Chapter

Foliar Application of Salicylic Acid on Growth and Yield Components of Tomato Plant Grown under Salt Stress

Salma Wasti, Salwa Mouelhi, Feriel Ben Aïch, Hajer Mimouni, Salima Chaabani and Hela Ben Ahmed

Abstract

Abiotic environmental stresses such as drought stress, mineral deficiency, heat stress, and salinity stress are major limiting factors of plant growth and productivity. Tomato (*Solanum lycopersicum* L.), one of the important and widespread crops in the world, is sensitive to moderate levels of salt in the soil. So many authors have reported large variation among tomato genotypes in their response to salinity. The present study was conducted to study the effect of different concentrations of salicylic acid on growth parameters, yield, and yield attributes of tomato under saline conditions. Tomato plants cv. Marmande were grown under normal or saline (100 mM NaCl) conditions. Different levels of salicylic acid: SA (0, 0.01, 0.1, and 1 mM) were applied as a foliar spray. The study was conducted at the vegetative and reproductive stage. Salt stress reduced significantly the whole plant growth at the two stages. Application of SA caused a significantly increase in biomass under non-saline conditions. However, in salt medium, treatment of leaves by SA induces a slight increase in biomass, leaf area and ameliorates the fruit diameter compared with plant grown only in the presence of salt. The beneficial effect of SA is more pronounced with the dose 0.01 mM.

Keywords: tomato, growth, foliar spray, fruit, salinity, salicylic acid

1. Introduction

During their development cycle, plants are exposed to several constraints under inappropriate environments without being able to escape them. Soil salinity is a major abiotic factor that reduced productivity of many crops.

About one third of the irrigated land in the world is affected by salinity to varying degrees [1]. According to FAO [2], more than 800 million hectares of land around the world are affected by salinity, accounting for more than 6% of the earth's surface. In Tunisia, saline soils cover about 23% of the total area, i.e., 8.7 million hectares of arable land [2]. It caused various deleterious effects on morphological, physiological, biochemical, and nutritional attributes. During the onset and development of salt stress within the plant, all mechanism such as: photosynthesis and protein synthesis are affected. So, plants' first reaction was to reduce the extension of leaf area, followed by extension cessation with the increase of stress [3].

Tomatoes (*Solanum lycopersicum* L.) are today the most consumed vegetable in the world. They are an important greenhouse crop in semiarid coastal areas of Mediterranean countries. In these regions, soil and groundwater salinity are insidious problems that affect both tomato yield and quality [4]. It is known that dry biomass and fruit yield of tomato plants are strongly affected by soil salinity [5]. In a recent study, Ors and al. [6] reported that photosynthetic rate, plant dry weight, stomatal conductance, chlorophyll reading value decreased with salt in tomato seedlings. Plants exposed to NaCl stress were confronted with three fundamental problems, which are reduction of water potential, ion toxicity associated with the excessive accumulation of sodium (Na^+) and chloride (Cl^-) leading to essential cations potassium (K^+) and calcium (Ca^{2+}) deficiency, and production of ROS [7]. Salinity causes also unfavorable conditions that limit normal plant production. The increase of salinity most often causes a decrease in plants development and in general the average weight, the diameter of the stems, and size of the fruits were reduced significantly. Thus, driving with high salinity results in, therefore, a loss of production [8].

Furthermore, many research studies have focused on the physiological responses of plant subjected to salinity. The development of plants tolerant to environmental stress is seen as a promising approach, which can help satisfy the growing food demands in the world. Thus, overcoming NaCl stress is a major objective to ensure the stability of agricultural production. Salicylic acid (SA) is a signaling molecule that plays an important role in the induction of acquired systemic resistance (ASR) against pathogens; it was first demonstrated to play a crucial role in biotic stress such virus, fungi, [9]. Progressively, it was shown that SA induces tolerance to major abiotic stresses such as drought and salinity. Most papers, on this subject, have reported on the protective effect of exogenous salicylic acid against abiotic stress [9]. The exogenous application of SA affects various physiological, biochemical, and molecular processes in plants. Gharbi and al. [10] reported that SA (0.01 mM) enhanced shoot growth in Solanum lycopersicum cv Ailsa Craig and its wild salt-resistant relative Solanum chilense. Moreover, Mimouni and al. [11] found that the application of SA (0.01 mM) restored photosynthetic rates and photosynthetic pigment levels under salt (NaCl) exposure.

The purpose of this work was to study the effect of different concentrations of salicylic acid on growth parameters; yield and yield attributes of tomato under saline conditions. The study was conducted at two stages (vegetative and reproductive) and based on growth parameters (biomass production and leaf area).

2. Materials and methods

2.1 Plant material and growth conditions

Plant material studied is the cultivated tomato (*Solanum lycopersicum* L.) *var* Marmande. The tomato seeds were germinated in Petri dishes. Boxes containing 20 seeds are placed in an enclosure air-conditioned at a constant temperature (25°C) and under an illumination at low intensity (10 μ mol m^{-2} s^{-1}). Eight days after, seedlings were transferred to nutrient solution composed by macroelements and microelements as described by Wasti and al. [12] and placed in a *growth chamber* under controlled environmental conditions with relative humidity of 80%, temperature 25/18°C (day/night), artificial light 150 µmol.m^{-2}. s^{-1}, and 16 h photoperiod. Two experiments were undertaken: one at the vegetative stage and the other at reproductive stage. The salicylic acid was applied as a foliar spray.

2.2 Experience 1

The plants were grown in pots, each pot containing four plants. The plants were grown for 11 days before the start of salt treatment. Each pot receives a basic nutrient solution. After an acclimation period of 11 days, the seedlings at three-leaf stage are divided into eight lots. Four control groups without NaCl continued to grow in the basic nutrient solution : Lot (1), the leaves are sprayed daily until the end of culture by distilled water, while the lots (2), (3), and (4) are sprayed with distilled water supplemented with SA (0.01, 0.1, 1 mM). The other four lots are transferred to nutrient solution enriched with NaCl (100 mM), and the leaves are sprayed daily until the end of the culture by distilled water added or not by salicylic acid (0.01, 0.1, 1 mM). The addition of salt is done gradually, with 25 mM every 24 hours, until a final concentration of 100 mM. The pH was adjusted to 5.9 with KOH (1N).

2.3 Experience 2

The second experiment was conducted under the same culture conditions as above, has tracked the growth and development of plants to produce fruit. The plants were divided into four groups. Two groups continued to grow on the nutrient solution, leaves of the first group were sprayed with distilled water while those of the second batch were sprayed with a solution of 0.01 mM SA. Plants of the third and fourth groups were transferred to a nutrient solution supplemented with 100 mM NaCl and leaves were sprayed with SA solution 0.01 mM. Spraying of SA continued until flowers were developed.

2.4 Growth parameters and ion analysis

* Dry mass (DM) was determined after desiccation at 80°C for 48h. * Sensitivity index (SI), i.e., the difference between dry matter production of treated plants and the control, expressed in percent of the latter, was calculated according to the following expression:

$$SI_{\text{treatment}} = \left(100 \text{ x} \left(DM_{\text{treatment}} - DM_{\text{control}}\right) / DM_{\text{control}}\right). \quad (1)$$

This parameter was more negative when the plant was sensitive to treatment
* *Leaf area* of the tagged leaf 5 was determined by using a leaf area meter AM 300.

3. Results

3.1 Plant growth

The tomato seedlings treated with 100 mM NaCl are less developed than the control plants. Indeed, salt stress reduced significantly the whole plant growth (42% compared with control). Application of SA caused a significantly increase in biomass of whole plant under non-saline conditions. This increase is about 45, 30, and 32% (compared with control plants sprayed with distilled water) respectively for the concentrations 0.01, 0.1, and 1 mM. (**Figure 1**). This beneficial effect is more pronounced at the root system where there is a significant increase in biomass, about 66, 52, and 57% respectively, compared with control for the doses (0.01, 0.1, and 1 mM), whereas in aerial organs, stimulation is about 52, 33, and 32% for leaves and 26, 19, and 25% for stems compared with the control respectively for doses (0.01, 0.1, and 1 mM). (**Figure 2**).

Salt negatively affects the three organs. However, the roots were much less sensitive to NaCl than the aerial parts (leaves and stems). The decrease in dry matter was respectively 16, 40, and 50% (**Figure 2**). Foliar application of SA reduced the damaging effect of salinity on plant. The masses of dry matter increased compared with plants subjected only to NaCl. Indeed, in the presence of NaCl 100 mM, inhibition of growth of the whole plant was about 42% compared with the control plants, it was 40% when plants treated by salt were sprayed with Sa 1 mM and the inhibition was even more attenuated (29 and 27%) with the lower doses of SA (0.1 and 0.01 mM) (**Figure 1**). The root system of plants subjected to salt and sprayed by 0.01 mM SA was stimulated by 4% compared with the control (**Figure 2**).

3.2 Leaf area

The salt induced a decrease in leaf area by 50% in leaves of rank 5. Foliar application of SA induced an increase in leaf area of stressed plants. The stimulation was significantly with SA application at 0.01 and 0.1 mM (**Table 1**). While the foliar spray of SA did not affect the expansion of leaf plants grown without NaCl.

3.3 Na^+ compartmentalization

Vacuolar compartmentalization of Na^+ ions is one of the major strategies for salt stress tolerance. In tomato *var*. Marmande, when the content of Na^+ ions increases,

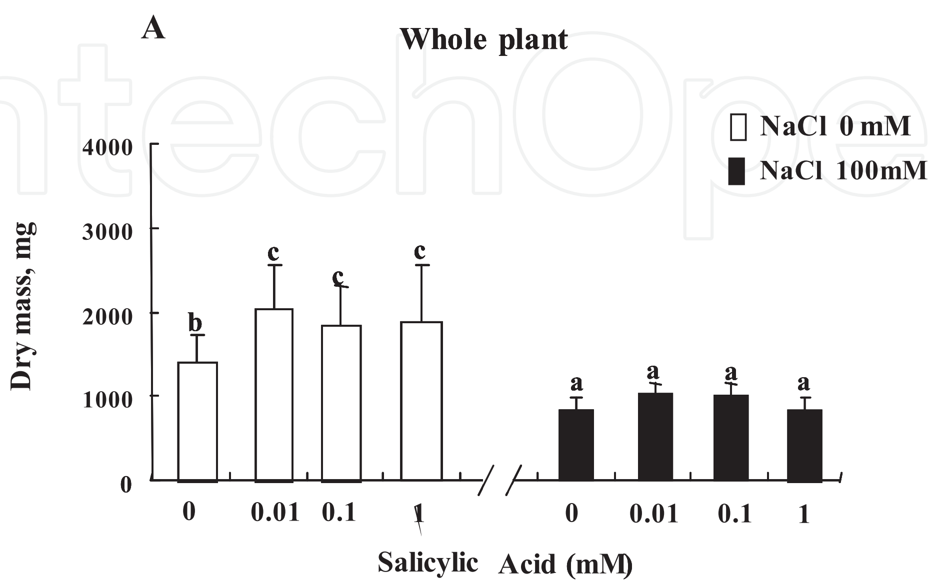

Figure 1.
Dry mass of the whole plant of tomato var Marmande submitted to 100 mM NaCl for 18 days and sprayed or not with salicylic acid (1; 0.1; 0.01 mM). Data are means of 16 replicates ± SE. Means with similar letters are not different at P ≤ 0.05 according to Duncan's multiple range test at 95%.

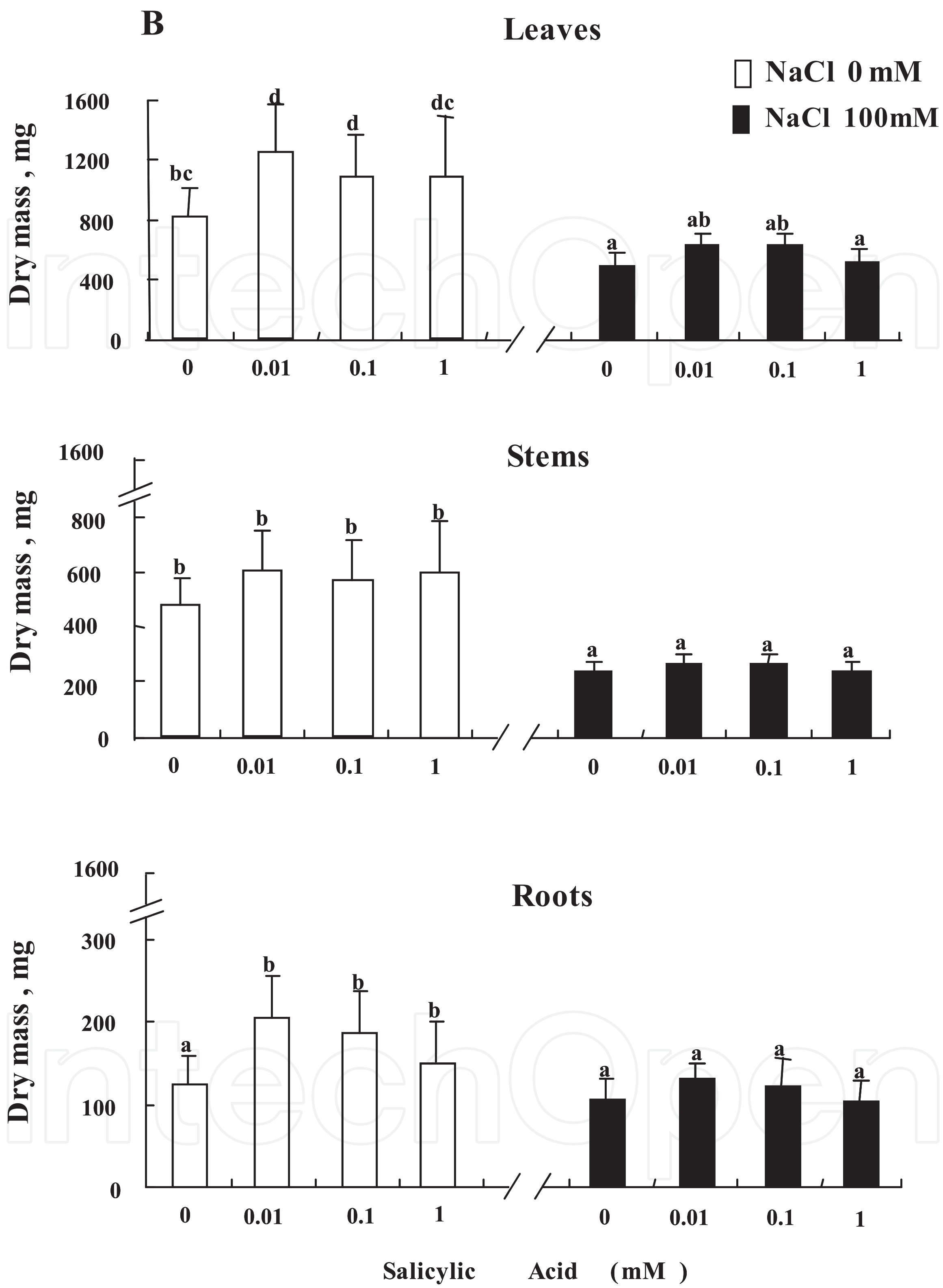

Figure 2.
Dry mass of leaves, stems, and roots of tomato seedlings submitted to 100 mM NaCl for 18 days and sprayed or not with salicylic acid (1;0.1; 0.01 mM). Data are means of 16 replicates ± SE. Means with similar letters are not different at P ≤ 0.05 according to Duncan's multiple range test at 95%.

a drop in the water content of leaf tissue is observed (**Figure 3**); this decrease suggests that Na^+ is not properly compartmentalized in the leaf tissue vacuole; on the contrary, it is accumulated in the extracellular spaces. This accumulation is associated with a tissue dehydration. In the presence of NaCl, foliar spray of salicylic acid with

SA, mM	0	1	0.1	0.01
Leaf area	129.8a	115.0a	102.1a	128.8a
NaCl 100mM+ SA	0	1	0.1	0.01
Leaf area	67.6a	71.7a	79.7b	77.8b

Table 1.
Leaf area (cm^2) of order 5 of tomato seedlings submitted to 100 mM NaCl for 18 days and sprayed or not with salicylic acid (1; 0.1; 0.01 mM). Data are means of 16 replicates ± SE.

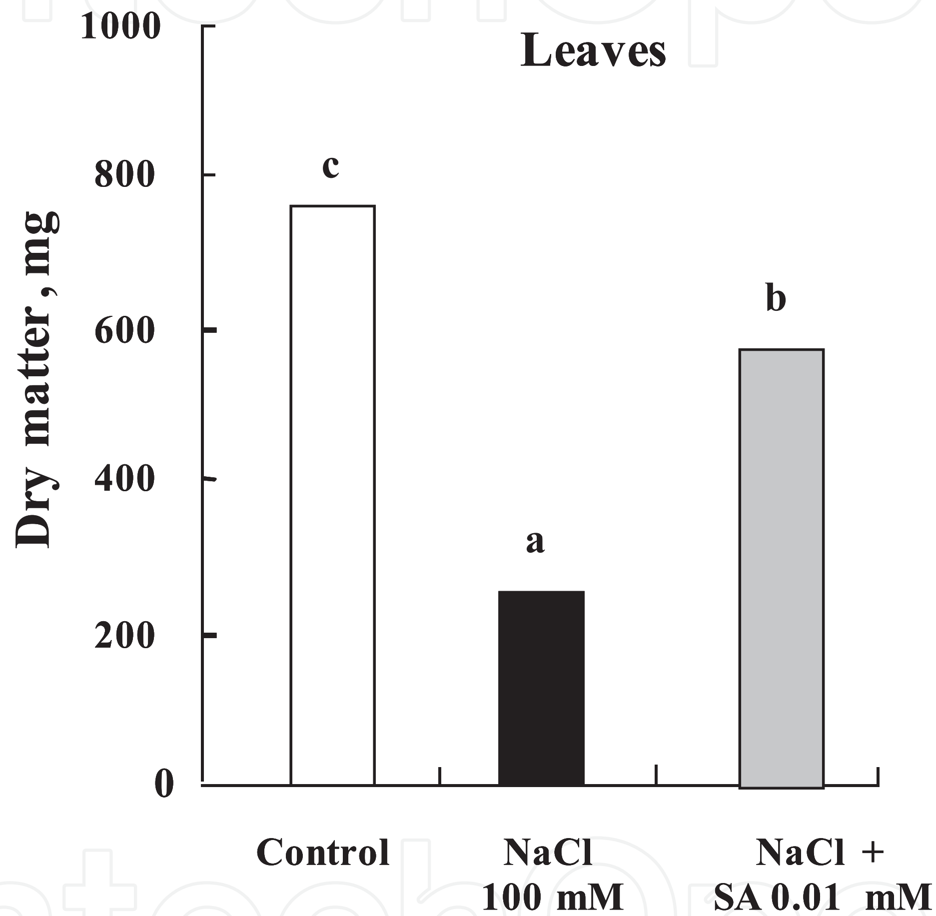

Figure 3.
Dry mass of leaves of tomato seedlings cultivated to the reproductive growth stage in the absence (Control) or presence of NaCl 100 mM and sprayed or not with salicylic acid 0,01 mM. Data are means of 16 replicates per treatment. Means with similar letters are not different at $P < 0.05$ according to Duncan's multiple range test at 95%).

different concentrations (1, 0.1, and 0.01mM) improves vacuolar Na^+ compartmentalization, as shown in **Figure 3**, since leaf water contents are relatively stable, despite the accumulation of leaf with sodium. Maintaining leaf tissue hydration despite the accumulation of sodium suggests that the leaves have a light ability to compartmentalize Na^+ in the vacuoles.

3.4 Reproductive growth stage

Based on the results of the first experiment, the better amelioration of salt tolerance of tomato plants was obtained with SA 0.01 mM, for this we have used the dose (0.01 mM) in this part of our study. Salt stress at the reproductive stage caused

Parameters	Treatments			
	Control	SA	NaCl	NaCl+SA
Number of fruit	14b	10b	4a	6a
Number of stalk	24.5b	26.5b	16.5a	16.5a
Plant height	170b	168b	75.5a	76a
Plant diameter	32.65b	31.9b	10.46a	17.85a
Root length	31.5b	39.5b	26a	38.5a

Data are means of 16 replicates per treatment. Means with similar letters are not different at P < 0.05 according to Duncan's multiple range test at 95%.

Table 2.
Yiedl parameters of tomato seedlings cultivated to the reproductive growth stage in the absence (Control) or presence of NaCl 100 mM and sprayed or not with salicylic acid 0.01 mM.

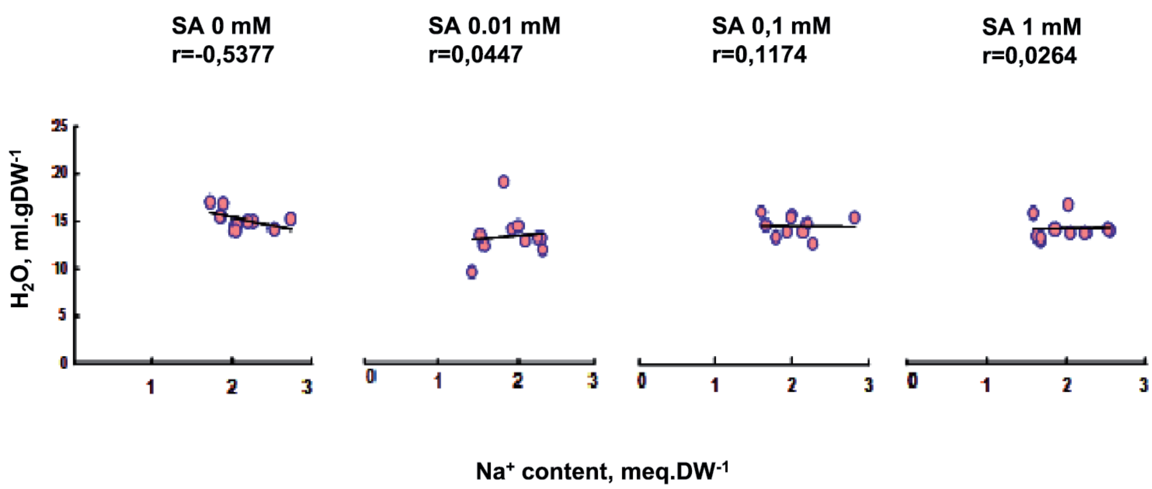

Figure 4.
Relationship between sodium and water in the leaves of tomato seedlings submitted to 100 mM NaCl for 18 days and sprayed or not with salicylic acid (1; 0.1; 0.01 mM). Data are means of 16 replicates.

a reduction in plant size, number of stalk, and fruit diameter. In detail, the length of the plants decreased from 170 cm to 75 cm, so compared with control, reduction was about 56%. In control medium, plants sprayed or not by SA at the stage were at 25 foliar stages. In the presence of 100 mM NaCl, they only have 17 stages and thus have a developmental delay. In addition, there was a significant decrease in the number and the size of fruit; it is respectively about 70 and 67% compared with control (**Table 2**).

The salt has a depressive effect on weight of aerial organs in particular stems. The decrease was equal to 70%. The foliar spray of salicylic acid (0.01 mM) attenuated the effect of salt. The reduction was more than 30% (**Figure 4**). The fruit diameter was enhanced. The amelioration was about 16% compared with plants subjected only to NaCl.

4. Discussion

Saline soils and saline irrigations constitute a serious production problem for vegetable crops as saline conditions are known to suppress plant growth [13].The present study demonstrates salinity adversely affected the growth of tomato *cv* Marmande regardless of SA treatments. Earlier studies have shown that the concentration of 100 mM NaCl decreased total dry biomass and leaf area [11, 14]. Also, previous study reported a decrease in whole plant DW, shoot DW, root DW, and leaf area in tomato plant *cv*. Marmande under NaCl stress [11].In fact, the reason of this reduction is due essentially to the nutritional imbalance and the specific ion toxicity [15]. On the other hand, it could be due to the decrease of the water content in relation to a decrease of external water potential [16]. However, foliar SA applications reduced the negative impact of salinity on growth of tomato plants. Application of SA caused a significantly increase in biomass under non-saline condition. Spraying leaves with SA at concentrations (0.01, 0.1, and 1 mM) in tomato seedlings grown on medium supplemented with 100 mM NaCl improves their tolerance to salinity, this increased tolerance is evidenced by the increase mass of dry matter and leaf area compared with plants that are subjected only to NaCl (**Figures 1** and **4**).Various studies on different plants, including quinoa [17], barley [18], and cowpea [19], showed that the use of SA ameliorates growth biomass under NaCl stress. Foliar applications of SA (0.01, 0.1, and 1 mM) in tomato seedlings grown on control medium induced a strong increase in biomass production at the whole plant, it is about 45, 30, and 32% respectively compared with the control for concentrations 0.01, 0.1, and 1 mM. These results are in agreement with those of El-Tayeb [8] and Arfan et al. [9], who reported that exogenous foliar application of SA ameliorated the adverse effects of salt stress on growth of barley and cowpea. Similarly the work of Noreen et al. [10] shows that exogenous application of SA stimulates foliar growth in sunflower plants grown in the absence or in the presence of salt. Similar results were obtained by Idrees et al. [11]. Also, Abdi et al. [12] showed that the salicylic acid causes a significant increase on the plant density and dry weight of root and shoot. Spraying maize plants "Single hybrid 10" with SA increased dry weight of stem, leaves, and whole plant [12].

To better assess the effect of salt and salicylic acid on growth of tomato seedlings *cv* Marmande, we have calculated a sensitivity index (SI) based on the dry matter production. **Table 3** shows that the presence of NaCl affects the three organs; however, it is the aerial organs, especially stems, that reflecting the greater depressive effect of salt. Foliar spraying of SA (0.01, 0.1, and 1 mM) reduces the effects caused by NaCl, this beneficial effect is more pronounced with the dose 0.01 mM, the improvement was about 15% compared with plants subjected only to NaCl. The protective effect of

Treatments	Whole plant	Roots	Stems	Leaves
NaCl	−42 a	−17.9 a	−50.6 a	−40.8 a
NaCl+SA 1mM	−40 a	−15.6 a	−51 a	−37.4 a
NaCl+SA 0.1mM	−29.3 b	−1,4 b	−45 a	−24.3 b
NaCl+SA 0.01mM	−27.6 b	+4.6 b	−43.7 a	−23 b
SA 1mM	+32.3 c	+57 c	+25.6 b	+32.6 c
SA 0.1mM	+30 c	+52.2 c	+19.3 b	+32.8 c
SA0.01mM	+45 c	+66.3 c	+26.4 b	+52.6 d

Table 3.
Index of salt sensitivity of roots, stems, leaves, and whole plant of Marmande tomatoes submitted to 100 mM NaCl for 18 days and sprayed or not with salicylic acid (1; 0.1; 0.01 mM).

exogenous salicylic on plants cultivated under abiotic stress have been also reported by Idrees et al. [21] on in lemongrass plants subjected to water stress and by Abdi et al. [22] on Marigold cultived under salt stress.

Most commercial tomato cultivars are moderately sensitive to salinity at all stages of development, including seed germination, vegetative growth, and reproduction, and therefore yield is markedly reduced [23].

Our study reports that during the whole development cycle, tomato was sensitive to NaCl. Dry weight of the leaves decreased significantly (−70%). Salt affected negatively yield and yield attributes of tomato (plant size, number of stalk, number, and size of fruit). Decreased shoot and root weight, plant height, and leaf number were reported in soybean plant due to salt stress [24]. Also Lauchli and Grattan [25] reported that salinity adversely affected performances of grain crops and cowpea plants at flowering and seed filling stage. Kinsou et al. [26]also report that salinity reduced the number of fruits in tomato (*Lycopersicon esculentum* Mill.) *var* Akikon. This number has increased from approximately 7.67 in the control plants to 5 fruits at 30 mM NaCl. Salt stress reduces also the size of tomato fruits, the productivity and increases flowering time. Foliar spray of salicylic acid (0.01 mM) counteracted salt-stress-induced growth inhibition and improved yield attributes of tomato. The fruit diameter was enhanced, amelioration was about 16% compared with plants subjected only to NaCl. According to Shakirova et al. [27], the positive effect of salicylic acid on growth and yield can be due to its influence on other plant hormones. Salicylic acid altered the auxin, cytokinin, and ABA balances in wheat and increased the growth and yield under both normal and saline conditions. Stimulation of yield under foliar application of salicylic acid could be assigned to the well-known roles of these plant hormones on photosynthetic parameters and plant water relations. Some studies showed that SA increased membrane permeability facilitating absorption and utilization of nutrients [28]. This would contribute to ameliorating the growth of the stressed plants.

In conclusion, from the results of this study, it can be affirmed that exogenous application of SA (0.1 mM) as foliar spraying once at vegetative and second time at reproductive stage influences growth parameters; yield and yield attributes of tomato under saline conditions, which could be used as a useful strategy in order to enhance the tolerance of tomato plants to salinity and biological yield.

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Conflict of interests

The authors declare that the research was conducted in the absence of any commercial or relationships that could lead to a conflict of interest.

Disclosure

The authors alone are responsible for the content and writing of the paper.

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