as on water status.

2.1. Effects of salicylic acids on drought tolerance, growth and yield of vegetable plants:

Salicylic acid (SA) is an endogenous growth regulator of phenolic nature and also is considered as a signaling molecule as it participates in the regulation of physiological processes in plants including growth, photosynthesis, and other metabolic processes.

Several studies indicated that salicylic acid can provide a practical solution for vegetable plants protection against drought especially in arid regions. Anosheh *et al.* (2012) indicated the importance of SA in reducing drought injury and found that the effect is due to better regulating of stomatal opening, maintenance of higher chlorophyll content of leaves and improvement of water-use efficiency. Ina *et al.* (2007) indicated that SA had a positive effect on root dry weight of carrot and high carotenoids and anthocyanin content of carrot plants. They found that SA has an important role in plant response to osmotic stress as well as its role in regulating the accumulation of proline content in leaves. However, Lakzayi *et al.* (2014) found that SA has an important role in signaling in plants resulting in reducing drought injury of plants. This signaling effect of SA is also supported by El Tayeb *et al.* (2010) who indicated that SA has an important role in plant signaling during stress and it could have an effective role on improving drought tolerance. El-Tohamy *et al.* (2020) studied the response of carrot plants to foliar application of salicylic acid (SA) under drought stress. Their results revealed that the application of SA resulted in reducing the negative effects of drought stress on carrot plants as indicated by higher growth, productivity and quality parameters. They found a significant improvement of carrot growth, productivity and quality of roots in response to SA application, indicating a better recovery from drought stress when carrot plants were treated by SA.

Moreover, Iosob *et al.* (2023) studied the role of SA in reliving the negative effects of drought stress on tomato plants and indicated that the foliar application of SA is able to control the growth and development of tomato plants cultivated in both the greenhouses and field, enabling the activation of the responses of tomato plants to water stress conditions.

According to Umebese *et al.* (2009) water stress significantly inhibited tomato stem height at the vegetative stages and the application of 3 mM of SA was effective in keeping plant height similar to the control. They referred this effect to the ability of SA to induce antioxidant responses that protect them from damage. The role of SA in amelioration of plant height under water stress may be related to improve mitosis and cell elongation. As flowering is directly related to yield and productivity of plants, Salicylic acid has been reported to induce flowering in several plants (Hayat *et al.,* 2010). Hussain *et al.* (2008) related the positive effects of exogenous application of SA on yield and yield related traits

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under drought stress to the maintenance of photosynthetic activity in response to SA application. Concerning the effects on osmotic adjustment, the organelles and cytoplasmic activities take place at about a normal pace and this in turn enable plants to perform better in terms of growth and photosynthesis (Ludlow and Muchow, 1990; Subbarao *et al.,* 2000). Moreover, researchers also indicated that exogenous SA enhanced yield and yield components of garlic under water stress conditions (Bideshki and Arvin, 2010). However, the increase in parameters of water stressed plants in response to SA may be due to the induction of antioxidant responses that help protecting the plant from oxidative damage, accumulation of proline and maintenance of RWC and photosynthesis. Accordingly, under drought conditions, SA treatment cause maintenance of RWC and photosynthesis and subsequently improves leaf area index.

In addition, the exogenous application of SA can be used as a powerful tool in activating the growth, productivity under various abiotic stresses in plants. Hayat *et al.* (2010) stated that the applications of SA hold a great promise as a management tool for providing tolerance to the agricultural crops against the constrains consequently crop productivity.

Abdul Qadir *et al.* (2019) stated that the exogenous application of salicylic acid (SA) and glycinebetaine (GB) show significant improvement in mitigating the negative effects of drought on cherry tomato. Their study focused on the role of exogenously applied SA and GB in ameliorating the production and quality of cherry tomato under different regimes of irrigation. Their results indicated that fresh and dry weight of leaves, saturated weight of leaves, relative water content, leaf chlorophyll content, plant height, stem diameter, fruit diameter, number of fruits, yield total soluble solid (TSS), titratable acidity, ascorbic acid and lycopene were significantly affected by levels of irrigation, osmoprotectants and there interaction. They found that the exogenously application of SA and GB showed a pronounced improvement in the parameters of cherry tomato under drought in addition to the enhancement of yield.

In a study on water-stressed tomato plants, Hayat *et al.* (2008) found SA improved water stress tolerance as indicated by improved several parameters during water stress including photosynthetic parameters, membrane stability index, leaf water potential, activity of nitrate reductase (NR), carbonic anhydrase , chlorophyll and relative water content. Moreover, in a study on potato plants, Metwaly and El-Shatoury (2017) found that the negative effects of water deficit on the growth and yield of potato can be mitigated by foliar application of SA. Their results clearly indicated the efficiency of exogenous application of salicylic acid (SA) in this respect. They found that regarding the interaction between irrigation water quantity and spraying salicylic acid the combination of 1300 m3/ fed. and 0.2 g/l salicylic was the best combination and it is recommended for potato cultivar Spunta grown under loamy soil conditions using drip irrigation system, as this combination obtained the maximum tubers yield and as well as improved its physical and chemical quality. Similar results were obtained by Nada and Abd El-Hady (2019) on cucumber plants, as they suggested that foliar application with salicylic acid at 0.3 g/l was the best treatment, and reduced the negative effects of shortage irrigation levels on the vegetative growth and fruits yield of cucumber. They found that the level of 1200 m3/fed. of irrigation water with foliar application of 0.3 g/l of salicylic was the best combination for cucumber as it gave the highest productivity and its chemical quality.

Also, Dawa *et al.* (2019) investigated the response of tomato plants to different water irrigation levels (60%, 80% and 100% from ETo) and some foliar application treatments including salicylic acid and their effects on vegetative growth characteristics and leaf chemical constituents of tomato plants (*Solanum lycopersicum* L) under surface drip irrigation system and found that the stimulating effect of foliar application of salicylic acid on tomato plants may be due to that salicylic acid – as a plant growth regulator- is involved in the regulation of many physiological processes in plants such as activating cell division, biosynthesis of organic compounds and availability and movement of nutrients in the leaves.

Moreover, Aires *et al.* (2022) evaluated the effect of salicylic acid on tomato plants under low water availability conditions and indicated the effectiveness of foliar application of SA on mitigating the deleterious effects of water deficit in tomato plants regarding the gas exchange and fruit production.

The positive effects of SA is also indicated by exogenous application as seed soaking as found by Sadeghipour and Aghaei (2012) who evaluated the effect of exogenous SA application on some traits of common bean under water stress conditions. They found that drought decreased bean growth including plant height, leaf area index (LAI) and decreased protein yield but increased seed protein content. They indicated that seeds soaking in SA (especially 0.5 mM) reduced drought damages and increased plant height, LAI and protein yield under water stress conditions. They concluded that exogenous application of SA is an effective tool for improving growth and production of common bean subjected to water stress.

The effects of SA on drought tolerance of pepper plants were also indicated by Khazaei and Estaji (2021) as they investigated the effect of drought stress on some physiological and chemical properties of the sweet pepper and the effect of the foliar application of salicylic acid (SA) on alleviating the negative effects of drought. They examined different levels of drought stress levels: 100% field capacity (as control), moderate stress (60% field capacity), and severe stress (30% field capacity) and found that that drought reduced shoot and root fresh weight and dry weight, relative leaf water content, fruit length and diameter, chlorophyll index, and leaf area, and increased electrical conductivity, antioxidant capacity, total phenolic content, ascorbate, polyphenol oxidase, and ascorbate peroxidase. They found that foliar of application SA resulted in electrical conductivity decreased and other above-mentioned characteristics increased, indicating that SA alleviates the negative effects of drought stress on pepper plants.

However, Morovvat *et al.* (2021) investigated the effects of foliar application of chitosan and salicylic acid on yield and its components of potato plants under drought stress conditions. Their results showed a direct relationship between reduced irrigation and reduced yield. They found that as drought stress increased, the yield, yield components, and the physiological indices of the crop were negatively affected and indicated that under drought stress conditions, the application of chitosan and salicylic acid increased the biological yield.

1.2. Effects of salicylic acids on water status of vegetable plants under drought stress conditions

Salicylic acid has pronounced effects on water status of vegetable plants when subjected to shortage of water or drought conditions. There is evidence from previous studies supporting this effect.

Relative water content (RWC) is a parameter indicating the physiological status of water in stressed plants. Khazaei and Estaji (2021) found RWC content of the pepper seedlings significantly decreased under drought stress and indicated that the exogenous application of SA (as a foliar application) significantly decreased the unfavorable effects of drought stress and thereby increased RWC.

As indicated by Aires *et al.* (2022), adjusting photosynthetic capacity under water stress is important for plant survival. They found that tomato plants under water deficit presented the modulation of gas exchange as a strategy as they reduce of stomatal conductance (gs) and transpiration (E), resulting in lower assimilation of CO_2 (A). Their results indicated that foliar application of SA resulted in an increase in gs and E and, consequently, in A. They also observed an effect on A/Ci, as it increased in tomato plants as a result of SA application, resulting in a better distribution of photo-assimilates to flowers and fruit and consequently floral abortion was reduced, and the fruits accumulated mass. They stated that foliar application of SA can be considered as a technique capable of mitigating the deleterious effects of water deficit on gas exchange and tomato production and this approach can be used for tomato production management under water stress conditions. As for cucumber plants, Nada and Abd El-Hady (2019) studied the influence of Salicylic Acid on cucumber plants under different irrigation levels. They investigated the impact of four foliar application rates of salicylic acid (0.0, 0.15, 0.30 and 0.45 g/l) and three irrigation levels (1200, 900 and 600 m3/fed.) on growth, yield and water relations of cucumber plants. Their results concerning SA effect indicated that relative water content (RWC) and water use efficiency characters were increased compared to the control. They found that the maximum values were noticed at 0.30g/l salicylic acid followed with 0.45 g/l salicylic acid compared to control which had the minimum values. Their results revealed that the maximum values of water use efficiency were achieved by using 600 m3 and 0.3 g/l salicylic acid.

With respect to the effect of foliar application of salicylic acid on water relations of potato plants, Metwally and El-Shatoury (2017) found that under different irrigation levels, SA resulted in increased growth, yield and relative water content of potato plants. They mentioned that the increase in RWC as a result of SA application could be related to the effect of SA on accumulation of some compatible osmolytes in plants tissues under water stress conditions as also indicated by Siamak and Kazemi-Arbat (2014). Such enhancement of water status were also observed under other environmental stresses such as salinity, as it is indicated that SA improved water status as revealed by Najafian *et al.* (2009) who stated that SA is effective in maintaining photosynthesis, transpiration, stomatal conductance and growth at higher rates in salts stress conditions compared to untreated rosemary plants. They found that the application of SA increased the water use efficiency in salt stressed plants. Similar results were obtained by Stevens *et al.* (2006) who found that transpiration rates and stomatal conductance were significantly higher in SA treated tomato plants under saline stress conditions.

Aiman and Dhriti (2018) indicated that the main functions of SA in drought stress alleviation in plants include several effects such as promoting seedling growth, help improving water status during drought as it can regulate plant water balance, improving plant antioxidant capacity, promoting the expression of stress-related genes in plants as well as regulating plant physiological metabolism

Moreover, Hayat *et al.* (2008) studied the growth of water-stressed tomato plants in response to salicylic acid application. They generally concluded that tomato plants subjected to water stress exhibited a significant reduction in several physiological parameters including photosynthetic parameters, membrane stability index, leaf water potential, activity of nitrate reductase, carbonic anhydrase, chlorophyll and relative water content (RWC). They found that when SA was applied, these parameters were significantly improved including water status parameters such as relative water content and leaf water potential.

For and explanation of SA effects on drought tolerance of plants, Rao *et al.* (2012) indicated that foliar application of SA and L-TRP may regulate stomatal openings and reduce transpirational water loss under drought stress conditions and this can help plants to maintain turgor, carry on photosynthesis and be productive under such stressful conditions and subsequently resulted in higher relative water content, leaf membrane stability index, chlorophyll and potassium content. As indicated by He *et al.* (2005) and Sakhabutdinova *et al.* (2003) salicylic acid application can increase the production of photosynthetic apparatus, resulting in more production of photosynthates. As a result, the photosynthetic activity is improved and the production of sap in leaves is increased resulting in a better maintenance of relative water content in leaf and better growth.

2. Conclusion

Salicylic acid (SA) is considered as a hormone which acts as a signaling molecule to mitigate the negative effects of abiotic stresses including drought. As most of vegetable plants are relatively sensitive to water deficit, salicylic acid provides a practical solution as it has pronounced effects on plants growth, ion absorption, and substance transport and also affecting the defense response of plants and increasing plant tolerance to biotic and abiotic stresses.

The previous studies revealed that the application of SA on vegetable plants resulted in reducing the negative effects of drought stress on as indicated by higher growth, productivity and quality parameters as well as a better recovery from drought stress when plants were treated by SA. The positive effects of SA application on plant growth and biomass accumulation under water deficit are also related to its effects on the maintenance of photosynthetic pigments and increased CO_2 assimilation. Foliar application of salicylic acid has an impact in reducing the negative effects of water deficit on gas exchange and fruit yield. Its main effects on improving drought tolerance include several roles such as improving seedling growth, plant antioxidant capacity, improving plant water balance, activating the expression of stress-related genes in plants as well as its effects on regulating plant physiological metabolism. Other important effects of SA include improving different processes such as photosynthetic performance, maintenance of membrane permeability, induction of stress proteins, and improving the activity of antioxidant enzymes. SA has also a regulating effect on stomatal opening and closure and subsequently reduce the negative effects of drought stress on vegetable plants. Salicylic acid has pronounced effects on water status of vegetable plants when subjected to shortage of water or drought conditions. There is evidence from previous studies supporting this effect. Salicylic acid can protect vegetable plants by improving water status under water deficit conditions as it can improve the relative water content (RWC) and water use efficiency under such conditions.

It can be concluded that SA application to vegetable plants has an important role in reducing the negative effects of water stress on gas exchange, water status, growth and production of vegetable under arid zones. Further research is needed to explore the effect of SA on different vegetable plants under various irrigation levels to determine the optimum level of SA for each vegetable crop and the timing of application.

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