Biochemical responses of olive *Olea europaea* L. seedlings treated with salicylic and ascorbic acids under salt stress

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Abstract:

The experiment was conducted in a greenhouse belonging at the Department of Horticulture and Landscape Gardening, College of Agriculture, Al-Qasim Green University, during the 2025–2026 growing season, Designed as a two-factor factorial experiment in a Randomized Complete Block Design (RCBD), the study aimed to evaluate the role of salicylic and ascorbic acid treatments in enhancing the biochemical efficiency of two-year-old olive seedlings. The first factor comprised three salinity levels (0 , 100 , and 200 mmol L^{-1}), while the second factor included biostimulants, a control 0 , salicylic acid at 150 mg L^{-1} , and ascorbic acid at 100 mg L^{-1} .

the results showed that exposing the seedlings to salt stress, especially at the high concentration (200 mmol L^{-1}), caused a significant decrease in the biochemical characteristics of the olive seedlings, where chlorophyll, carbohydrates, and relative water content decreased, while in contrast, there was an increase in the leaf content of the amino acid proline and total phenols, and an increase in membrane permeability, foliar spraying with bio-stimulants led to physiological superiority, as the seedlings treated with salicylic and ascorbic acids overcame the negative effects of salinity, and the salicylic acid treatment achieved cellular membrane stability, increased leaf content of chlorophyll and carbohydrates, and increased relative water content, the maximum effectiveness of the dual interaction was demonstrated when exposing the seedlings to the highest salinity levels (200 mmol L^{-1}) with salicylic and ascorbic spraying, where the leaf content of proline increased, providing integrated osmotic and oxidative protection that enabled the seedlings to maintain balanced vegetative growth and a good photosynthetic system under severe stress conditions.

Introduction

Olive (*Olea europaea* L.) is a subtropical evergreen plant from the Oleaceae family which includes 29 genera, including the genus Olea, which comprises 35 species, with olive being one of the most important species, producing edible fruits; according to the sources the olive tree's original habitat is the eastern Mediterranean basin, and it is widely cultivated between latitudes 30-45 north and south, having a high adaptability to different environmental conditions (Besnard et al., 2018). The cultivation of this strategic crop was introduced to Iraq in a large scale to include the central and southern provinces (Townsend & Guest, 1980) and the Khastawi cultivar is one of the important local cultivars with high adaptability to the prevailing climatic and environmental condition in the region (Al-Dujaili, 2015).

Over time the accumulation of dissolved salts, mainly sodium chloride (NaCl), in the root zone makes the Salinity Stress one of the most important environmental stresses limiting the expansion of olive cultivation and productivity, because the osmotic and ionic interference disturbs the vital processes of the plant causing high production of Reactive Oxygen Species (ROS) such as hydrogen peroxide (H2O2) and superoxide radicals (O-2), which attack cellular components that exceed the natural defence system of the plants, resulting in a high oxidative stress and causing a Lipid peroxidation, degradation of the plasma membrane integrity and decrease in the

efficiency of Photosystem II (PSII) efficiency by destroying the complexes of chlorophyll and declining in carbon assimilation rates (Kesawat et al., 2023; Boussadia et al., 2023; Tadić et al., 2024).

In this context, innovative and economic applied solutions should be found to reduce the severity of this stress and to improve the internal tolerance mechanisms of olive saplings, where interest is focused on the use of antioxidants and the exogenous growth regulators (salicylic and ascorbic acids). Among phenolic plant growth regulators, salicylic acid is one of the most fundamental regulators and modifiers of numerous physiological and vital processes in plants, which has recently been shown to effectively promote the resistance of plants to environmental stresses, via multiple mechanisms, including regulation of stomatal opening and closing, and stimulation of plant production of defensive compounds and enzymes, in addition to improving the anatomical characteristics of plant tissues, especially under salinity stress (Kostiw & Staniak, 2026; Sharma et al., 2023).

Vitamin C (Ascorbic acid) is one of the major and abundant non-enzymatic antioxidants of plant cells. The current study is aimed at assessing the efficiency of foliar application of salicylic acid and ascorbic acid on growth indicators and stimulating biochemical responses of Khastawi olive seedlings under different salinity levels in central Iraq and the role of these compounds as free radical scavenging compounds, but also as precursors for the synthesis of numerous organic acids and secondary metabolites, and in relatively tolerant plants like olives, ascorbic acid has a defensive function under conditions of stress, working efficiently with the ascorbate-glutathione cycle in the chloroplasts to neutralize hydrogen peroxide (H2O2) and to scavenge the reactive oxygen species which ensure the integrity and permeability of the plasma membranes of the chloroplasts and protect them from degradation caused by oxidative stress (Rudenko et al., 2023; Foyer et al., 2024) . Given the high economic and nutritional value of olive trees, and lack of studies aimed at assessing the efficacy of foliar application of salicylic and ascorbic acids and their effects on the growth indices and biochemical reaction of Khastawi olive seedlings under different levels of salinity stress in central Iraq, the current study was conducted to evaluate the efficiency of foliar spraying with salicylic and ascorbic acids and its effects on the response of the Khastawi olive seedlings in terms of growth indices and biochemical response under salinity stress.

Materials and Methods

The experiment was conducted in the lath house belonging to the Department of Horticulture and Landscape Architecture on olive seedlings of the Khastawi cultivar, two years old, as uniform in size and growth as possible, brought from one of the certified private nurseries, planted in pots with a capacity of 5 liters containing a mixed growth medium (river soil + peat moss), the seedlings were healthy and free from insect and fungal infectionsA randomised complete block design (RCBD) with a factorial experiment of two factors was used in the experiment.

factors:

- First factor: salt stress (3 concentrations):

1. Irrigation with distilled water (comparison) 0 mmol L^{-1}
2. Salinity at a concentration of 100 mmol L^{-1}
3. Salinity at a concentration of 200 mmol L^{-1}

- Second factor: bio-stimulants (3 foliar spray concentrations):

1. Spraying with distilled water only.
2. Spraying salicylic acid at concentrations of (150) mg L^{-1}.
3. Spraying ascorbic acid at concentrations of (100) mg L^{-1}

Experimental implementation steps

The seedlings were placed in the lath house and irrigated with tap water to ensure establishment, uniformity growth, and acclimatization to the lath house conditions, Subsequently, irrigation with saline water was

applied every 3–4 days depending on regional weather conditions. Foliar spraying was performed in the morning, one day after irrigation to ensure stomatal opening and optimal hydration and was repeated at 7-day intervals, following the protocol described by **Saleem *et al*. ,(2025)**, and the experiment continued for two months, after which all treatments were irrigated with distilled water only once to wash off surface salts before performing the final measurements at the end of the experiment .

Studied traits

1. Total chlorophyll content in leaves (mg 100 g^{-1} fresh weight): The total chlorophyll content of plant leaf tissues was estimated in green leaves according to Porra.(2002)
2. Total carbohydrates (mg 100 g^{-1}): Total carbohydrates in olive leaves were estimated using a Spectrophotometer according to the Modification of Phenol Colorimetric Method Sulphuric acid modified by Dubois et al(1956) .
3. Relative water content (RWC%): Using the equation (fresh, saturated, and dry weight) based on the method of (Barrs and Weatherley,1962).
4. Membrane Stability Index (MSI)%: The membrane stability index was estimated according to the method of Belkhadi et al., (2010) based on Farhangi-Abriz and Ghassemi-Golezani.(2018) .
5. Proline amino acid content in leaves (µg g^{-1} dry matter): Proline acid in leaves was estimated according to the method described in (Troll& Lindesly,1955).
6. Total phenols (mg g^{-1} dry weight): Total phenols were estimated according to the Folin- Denis method mentioned in Dalaly and Al-Hakim (1987).

Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) as a 3 × 3 factorial setup with three replicates. Each experimental unit comprised three seedlings, resulting in a total of 27 experimental units across the study, the first factor represents the salinity concentrations and with three levels while the second factor is spraying with salicylic and ascorbic acids in addition to the control treatment and with three levels and the averages were compared according to the Least Significant Difference LSD test at a probability level of 0.05 (Al-Rawi and Khalaf Allah, 2000).

Results and Discussion

Table (1) shows the effect of salinity levels and spraying with ascorbic and salicylic acids on total chlorophyll of olive seedling leaves of the Khastawi cultivar, it is noted that the highest concentration of total chlorophyll was in the control treatment 0 mmol L^{-1} as it reached 5.243 mg $100g^{-1}$ fresh weight and with a significant difference from the rest of the treatments, while the treatment 200 mmol L^{-1} recorded the lowest concentration of total chlorophyll with an average of 1.927 mg 100 g^{-1}.

The table also shows the significant effect of spraying treatments on total chlorophyll concentration, as the spraying treatment with salicylic acid at a concentration of 150 mg L^{-1} recorded the highest total chlorophyll concentration reaching 3.923 mg $100g^{-1}$ fresh weight and with a significant difference from the rest of the treatments, followed in effect by the spraying treatment with ascorbic acid at a concentration of 100 mg L^{-1} which recorded 3.527 mg $100g^{-1}$ fresh weight, while the lowest concentration of total chlorophyll was in the control treatment which gave 3.05 mg $100g^{-1}$ fresh weight.

As for the binary interaction between salinity levels and spraying treatments, it was significant, where the highest concentration of total chlorophyll was in the binary interaction (0 mmol L^{-1} + 150 mg L^{-1} salicylic) where it reached 5.760 mg $100g^{-1}$ fresh weight, while the lowest concentration of total chlorophyll was in the binary interaction between (200 mmol L^{-1} + 0 mg L^{-1}) where it reached 1.610 mg $100g^{-1}$ fresh weight.

Table (1) effect of salinity levels and spraying with salicylic and ascorbic acids on total chlorophyll content mg g-1 fresh weight for olive seedling leaves

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	4.710	5.760	5.260	5.243
100	2.830	3.770	3.390	3.33
200	1.610	2.240	1.930	1.927
Rate of impact of enhancers	3.050	3.923	3.527	For interference = 0.165
L.S.D value (0.05)	For salinity= 0.097	For the additives= 0.097		

Table (2) shows the effect of salinity levels and spraying with ascorbic and salicylic acids on the concentration of total soluble carbohydrates in the leaves of Khastawi olive cultivars. The results showed that the highest concentration of total soluble carbohydrates was at the salinity concentration of 0 mmol L^{-1} with an average of 13.19 mg 100 g^{-1}, and without a significant difference from the concentration of 100 mmol L^{-1} with an average of 12.31 mg 100 g^{-1}, while the concentration of 200 mmol L-1 gave the lowest concentration with an average of 6.18 mg 100 g^{-1}. The table also shows the significant effect of salinity improvers on the concentration of total soluble carbohydrates, as the spraying treatment with salicylic acid at a concentration of 150 mg L^{-1} recorded the highest concentration of total soluble carbohydrates reaching 11.74 mg 100 g^{-1}, with a non-significant difference from the spraying treatment with salicylic acid at a concentration of 100 mg L^{-1}, while the lowest concentration of total soluble carbohydrates was in the spraying treatment at a concentration of 0 mg L^{-1}, which gave 9.29 mg 100 g^{-1}.

As for the binary interaction between salinity levels and spraying treatments, it was significant, as the highest concentration of total soluble carbohydrates was in the binary interaction between (0 mmol L^{-1} salinity + 150 mg L^{-1} salicylic), recording the highest average of 15.10 mg 100 g^{-1}, while the binary interaction (200 mmol L^{-1} salinity + 0 mg L^{-1}) recorded the lowest average of 5.79 mg 100 g^{-1}.

Table (2) the effect of salinity levels and spraying with salicylic and ascorbic acids on the total carbohydrate content mg 100 g^{-1} for the leaves of olive seedlings

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	12.43	15.10	13.55	13.19
100	9.66	13.59	12.17	12.31
200	5.79	6.52	6.24	6.18
Rate of impact of enhancers	9.29	11.74	10.65	For interference =5.401
L.S.D value (0.05)	For salinity= 3.118	For the additives= 3.118		

The data in Table (3) showed that exposing olive seedlings to salt stress led to a gradual and significant decrease in the relative water content of the leaves, as the control treatment (0 mmol L^{-1}) recorded the highest average relative water content of 84.62%, while this rate decreased significantly to 72.78% at the medium salinity level (100 mmol L^{-1}) and continued to decline to reach its lowest value at the high salinity level (200 mmol L-1), recording 60.3%.

The results indicated a clear significant superiority of the spray treatments in maintaining the percentage of relative water content of the leaves compared to the distilled water spray treatment, where seedlings treated with salicylic acid recorded the highest overall rate of relative water content reaching 78.03%, followed by the ascorbic acid treatment with an average of 72.68%, and both treatments significantly outperformed the control treatment (spraying with water only) which recorded the lowest rate of 66.98%.

The dual interaction between the study factors showed a significant effect, with the interaction treatments between (0 mmol L^{-1} salinity + 150 mg L^{-1} salicylic) excelling by recording the highest percentage of relative water at a rate of 87.65%, while the dual interaction between (200 mmol salinity + 0 mg L^{-1} enhancers) recorded the lowest percentage of relative water at a rate of 51.65%.

Table (3) effect of salinity levels and spraying with salicylic and ascorbic acids on the relative water content % of olive seedlings

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	81.90	87.65	84.30	84.62
100	67.40	78.10	72.85	72.78
200	51.65	68.35	60.90	60.3
Rate of impact of enhancers	66.98	78.03	72.68	4.11=For interference
L.S.D value (0.05)	2.36 = For salinity	2.36 = For the additives		

The results shown in Table (4) showed that exposing olive seedlings to salt stress caused a gradual and significant increase in the percentage of cell membrane permeability, as the control treatment (0 mmol L^{-1}) recorded the lowest membrane permeability rate of 13.27%, while this rate increased significantly to 21.72% at the medium salinity level (100 mmol L^{-1}) and continued to rise rapidly to reach its peak at the high salinity level (200 mmol L^{-1}) recording 31.31%.

The results indicated a clear significant superiority for the enhancer spray treatments in reducing the percentage of membrane permeability (maintaining its integrity and stability) compared to the distilled water spray treatment, where seedlings treated with a concentration of 150 mg L salicylic acid recorded the lowest membrane permeability rate of 18.40%, followed by the 100 mg L ascorbic acid treatment with an average of 20.49%, and both significantly outperformed the control treatment (spraying with water only) which recorded the highest damage and permeability rate of 27.28%.

The table results showed the significant effect of the interaction between the two study factors, as the dual interaction of 200 mmol L^{-1} salinity and 0 mg L^{-1} enhancers excelled by recording the highest percentage of membrane permeability with a rate of 38.80%, while the dual interaction (0 mmol L^{-1} salinity + 150 mg L salicylic acid) recorded the lowest percentage of 11.15%.

Table (4) effect of salinity levels and spraying with salicylic and ascorbic acids on membrane stability % for olive seedling leaves

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	16.45	11.15	12.20	13.27
100	26.60	18.40	20.15	21.72
200	38.80	25.65	29.12	31.31
Rate of impact of enhancers	27.28	18.40	20.49	2.49=For interference
L.S.D value (0.05)	1.43 = For salinity		1.43 = For the additives	

It is observed from Table (5) that exposing olive seedlings to salt stress led to a gradual and significant increase in the proline content of the leaves as salinity increased, where the control treatment (0 mmol L^{-1}) recorded the lowest proline rate of 16.374 µg g^{-1} dry matter, while the rate increased significantly to 22.117 µg g^{-1} at the medium salinity level (100 mmol L^{-1}) and continued to rise to reach its highest value at the high salinity level (200 mmol L^{-1}) with a rate of 29.47 µg g^{-1}.

The results indicated a clear significant superiority for the external stimulant spray treatments, as the control treatment seedlings 0 mg L recorded the highest internal proline content with a rate of 29.312 µg g^{-1}, followed by the ascorbic treatment with an average of 20.55 µg g^{-1}, and both treatments significantly outperformed the salicylic treatment, which recorded a rate of 18.10 µg g^{-1}.

The dual interaction between the two study factors showed a significant effect, as the dual interaction treatment (high salinity 200 mmol L^{-1} + 0 mg L^{-1}) recorded a value of 35.01 µg g^{-1} as a natural response from the plant to salt stress, but when spraying the stressed seedlings with ascorbic and salicylic acids under the same stress level (200 mmol L^{-1}), the proline content increased, recording 28.56 and 24.83 µg g-1 respectively, while the dual interaction (0 mmol salinity + 150 mg L salicylic) recorded the lowest proline content of 12.87 µg g^{-1}.

Table (5) effect of salinity levels and spraying with salicylic and ascorbic acids on the amino acid proline µg g-1 dry matter for olive seedling leaves

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	21.701	12.87	14.55	16.37
100	31.22	16.60	18.53	22.11
200	35.01	24.83	28.56	29.47
Rate of impact of enhancers	29.31	18.10	20.55	3.528=For interference
L.S.D value (0.05)	2.037 = For salinity		2.037 = For the additives	

The results of the statistical analysis shown in Table (6) indicate the effect of salinity levels and conditioners on the phenol content of olive seedling leaves. Salinity periods had a significant effect, with the 200 mmol L^{-1} salinity treatment outperforming other treatments and recording the highest average of 29.47 mg g^{-1}, while the 100 mmol L^{-1} salinity treatment recorded an average of 22.12 mg g^{-1}, whereas the control treatment of 0 mmol L^{-1} salinity recorded the lowest average of 16.37 mg g^{-1}.

Salinity conditioners also had a significant effect on the phenol content of the leaflets, as the ascorbic acid spray treatment outperformed the other treatments and recorded the highest average of 29.31 mg g^{-1}, surpassing the salicylic 150 mg L-1 and 0 mg L^{-1} treatments, which recorded averages of 20.55 and 18.10 mg g^{-1}, respectively.

The bilateral interaction between the study factors yielded significant differences, as the interaction between (200 mmol L^{-1} salinity + 100 mg L^{-1} ascorbic) treatments outperformed by recording the highest average of 35.01 mg g^{-1}, while the interaction between (0 mmol L^{-1} salinity + 0 mg L^{-1} conditioners) recorded the lowest phenol average of 12.87 mg g-1.

Table (6) effect of salinity levels and spraying with salicylic and ascorbic acids on total phenols mg g^{-1} dry weight of olive seedling leaves

Salinity concentration (mmol L^{-1})	Salinity improvers (mg L^{-1})			Salinity effect rate
	0	Salicylic150	Ascorbic100	
0	12.87	14.55	21.70	16.37
100	16.60	18.53	31.22	22.12
200	24.83	28.56	35.01	29.47
Rate of impact of enhancers	18.10	20.55	29.31	3.520=For interference
L.S.D value (0.05)	2.036 = For salinity	2.036 = For the additives		

The results of the study showed a significant decrease in the studied traits when treated with saline concentrations. The decrease in total chlorophyll and carbohydrate content in olive seedling leaves may be attributed to the disruption of physiological and biochemical processes resulting from the osmotic and ionic effects of salt stress (Lu et al., 2023). On one hand, the excessive accumulation of (Na+) and (Cl-) ions within the leaf tissues stimulates the activity of the Chlorophyllase enzyme, which is responsible for the degradation of chlorophyll pigments, coinciding with the generation of reactive oxygen species (ROS) that cause oxidative stress leading to the destruction of chloroplast thylakoid membranes and the inhibition of pigment synthesis (Arif et al., 2020). This deterioration in the photosynthesis process is linked to a decrease in total and soluble carbohydrate content, as the rise in irrigation water salinity limits the roots' ability to absorb water from the soil, creating a water deficit in the cellular tissues of the leaves. Additionally, salt stress causes damage to the structural integrity of cellular membranes and causes them to lose their selective permeability (as shown in Table 4), leading to the leakage of water and cellular contents and the loss of cell turgor pressure, thus decreasing the relative water content (Munns & Tester, 2008). Furthermore, the increase in membrane permeability may be due to the destruction of plasma membrane integrity by oxidative stress and lipid peroxidation, leading to the leakage of ions and dissolved nutrients (such as potassium and magnesium) from the cytoplasm to the outside, which causes high membrane permeability (Demidchik et al., 2014; Mansour, 2013). Also, the accumulation of (proline) increases at saline concentrations as a response from the plant to face salt stress through the osmotic adjustment mechanism, as proline is one of the most important osmotically compatible solutes that the plant stimulates its biosynthesis within the cytoplasm when exposed to salinity (Shafi et al., 2019). The significant increase in total phenolic compounds content when exposed to high saline concentrations is attributed to the plant's defensive response to face the secondary oxidative stress caused by salinity, as accumulated phenols act as non-enzymatic antioxidants that protect cellular membranes and chloroplasts from degradation. This result is consistent with the nature of olive trees

(Olea europaea L.) as a plant naturally rich in phenolic compounds (such as oleuropein and hydroxytyrosol), where raising the concentration of these compounds represents a physiological mechanism that grants the Khastawi cultivar the ability to tolerate salinity (Hussain et al., 2026; El Yamani & Cordovilla, 2024).

The positive results associated with treating salt-stressed olive seedlings with salicylic acid are attributed to its role as a plant growth regulator and a signaling hormone that possesses the ability to stimulate physiological and biochemical adaptation and defense mechanisms to face stress (Decsi et al., 2025). Salicylic treatment led to an increase in chlorophyll and carbohydrate content due to its direct role in accelerating the formation and synthesis of chlorophyll pigments, protecting chloroplast cellular membranes from oxidative degradation, and increasing the efficiency of antioxidants, which improved the efficiency of the photosynthesis process, and consequently increased the photosynthetic products of carbohydrates (Hayat et al., 2025). This mechanism is closely linked to the ability of salicylic acid to regulate the relative water content in leaves, as it works to regulate the opening and closing of stomata in a way that ensures reducing transpiration and preserving water within the tissues. This stimulates the accumulation of osmotic solutes within the cytoplasm, especially proline, as spraying with salicylic acid led to raising proline levels, which contributed to lowering the internal osmotic potential of the cells, thereby enabling olive seedlings to draw water from saline soil and maintain cellular turgor pressure and a high relative water content. As for cellular membrane permeability, salicylic acid treatment showed a role in maintaining the integrity and stability of cellular membranes by the ability of salicylic acid to regulate the levels of secondary metabolite compounds, as it stimulated the accumulation of phenolic compounds at a balanced level consistent with the nutritional and physiological state of the olive plant. These accumulated phenols (such as flavonoids) act as powerful non-enzymatic antioxidants that scavenge free radicals ROS and prevent the oxidation of phospholipids composing the cellular membranes, which maintained optimal selective permeability of the membranes, prevented the leakage of vital ions to the outside, and regulated ion absorption by enhancing the exclusion of toxic sodium and chlorine ions and stimulating potassium absorption (Elsisi et al., 2024; Song et al., 2023).

The results show the positive role of foliar spraying with ascorbic acid in increasing the tolerance of olive seedlings exposed to salt stress,and this is due to the nature of ascorbic acid being a powerful endogenous antioxidant and a primary electron donor in the ascorbic-glutathione cycle, which makes it capable of reducing the negative effects of salt stress, the treatment significantly affected the leaf content of chlorophyll and carbohydrates, in activating and protecting the photosynthesis process, as an electron donor and antioxidant, and this prevented the

degradation of chlorophyll pigments and protected the chloroplast membrane

(El Refaey et al.,2022), ascorbic acid contributed to improving the internal hormonal balance of the plant which helped olive seedlings to regulate nutrient absorption and increase the efficiency of stomatal opening and closing to limit water loss and thus improve the relative water content and proline content, and this water regulation coincides with the role of ascorbic acid in stimulating the plant to produce and accumulate osmotic solutes, most importantly proline, since the accumulation of proline reduced the osmotic potential of the cells, enabling the seedlings to maintain their strength and draw water from the saline environment and maintain a high relative water content in the leaf tissues (Chen et al.,2024), as for the permeability of cellular membranes and phenolic compounds, ascorbic acid had an important role in reducing membrane permeability, meaning reducing ion leakage under salt stress conditions, as ascorbic acid protects membrane phospholipids from oxidation

due to its high ability to scavenge free radicals, it also acts as a biostimulant that

regulates secondary metabolism levels, which prompted the seedlings to accumulate phenolic compounds at a level consistent with the physiological and nutritional status of the plant (Pohl&Hannesschlaeger,2018).

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