The Effect of Salicylic Acid on the Performances of Salt Stressed Strawberry Plants, Enzymes Activity, and Salt Tolerance Index

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Abstract: The influence of salicylic acid (SA) on growth, yield, fruits’ quality and enzymes’ activities was monitored in strawberry plants cv. Camarosa grown under salinity stress via two pot experiments in two successive years of 2018 and 2019. The examined concentrations of SA were 30, 60, and 90 ppm, which foliary applied in addition to control (sprayed with water), while the used levels of salinity were 20, and 40 mM as NaCl as irrigation application in addition to control (without salinity). The results showed a significant effect of salinity at 40 mM where the mean values of shoot fresh and dry weights, chlorophyll, leaves’ NPK, yield plant−1, yield ha−1, and fruits’ ascorbic acid were significantly decreased. However, the 40 mM salinity resulted in a significant increase in leaves’ content of Na and proline as well as catalase (CAT) and peroxidase (POD) enzymes’ activity and the fruits’ TSS and acidity. The application with 90 ppm SA was found to be the most significant positive treatment for all of the studied characters except the Na leaves’ content. Regarding tolerance index percentages (STI%), the high values of CAT, POD, and proline referred to the ability to use them as indicators for strawberry salinity response in other physiological and plant breeding studies. The findings of this study suggest that the 90 ppm SA foliar application can ameliorate the negative effect of salinity on the growth of strawberry cv. Camarosa.

Keywords: strawberry; salinity; salicylic acid; salt tolerance index; enzymes activity

1. Introduction

Strawberry (Fragaria × ananassa Duch.) is one of the most economically important and famous vegetable crops that is consumed worldwide because of its great nutritional value and lovely flavor. This crop’s great economic return and high global demand led to the expansion of its cultivation areas [1,2]. The total world production of strawberries has reached up to 8,337,099 tons [3].

About 7% of total land area and about 20% of the irrigated arable land is suffering from salt stress [4]. Salinity, especially in irrigation water, is the most common and widespread environmental stress problem increasing in agricultural areas, especially in arid and semi-arid regions as found in the Middle East countries [5].

The adverse effect of salinity stress can be discussed in three directions, for example, osmotic stress, specific-ionic stress and oxidative stress; however, oxidative stress is considered to be the most harmful one [6,7]. Oxidative stress induces accumulation of damaging reactive oxygen species (ROS) in plant cells that produce membrane lipids, proteins and nucleic-acid damage [8]. Concerning strawberry salinity tolerance, it is considered a salt-sensitive vegetable crop with different responses among the cultivars due to salt stress, which likely depends on their genetic potential [9].

Salicylic acid is a phytohormone that is considered a universal signaling molecule, which protects plants from several biotic and abiotic stress cases [10] where it was found...
that SA is participating in the regulation of many plant physiological processes such as ion uptake, cell membranes’ permeability and photosynthetic rate and their pigment content [11–13] as well as increasing the antioxidant enzymes’ activities and proline content [13–15] of stressed strawberry plants. Moreover, the foliar spray of (SA) was found to have a significant effect on ameliorating salt tolerance of strawberry plants [16,17].

The aim of this study is to investigate the effect of different concentrations of salicylic acid (SA) on confronting the negative effects of graded levels of salinity stress of strawberry plants cv. “Camarosa” in addition to screening the salt tolerance index (STI%) for all the studied characters for indicating which character(s) could be used as an indicator for salinity tolerance in strawberry plants.

2. Materials and Methods

Two pot experiments in 2018 and 2019 were conducted on a private farm in the El-Bostan region (30.803, 30.479) to investigate the effect of graded levels of salinity in irrigation water and the ameliorative effect of foliar application of different concentrations of salicylic acid and their interaction on growth, leaves’ chemical composition, yield, fruits’ chemical quality, leaves’ proline, and leaves’ enzymes’ activity of strawberry cv. “Camarosa”. In addition, the salt tolerance index percentages (STI%) were calculated for the different studied characters.

2.1. Cultivation and Experimental Layout

Cold-stored strawberry transplants (Fragari × ananassa Duch. cv. Camarosa) with one well-developed crown with a diameter of about 10 mm were planted individually in 20 cm diameter plastic bags filled with a mixture of commercial perlite and peat moss (1:1 V/V). Strawberry transplants were transplanted on October 5th and 8th for the first and second seasons, respectively. All strawberry plants were irrigated every 48 h manually using a watering can, with Hoagland solution [18], which was added uniformly for all plants for three weeks after transplanting (250 cm³ for each pot). The salinity treatments were applied when the strawberry plants had 4–5 fully expanded leaves (about three weeks after transplanting). There were three salinity treatments: control (water), 20, and 40 mM of NaCl that were applied with irrigation once every 48 h. After one week of salinity treatments’ application, the foliar spray of different salicylic acid (SA) concentrations was applied as control (water), 30, 60 and, 90 ppm once every week using a handgun sprayer (2 L in volume).

The following experimental design was a randomized complete blocks design (RCBD) in split-plot arrangement, in which the salinity treatments were applied in main plots and the SA treatments were allocated in subplots. Every subplot contained 16 plastic bags that were surrounded by a strip area of 0.5 m wide to prevent overlaps between foliar spray treatments. The water used for all irrigation or foliar applications was tap water with the following analysis:

2.2. Shoot Fresh and Dry Weights

After two months from experiment initiation, the shoot fresh weight (g) and shoot dry weight (g) were recorded.

2.3. Leaves Chlorophyll and Chemical Composition

The strawberry leaves’ chlorophyll was determined by a nondestructive method using a SPAD-502 chlorophyll meter [19]. Concerning leaves’ chemical composition, nitrogen, phosphorus, potassium as % and sodium as mg g⁻¹ in strawberry leaves were each determined according to the methods illustrated by [20].

2.4. Proline Content and Enzymes Activity

The samples of fresh leaves of strawberry plants were taken for estimating the proline content (mg g⁻¹ FW) as described by [21]; the enzymes’ activities (U min⁻¹ g⁻¹ FW) were
determined spectrophotometrically following the method of [22] for catalase (CAT) and following the methods of [23] for peroxidase (POD).

2.5. Yield

After the end of harvesting time, the total yield of strawberry fruits was measured in grams per plant. Concerning the total yield ha\(^{-1}\), it was calculated by multiplying the mean values of total yield plant\(^{-1}\) by the supposed number of strawberry plants per hectare that is about 95,000 plants.

2.6. Fruits’ Chemical Quality

Following the methods described by [24], the fruit samples were taken from the second harvest to determine total soluble solids (TSS as Brix\(^{\circ}\)), which were measured by using a hand refractometer; ascorbic acid (mg g\(^{-1}\) FW), which was measured spectrophotometrically; and titratable acidity (g 100 g\(^{-1}\)), which was measured by the NaOH titration method.

2.7. Salinity Tolerance Index (STI)

It was calculated as percentages (%) for all the studied characters as suggested by [25] with slight modification in symbols used as follow: STI = (T\(_{\text{salt}}\)/T\(_{\text{cont}}\)) \times 100, where T\(_{\text{salt}}\) is the mean value of the trait under the highest used salinity level (40 mM) and T\(_{\text{cont}}\) is the mean value of the trait under the control treatment.

2.8. Statistical Analyses

Data were statistically analyzed using CoStat program [26]. A Least Significant Difference test (LSD) was used at 0.05 probability level to verify the significance between treatments by using the same program.

3. Results

The results concerning the effect of the two main factors of salinity and SA foliar spray as well as their interaction on growth, leaves’ nutrients’ composition, yield, fruit chemical quality, and leaves’ proline content and activity of catalase (CAT) and peroxidase (POD) enzymes of strawberry cv. Camarosa are listed in Tables 1–5.

Table 1. Chemical analysis of the tap water used.

| Parameter | Mean Value |
|-----------|------------|
| pH        | 7.4        |
| EC (Ds/m) | 2.3        |
| TDS (mg/L)| 162        |
| N (mg/L)  | 0.00       |
| P (mg/L)  | 0.00       |
| K (mg/L)  | 4.7        |
| Na (mg/L) | 6.7        |
| Cl (mg/L) | 56         |

EC—Electric conductivity, TDS—Total dissolved solids.
Table 2. The main effects of salinity and salicylic acid (SA) foliar spray and their interaction on shoot fresh and dry weights of strawberry cv. Camarosa in 2018 and 2019 seasons.

| SA Levels | 2018 Season | 2019 Season | 2018 Season | 2019 Season |
|-----------|--------------|--------------|--------------|--------------|
|           | Shoot Fresh Weight (g) | Shoot Dry Weight (g) | Shoot Fresh Weight (g) | Shoot Dry Weight (g) |
| 0 ppm     | 43.89 g      | 2.89 g       | 41.72 de     | 2.89 g       |
| 30 ppm    | 77.91 d–f    | 7.62 C       | 48.44 bc     | 7.62 C       |
| 60 ppm    | 81.63 c–e    | 13.97 b–d    | 13.52 B      | 13.52 B      |
| 90 ppm    | 92.85 bc     | 12.70 de     | 10.01 ab     | 12.70 de     |
| Mean      | 75.90 B      | 12.61 B      | 71.34 A      | 12.61 B      |

* The mean values with the same letters do not differ significantly at 0.05 level.

Table 3. The main effects of salinity and SA foliar spray and their interaction on leaves content of N, P, K and Na of strawberry cv. Camarosa in 2018 and 2019 seasons.

| SA Levels | 2018 Season | 2019 Season | 2018 Season | 2019 Season |
|-----------|--------------|--------------|--------------|--------------|
|           | Chlorophyll (SPAD) | N% | Chlorophyll (SPAD) | N% |
| 0 ppm     | 48.1 bc * | 2.43 c       | 0.314 de     | 0.344 de     |
| 30 ppm    | 49.40 a–c  | 2.59 a–c     | 0.350 b–d    | 0.350 b–d    |
| 60 ppm    | 50.60 ab   | 2.71 ab      | 0.360 bc     | 0.360 bc     |
| 90 ppm    | 54.03 a    | 2.67 ab      | 0.357 b      | 0.357 b      |
| Mean      | 50.54 A    | 2.60 A       | 0.358 A      | 0.358 A      |
**Table 3.** Cont.

| SA Levels | Salinity Levels | 2018 Season                        | 2019 Season                        |
|-----------|----------------|-----------------------------------|-----------------------------------|
|           |                | 0 mM | 20 mM | 40 mM | Mean | 0 mM | 20 mM | 40 mM | Mean |
|           |                | K%   |       |       |      | K%   |       |       |      |
| 0 ppm     |                | 2.63 bc | 2.53 cd | 1.70 f | 2.29 C | 2.59 cd | 2.49 d | 1.75 g | 2.28 C |
| 30 ppm    |                | 2.74 a–c | 2.56 cd | 2.05 e | 2.45 B | 2.78 ab | 2.56 d | 1.94 f | 2.40 B |
| 60 ppm    |                | 2.9 a  | 2.59 b–d | 2.09 e | 2.53 B | 2.65 b–d | 2.59 cd | 1.96 f | 2.43 B |
| 90 ppm    |                | 2.94 a | 2.81 ab | 2.39 d | 2.71 A | 2.88 a | 2.72 a–c | 2.25 e | 2.62 A |
| Mean      |                | 2.80 A | 2.62 B | 2.06 C | 2.73 A | 2.59 B | 1.98 C |

Na (mg g\(^{-1}\) DW)

| SA Levels | Salinity Levels | 1st Season                        | 2nd Season                        |
|-----------|----------------|-----------------------------------|-----------------------------------|
|           |                | 0 mM | 20 mM | 40 mM | Mean | 0 mM | 20 mM | 40 mM | Mean |
|           |                | Proline (mg g\(^{-1}\) FW)       | CAT (U min\(^{-1}\) g\(^{-1}\) FW) | POD (U min\(^{-1}\) g\(^{-1}\) FW) |
|           |                | 0 ppm     | 0.233 f * | 0.427 cd | 0.673 b | 0.444 C | 0.230 e | 0.390 cd | 0.690 ab | 0.437 C |
|           |                | 30 ppm    | 0.327 e | 0.453 cd | 0.700 ab | 0.487 BC | 0.280 e | 0.407 c | 0.640 b | 0.442 B |
|           |                | 60 ppm    | 0.337 e | 0.413 bc | 0.710 ab | 0.493 B | 0.343 d | 0.390 de | 0.473 bc | 0.411 B |
|           |                | 90 ppm    | 0.383 de | 0.48 c | 0.750 a | 0.538 A | 0.380 cd | 0.417 c | 0.727 a | 0.508 A |
| Mean      |                | 0.320 C | 0.443 B | 0.708 A | 0.308 C | 0.401 B | 0.684 A |

* The mean values with the same letters do not differ significantly at 0.05 level.

**Table 4.** The main effects of salinity and SA foliar spray and their interaction on proline content and the enzymes activity of catalase (CAT) and peroxidase (POD) of strawberry leaves cv. Camarosa in 2018 and 2019 seasons.

| SA Levels | Salinity Levels | 1st Season                        | 2nd Season                        |
|-----------|----------------|-----------------------------------|-----------------------------------|
|           |                | 0 mM | 20 mM | 40 mM | Mean | 0 mM | 20 mM | 40 mM | Mean |
|           |                | Proline (mg g\(^{-1}\) FW)       | CAT (U min\(^{-1}\) g\(^{-1}\) FW) | POD (U min\(^{-1}\) g\(^{-1}\) FW) |
|           |                | 0 ppm     | 1.32 f | 3.10 d | 4.95 b | 3.12 C | 1.36 f | 3.00 d | 5.00 b | 3.12 C |
|           |                | 30 ppm    | 1.38 f | 3.39 cd | 5.06 ab | 3.28 BC | 1.41 f | 3.30 d | 5.01 b | 3.24 BC |
|           |                | 60 ppm    | 1.57 ef | 3.43 cd | 5.29 ab | 3.43 B | 1.56 ef | 3.37 cd | 5.26 ab | 3.40 B |
|           |                | 90 ppm    | 1.97 e | 3.70 c | 5.53 a | 3.73 A | 1.88 e | 3.72c | 5.60 a | 3.73 A |
| Mean      |                | 1.56 C | 3.41 B | 5.21 A | 1.55 C | 3.35 B | 5.22 A |

* The mean values with the same letters do not differ significantly at 0.05 level.
Table 5. The main effects of salinity and SA foliar spray and their interaction on total yield plant$^{-1}$ and total yield ha$^{-1}$ of strawberry cv. Camarosa in 2018 and 2019 seasons.

| SA Levels | 2018 Season | 2019 Season | | | |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|           | 0 mM        | 20 mM       | 40 mM       | Mean        | 0 mM        | 20 mM       | 40 mM       | Mean        | 0 mM        | 20 mM       | 40 mM       | Mean        |
|           | Total Yield Plant$^{-1}$ (g) |                              | Total Yield ha$^{-1}$ (ton) | | | | | | | | | | 
| 0 ppm     | 277.84 ab * | 140.26 f    | 156.38 ef   | 191.49 D    | 20 mM       | 149.79 f    | 165.18 ef   | 195.26 D    | 20 mM       | 149.79 f    | 165.18 ef   | 195.26 D    |
| 30 ppm    | 270.20 ab   | 214.58 cd   | 188.20 de   | 224.33 C    | 40 mM       | 279.15 ab   | 224.65 cd   | 231.59 C    | 40 mM       | 279.15 ab   | 224.65 cd   | 231.59 C    |
| 60 ppm    | 280.58 ab   | 272.19 ab   | 201.37 d    | 251.38 B    | 60 ppm      | 282.52 ab   | 276.59 ab   | 256.99 B    | 60 ppm      | 282.52 ab   | 276.59 ab   | 256.99 B    |
| 90 ppm    | 284.72 ab   | 298.88 a    | 253.01 bc   | 278.87 A    | 90 ppm      | 303.68 a    | 300.17 a    | 286.34 A    | 90 ppm      | 303.68 a    | 300.17 a    | 286.34 A    |
| Mean      | 278.33 A    | 231.48 B    | 199.74 C    | 284.04 A    | Mean        | 237.80 B    | 205.80 C    | 231.48 B    | Mean        | 237.80 B    | 205.80 C    | 231.48 B    |

* The mean values with the same letters do not differ significantly at 0.05 level.

3.1. Shoot Fresh and Dry Weights

The mean values listed in Table 2 showed a significant effect of increasing salinity stress levels, 0 mM, 20 mM, and 40 mM on shoot fresh weight and shoot dry weight, in both seasons of study. The highest salinity level was found to exhibit the lowest mean values of shoot fresh weight and shoot dry weight with decreasing percentages estimated at 31.24% and 32.05%, respectively, as a mean of both seasons of study, when compared with control (0 mM).

Concerning the main effect of foliar spray of SA on strawberry shoot fresh and dry weights, a significant positive effect of these applications was found in both seasons of study, with the superiority of 90 ppm SA treatment compared with other SA treatments as well as control, in both seasons of study. The mean percentages of both seasons’ increment in shoot fresh weight and shoot dry weight due to the highest SA application over control were estimated at 48.71% and 52.48%, respectively.

Moreover, the interaction effect between salinity levels and SA applications was found to be significant for strawberry shoot fresh weight and shoot dry weight in both seasons of study. Under the highest salinity level of 40 mM, the foliar application with 90 ppm of SA gave the highest mean values of shoot fresh and dry weight in both seasons, with mean increment percentages estimated at 68.30% for shoot fresh weight and 66.79% for shoot dry weight when compared with strawberry plants that did not receive SA treatments under the same salinity level.

3.2. Leaves Chlorophyll and Chemical Composition

The main effect of increasing salinity level on strawberry leaves’ chemical composition (Table 3) was found to significantly decrease the leaves’ content of chlorophyll, N, P, and K; but the Na content was significantly increased, in both seasons of study. In addition, the strawberry plants under 40 mM salinity level showed the most significant lowest mean values of leaves’ content of chlorophyll, N, P, and K and the highest significant mean values of leaves’ Na, in both seasons of study. The two seasons mean percentages of decreasing the leaves’ chlorophyll, N, P, and K were estimated at 10.23%, 15.57%, 23.43%, and 26.95%, respectively; however, the leaves’ Na increasing percentage was 31.55% when compared with control.
The foliar application with SA revealed a significant effect of strawberry leaves’ chemical composition, in both seasons. The SA foliar spray with 90 ppm resulted in a significant increase in leaves’ chlorophyll, N, P, and K but a significant decrease in leaves’ Na, in both seasons. The mean values of leaves’ chlorophyll, N, P, K, and Na were significantly affected because of the SA foliar spray, particularly under the foliar treatment of 90 ppm SA, which was found to give the highest mean values, in both seasons of study. The average of both seasons’ increment percentages of leaves’ chlorophyll, N, P, K under 90 ppm SA treatment was estimated at 16.96%, 16.49%, 30.54%, and 14.25%, respectively, while the leaves’ Na decreasing percentage was 51.38% compared with control.

Moreover, the interaction effect between the two main factors of this study was found to be significant for strawberry leaves’ chlorophyll, N, P, K, and Na, in both seasons of study. The foliar application of 90 ppm SA was found to be the best treatment for a significant increase in leaves’ chlorophyll, N, P, and K, and a significant decrease in leaves’ Na of the strawberry plants grown under 40 mM of NaCl, in both seasons of study. In addition, it could be estimated that the average increment percentages of both seasons of 40 mM salinity level +90 ppm of SA comparing with 40 mM salinity level were 22.65% for chlorophyll, 24.71% for N, 41.99% for P, and 25.55% for K; however, the same circumstances resulted in a decrease in strawberry leaves’ content of Na at 68.63%.

3.3. Proline Content and Enzymes Activity

According to the mean values listed in Table 4, the salinity levels significantly increased the strawberry leaves’ content of proline as well as the CAT and POD enzymes’ activities where they reached the maximum when strawberry plants were grown under 40 mM of NaCl, in both seasons of study. The highest salinity level produced an increase in proline content and CAT and POD activities estimated at 121.67%, 235.37% and 182.08%, respectively, as an average of both seasons of study when compared with control.

The main effect of SA foliar application on strawberry leaves’ content of proline as well as the CAT and POD enzymes’ activities was found to be significant in increasing their mean values with superiority of foliar spray with 90 ppm of SA, in both seasons of study. If a comparison is made between the mean values of proline content and the activity of CAT and POD enzymes of leaves of plants that received 90 SA treatment with the control, we will find that this treatment has caused an increase of 15.73%, 16.35%, and 12.75%, respectively, as an average for both study seasons.

In addition, the interaction between salinity levels and SA treatments was found to have a significant effect on leaves’ content of proline as well as the CAT and POD enzymes’ activity, in both seasons of study. Moreover, the foliar application of 90 ppm SA was found to be the most favorable ameliorative treatment for strawberry plants grown under the highest level of salinity (40 mM NaCl), in both seasons without significant difference with 60 ppm SA treatments, in most cases. And if we move to the comparison between treatment of 90 ppm SA and control under the salinity level of 40 mM, we will find that this treatment has resulted in an increase of about 2.59% for the leaves’ content of proline and 10.60% and 12.37% for the activity of the enzymes CAT and POD, respectively.

3.4. Yield

The mean values of total yield plant$^{-1}$ and total yield ha$^{-1}$ were found to have a significant decrease due to increasing salinity level up to 40 mM (Table 5), which gave the lowest mean values, in both seasons of study. Also, the decreasing percentage was found to be 27.90% for mean values of each of total yield plant$^{-1}$ and total yield ha$^{-1}$ as a mean of both seasons, if compared with control (0 mM).

Concerning the main effect of SA foliar applications, the results in Table 5 show a significant increase in total yield plant$^{-1}$ and total yield ha$^{-1}$ mean values, especially when treated with 90 ppm SA, in both seasons of study. Also, the increment percentage when strawberry plants were treated with 90 ppm SA was found to be 46.10% for each of total yield plant$^{-1}$ and total yield ha$^{-1}$ as an average of both seasons comparing with control.
The traits of total yield plant\(^{-1}\) and total yield ha\(^{-1}\) were found to follow the same trend as the previous traits concerning their significant response to the interaction effect between salinity levels and SA foliar spray treatments, where treatment of 90 ppm of SA gave the best treatment for strawberry plants grown under 40 mM of salinity. In addition, it was found that this treatment contributed to the increase in each of the total yield plant\(^{-1}\) and total yield ha\(^{-1}\) of strawberry plants growing under the salinity level of 40 mmol by 58.13% as an average for both seasons compared with those that were not treated.

3.5. Fruits Quality

The illustrated mean values of strawberry fruits’ chemical quality in Table 6 showed a significant effect of salinity levels on TSS, ascorbic acid, and titratable acidity, in both seasons of study. In addition, the trend in both seasons of each trait was found to differ where the TSS and titratable acidity were increased in their mean values due to increasing the salinity level up to 40 mM of NaCl with increasing average that estimated by 20.22% and 47.88%, respectively, comparing with those of control; however, the fruits’ ascorbic acid content was found to decrease significantly, with an average decreasing percentage of 34.15%.

Table 6. The main effects of salinity and SA foliar spray and their interaction on total soluble solids (TSS), ascorbic acid and titratable acidity of strawberry fruits cv. Camarosa in 2018 and 2019 seasons.

| SA Levels | 2108 Season | 2019 Season |
|-----------|-------------|-------------|
|           | 0 mM  | 20 mM  | 40 mM  | Mean  | 0 mM  | 20 mM  | 40 mM  | Mean  |
| TSS (Brix\(^{\circ}\)) |       |       |       |       |       |       |       |       |
| 0 ppm    | 6.56 f* | 7.73 cd | 8.16 bc | 7.43 B | 6.80 f | 7.81 cd | 8.25 bc | 7.62 B |
| 30 ppm   | 6.93 ef | 7.87 b–d | 8.28 bc | 7.69 B | 7.12 ef | 7.89 cd | 8.36 a–c | 7.79 B |
| 60 ppm   | 6.82 ef | 7.88 b–d | 8.40 ab | 7.70 B | 7.13 ef | 7.87 cd | 8.45 ab | 7.83 B |
| 90 ppm   | 7.4 de | 7.98 b–d | 8.99 a  | 8.18 A | 7.45 de | 8.36 a–c | 8.88 a  | 8.23 A |
| Mean     | 6.93 C  | 7.91 B  | 8.41 A  | 7.13 C | 7.98 B  | 8.49 A  |       |       |
| Ascorbic Acid (mg g\(^{-1}\) FW) |       |       |       |       |       |       |       |       |
| 0 ppm    | 1.10 b–d | 0.88 e  | 0.56 g  | 0.84 C  | 1.26 bc | 1.09 d  | 0.70 f  | 1.01 C |
| 30 ppm   | 1.18 a–c | 1.07 cd | 0.75 f  | 1.00 B  | 1.35 ab | 1.21 c  | 0.84 e  | 1.13 B |
| 60 ppm   | 1.14 a–d | 1.05 d  | 0.83 ef | 1.01 B  | 1.34 ab | 1.31 ab | 0.86 e  | 1.17 B |
| 90 ppm   | 1.26 a  | 1.21 ab | 1.03 d  | 1.17 A  | 1.39 a  | 1.34 ab | 1.03 d  | 1.25 A |
| Mean     | 1.17 A  | 1.05 B  | 0.79 C  | 1.34 A  | 1.24 B  | 0.86 C  |       |       |
| Titratable Acidity (g 100 g\(^{-1}\)) |       |       |       |       |       |       |       |       |
| 0 ppm    | 1.05 f  | 1.38 de | 1.67 bc | 1.37 C  | 1.20 g  | 1.40 ef | 1.81 bc | 1.47 C |
| 30 ppm   | 1.21 ef | 1.45 c–d | 1.83 ab | 1.50 BC | 1.25 fg | 1.54 de | 1.94 b  | 1.58 BC |
| 60 ppm   | 1.28 d–f | 1.50 cd | 1.84 ab | 1.54 B  | 1.45 e  | 1.55 de | 1.98 b  | 1.64 B |
| 90 ppm   | 1.44 c–e | 1.63 bc | 2.07 a  | 1.71 A  | 1.49 de | 1.65 cd | 2.18 a  | 1.77 A |
| Mean     | 1.25 C  | 1.49 B  | 1.85 A  | 1.34 C  | 1.53 B  | 1.98 A  |       |       |

* The mean values with the same letters do not differ significantly at 0.05 level.

In addition, the results of this investigation showed a significant effect of SA foliar application on the fruits’ chemical quality traits, in both seasons of study. With some details, the application of SA in a concentration of 90 ppm was found to be the significant superior treatment that increased the mean values of TSS, ascorbic acid, and titratable acidity, in both seasons. Moreover, the two seasons’ average increasing percentages due to foliar
application of 90 ppm SA were found to be 8.29% for TSS, 23.71% for ascorbic acid, and 18.42% for titratable acidity.

Moreover, the salinity and SA levels’ interaction effect was found to significantly affect the strawberry fruits’ chemical quality characters, in both seasons of study. In addition, the results revealed that the foliar application with 90 ppm SA was found to be the favorable treatment for the fruits’ chemical quality characters of strawberry plants grown under the highest salinity level (40 mM), in both seasons of study, if compared with control. Under the same comparison, it could be found that the two seasons’ increment average was 8.16% for TSS, 38.84% for ascorbic acid, and 18.15% for titratable acidity when compared with corresponding mean values of untreated plants with SA.

3.6. Salinity Tolerance Index (STI)

The data in Table 7 illustrate the STI as percentages of all studied characters between the mean value under control and the mean value under the highest salinity level (40 mM), in both seasons of study. In addition, the STI% revealed that the most responded character to salinity stress was CAT activity comparing with other STI% of other characters, which were 376.03% and 367.86%, in 2018 and 2019, respectively. Proline content and POD activity were in second place for salinity response without significant differences between them. Moreover, leaves’ Na and fruits’ acidity exhibited the same response to salinity followed by fruits’ TSS, in both seasons. In addition, the traits of chlorophyll, N, P, K ascorbic acid total yield plant\(^{-1}\), total yield ha\(^{-1}\) and ascorbic acid did not differ significantly in their STI%. The lowest responded characters to salinity stress were shoot fresh weight, which gave 38.29% and 31.93%, and shoot dry weight, which gave 24.60% and 28.45%, in 2018 and 2019, respectively.

Table 7. Salt tolerance index (STI) of all the studied characters of strawberry cv. Camarosa during 2018 and 2019 seasons.

| Characters                      | Salt Tolerance Index (%) |
|--------------------------------|--------------------------|
|                                | 2018 Season | 2019 Season |
| Shoot fresh weight             | 38.29 fg    | 31.93 h     |
| Shoot dry weight               | 24.60 g     | 28.45 h     |
| Chlorophyll                    | 79.03 e     | 81.66 e     |
| N%                             | 75.48 e     | 78.68 ef    |
| P%                             | 57.19 e–g   | 67.82 e–g   |
| K%                             | 64.83 ef    | 67.64 e–g   |
| Na                             | 177.81 c    | 151.64 c    |
| Proline                        | 293.33 b    | 300.26 b    |
| Peroxidase, POD                | 318.61 b    | 303.57 b    |
| Catalase, CAT                  | 376.03 a    | 367.86 a    |
| Total yield plant\(^{-1}\)     | 56.19 e–g   | 60.65 fg    |
| Total yield ha\(^{-1}\)        | 56.19 e–g   | 60.65 fg    |
| Total soluble solids, TSS      | 121.91 d    | 121.58 d    |
| Ascorbic acid                  | 50.67 e–g   | 55.63 g     |
| Acidity                        | 162.28 c    | 151.50 c    |

*The mean values with the same letters do not differ significantly at 0.05 level.

4. Discussion

The problem of salinity is one of the prominent problems in the agricultural sector in the world because it has caused a severe decline in different performances of salinity-
stressed plants, which is, consequently, reflected in quantity and quality of the produced yield, especially the crops sensitive to salinity as in strawberries.

In this study, the results showed that shoot fresh and dry weights decreased linearly with an increase in salinity level (Table 2), and this may be the result of decreasing the leaves’ content of chlorophyll, N, P, and K but increasing leaves’ Na content (Table 3). There were many authors who illustrated the role of salinity in causing ionic imbalance [27], which may be a result of defects in the integrity of the cells’ plasma membranes [28] as well as the antagonistic relationship between Na and other macro and micronutrients [29]. These findings in strawberries were found to be in harmony with those of [30].

The plants under the influence of salinity stress perform many mechanisms that give them some kind of ability to confront such types of stress, such as increasing the osmotic pressure of their cells by increasing the concentration of some osmolytes such as proline, in parallel with increasing the activity of some antioxidant enzymes such as CAT and POD [31], which have a great role in scavenging reactive oxygen species (ROS), which is considered one of the most important exhibitions of oxidative stress that results from saline stress [32,33]. This is in agreement with the results obtained from this study (Table 4), where there was a significant increase in the concentration of proline, as well as activity of CAT and POD enzymes, for each increase in the concentration of salinity in strawberry plants as illustrated by [34,35]. The expected result of all of the above was the significant decrease in yield for plant and for hectare (Table 5) as a result of the impact of the salt stress on strawberry plants. These results are in line with those of [9,36].

Concerning the characteristics of the chemical quality of strawberry fruits, their behavior was somewhat different (Table 6), where it was found that TSS and acidity increased significantly with increasing salinity concentration while ascorbic acid decreased (Table 7). These results are in line with the results of [37], which reported a significant increase in TSS and acidity and a decrease in ascorbic acid in strawberry fruits as a result of increasing the salinity level up to 10 mM, and [38], which found a significant decrease in ascorbic acid in strawberry fruits due to increasing the salinity level up to 40 mM. Moreover, [39] stated that the TSS and acidity of strawberry fruits of cv. Camarosa were significantly increased under salinity level of 40 mM.

Regarding the foliar spray SA under normal circumstances, the results showed its positive and significant effect on the various characteristics of vegetative growth, chlorophyll, minerals, yield and quality of strawberry fruit under this study, in particular with a concentration of 90 ppm (Tables 1–5). However, this treatment caused a significant reduction in the leaf content of Na. All of the above is consistent with many studies that have been carried out in this regard [17,40–42]. Salicylic acid has many important physiological functions in plants, such as enhancing nutrients’ uptake and the level of chlorophyll and carotenoid pigments, modifying of some enzymes’ activities, and integrity conservancy of the cell membrane [11–13]. Such favorable effects on plants’ growth and yield could be due to the role of SA in influencing the balances of plant hormones such as auxin, cytokinin and ABA under any circumstances [43].

These aforementioned functions of SA are more prominent under conditions of abiotic stress, for example, salinity stress. Many research papers stated the vital role of exogenous application of SA in ameliorating the harmful effects of salinity stress [12,44]. In this study, and under the highest concentration of salinity used (40 mM), foliar spray with SA at a concentration of 90 ppm had a significant effect in mitigating the harmful effects of salinity that strawberry plants confront. Such an improving effect was exhibited in mean values of shoot fresh and dry weights (Table 2) and the leaves’ content of chlorophyll, N, P and K (Table 3), except for Na, which decreased significantly. Also, the foliar application of SA improved the leaves’ content from proline where it is a well-known osmolytes emerged under stressful conditions [45] and the activity of enzymes CAT and POD (Table 4). Consequently, the strawberry fruits’ yield in terms of quantity and quality was significantly enhanced (Tables 5 and 6). These achieved results of this study are consistent with those obtained from [13,15,42,46].
In the case of STI%, the studied characters in this investigation could be classified into three groups on the bases of STI percentages values. The first group contains the characters that presented STI% more than 100% as found with CAT, POD, proline, Na, acidity, and TSS, descending in both seasons of study; the second one is the characters that showed STI% more than 50% and below 100%, such as chlorophyll, N, K, P, total yield plant\(^{-1}\), total yield ha\(^{-1}\) and ascorbic acid, in descending order, in both seasons of study; and the third group is for traits that gave STI% values less than 50% as found with shoot fresh weight followed by shoot dry weight, in both seasons of study. According to high STI% values for CAT and POD enzymes’ activity and leaves’ proline content, it could be suggested that it is possible to use such traits as clear indicators to strawberry plants’ reaction against salinity stress. There were some scientific publications that discussed the STI as a salinity-response indicator in strawberries where it could be in the bases of total chlorophyll content and leaf, and root dry weights [47], fresh weight of plants [48], and dry weight of plants [49].

In this paper, it could be announced that this is the first time that the salt tolerance index percentage (STI%) has been estimated in a wide range of characters in strawberry plants, which could be useful for other researchers in physiology and plant breeding.

5. Conclusions

In summary, the results in this study emphasize the deleterious effects of increasing salinity on the different performances of strawberry plants cv. Camarosa. In addition, it found that the foliar application of SA at a concentration of 90 ppm could be considered as a beneficial treatment for enhancing the growth, yield, and fruits’ chemical quality as well as the monitored enzymes’ activities of strawberry plants cv. Camarosa under either normal or saline-stressed conditions. Moreover, and according to the STI% values, enzymes’ activities of CAT and POD as well as leaves’ proline content could be clear indicators to a strawberry plant’s response to salinity stress.

Author Contributions: Conceptualization, A.E.-D.R. and A.E.; methodology, A.A. and K.A.; data curation, A.E.-D.R.; writing—original draft preparation, R.A.-O.; writing—review and editing, A.E.; funding acquisition, A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded through research group no (RG-1440-046).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are openly available in the public domain given in the references.

Acknowledgments: The authors thank the Deanship of Scientific Research, King Saud University, for funding this work through research group no (RG-1440-046).

Conflicts of Interest: The authors declare no conflict of interest.

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