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Effects of Saline Irrigation Water on Verticillium Wilt Severity and Tomato Growth

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ABSTRACT

The present study describes the combined interactive effect of water salinity and *Verticillium dahliae* on tomato, and quantifies the effect of this abiotic stress on Verticillium wilt (VW) severity, plant growth and subsequent yield loss. The effects of six saline levels added to Potato Dextrose Agar (PDA) medium on the pathogen mycelial growth *in vitro* at 25°C was shown to be insignificant at $P \leq 0.05$ but reduced mycelium density and increased microsclerotia production, compared to the unamended controls, were recorded with highest NaCl doses such as 8 and 10 g/l. Increasing the salinity stress (2 to 10 g of NaCl/l) to inoculated cv. 'Ventura' tomato plants enhanced the severity of VW disease and resulted in a significant increase in leaf damage index (LDI) recorded from 35 to 62 days post-planting (DPP). Moreover, LDI noted on plants under highest salt stress (8 and 10 g of NaCl/l) was more than four times higher than the LDI recorded at 0 g/l. Watering plants (inoculated or not with *V. dahliae*) with saline water, from 15 DPP until the end of the assay (i.e., 62 DPP), negatively affected plant growth: height decreased with increasing salinity. A similar effect was noted after inoculation with *V. dahliae*. The aerial part fresh and dry weights (FW and DW, respectively) were generally lower as the salinization level increased; these parameters were reduced by 52-57 and 33-43% with higher salt treatments tested (8 and 10 g of NaCl/l) compared to the non-saline water (0 g/l), respectively. The decrease in root FW and DW ranged between 12-73 and 9-57% when salinity levels increased from 2 to 10 g of NaCl/l, compared to the control plants irrigated with non-saline water. The fruit FW was also adversely affected by the highest NaCl doses tested (8 and 10 g/l); it was reduced by 38 and 72% when compared to the non-saline treatment.

Keywords: biotic stress, disease incidence, *Lycopersicon esculentum* Mill., leaf damage, mycelial growth, salt stress, yield

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a major food plant in the world. In Tunisia, tomato is a strategic crop cultivated for fresh consumption, processing, and export. However, this crop is threatened by several parasitic microorganisms including fungi, bacteria and nematodes. The fungal species *Verticillium dahliae*, the predominant one, *V. albo-atrum* and *V. tricorpus* are involved in tomato Verticillium wilt (VW) (Hajlaoui *et al*. 2003; Jabnoun-Khiareddine *et al.* 2005). Under favorable conditions and in the absence of genetic resistance, *V. dahliae* and *V. albo-atrum* were reported to be responsible for 30 to 69% of yield losses (Jones and Crill 1975). Economic losses caused by these pathogens can reach 50% especially on tomato cultivars severely infected by *V. dahliae* (Jabnoun-Khiareddine *et al.* 2007). However, lasting recent years, several cases of resistance breakdown were noted on many resistant tomato cultivars such as 'Colibri' and 'Riogrande'. In fact, the emergence of race 2 of *V. dahliae* in Tunisia was recently reported and was shown to be involved in the outbreak of VW symptoms on resistant tomato cultivars (Daami-Remadi *et al.* 2006).

In addition to these biotic constraints related to diversity and evolution within pathogen populations, several other abiotic factors, such as fertilization and salinity, are involved in tomato VW development. In fact, mineral fertilization, via its balance, deficiency or excess may affect the severity of tomato vascular diseases such as VW (Messiaen *et al*. 1991). Thus, nitrogenous fertilizers were reported to accentuate virulence of different *Verticillium* species. Moreover, Chernyaeva *et al.* (1984) showed that fertilizers containing NH^{4+}-N stimulate soil biological activity, especially of *V. dahliae* antagonists. The effect of potassium fertilizers on reduction of VW was reported by several authors (Abdel-Raheem and Bird 1967; Hafez *et al.* 1975; Ashworth *et al.* 1982).

The effect of NaCl on VW development has been extensively studied. In fact, this disease, which is normally favored by moderate temperatures of about 20-25°C (Edginton and Walker 1957), may occur under warm conditions when the osmotic potential of the medium decreased (Besri 1980).

Irrigation with saline water may negatively affect not only the physical and chemical soil properties but also plant growth, production and metabolism leading to increased severity of some diseases (Triky-Dotan *et al.* 2005). Interaction between *V. dahliae* and water salinity was studied on potato (Nachmias *et al*. 1993) where disease expression and colonization by the pathogen were more severe on cultivars irrigated with saline water compared with those irrigated with fresh water. Similarly, Levin *et al.* (2003) reported the existence of a positive synergistic interaction between salinity and *V. dahliae* attacking olive trees where disease severity was observed exclusively at high salt concentrations.

NaCl was shown to considerably affect the incidence and severity of tomato root and crown rot caused by *F. oxysporum* f. sp. *radicis-lycopersici* (FORL) (Triky-Dotan *et al.* 2005) and tomato vascular wilt caused by *Fusarium oxysporum* f. sp. *lycopersici* (FOL) (Besri 1980; Daami-Remadi *et al*. 2009). Benyahia *et al.* (2004) reported that the increase of osmotic potential of irrigation solution by the addition of NaCl or Na_2SO_4 enhanced the development of root rot on tested rootstocks. Moreover, the osmotic pot-

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ential was increased by NaCl, predisposing roots to intense colonization by *Phytophthora parasitica*.

In Tunisia, the majority of water available for plant irrigation is brackish (El Mahjoub *et al*. 1979; Askri 2001), especially in coastal zones where infiltration of sea water causes serious salinity problems. This situation is more evident in the Sahel region where salt concentration reached 7 g/l and 50% of surface wells available for irrigation presented a salinity level higher than 4 g/l (Anonymous 2007). Moreover, the development of agricultural techniques in recent years has continuously accumulated salt in soils and salinity stress is becoming the major problem in Tunisian agriculture. The frequent use of heavy quantities of chemical fertilizers and the overexploitation of agricultural areas, especially in Sahel regions, has dramatically multiplied the surface area affected by salinity.

Due to these elementary effects of biotic and abiotic stresses on plants in general and tomato in particular, we intended to 1) study the *in vitro* action of NaCl on *V. dahliae* development, in particular, the salinity × pathogen interaction, and 2) to elucidate the *in vivo* multiple effects of the tripartite complex salinity × pathogen × plant on vegetative growth and production of tomato and on VW severity.

MATERIALS AND METHODS

Plant material

Verticillium-susceptible (*ve*) tomato seeds (*Lycopersicon esculentum* Mill. cv. 'Ventura') used were gratefully provided by the laboratory of seed and plant control of the General Direction of the Protection and Control of the Agricultural Product Quality, Tunisia.

Tomato seeds were superficially disinfected by immersion in absolute ethanol for 2 min and then extensively rinsed in sterile distilled water (SDW). Seeds were then sown in alveolus plates filled with peat previously sterilized at 107°C during 1 h. Seedlings were grown in a greenhouse and watered daily until use. Experiments were performed with 4-week-old tomato plants i.e. at the two to the three-leaf stages generally chosen for pathogen inoculation (Jabnoun-Khiareddine *et al*. 2006).

Pathogen

V. dahliae tested in the present study was isolated from tomato plants showing wilt symptoms and vascular discoloration. Monoconidial isolates were cultured at 20°C on PDA (potato dextrose agar) medium added with 300 mg/l of streptomycin sulphate (Pharmadrug Production Gmbh, Hamburg, Germany) and their pathogenicity was previously verified on cv. 'Ventura' tomato plants (Daami-Remadi *et al*. 2006).

Liquid cultures used for substrate inoculation were prepared on PDB (potato dextrose broth) and incubated at 20°C under continuous agitation at 150 rpm during 4 to 5 days. The obtained spore suspension was adjusted to 10^7 spores/ml by a Malassez cytometer. For their long-term preservation, pathogen isolates were stored up to 12 months at -20°C in a 40% glycerol solution.

Effect of different salinity levels on *V. dahliae* mycelial growth

The different quantities of NaCl (i.e. doses) tested were added to Erlenmeyer flasks containing 200 ml of PDA, just before pouring it in Petri dishes (diameter 9 cm), in order to modify the osmotic potential of the medium. Agar plugs (diameter 4 mm) of 21 days-old cultures, taken from the edges of actively growing colonies, were plated in the center of each treated Petri dish. The mean diameter of the pathogen colonies was noted after 7 days of incubation at 25°C. These *in vitro V. dahliae* × salinity level interactions were completed by several macroscopic and microscopic observations of pathogen colonies.

Statistical analyses were performed following a completely randomized design where salt treatment represented the sole fixed factor. Five replicates (five Petri plates for each salinity treatment) were used per salinity level and means were separated using Fisher's protected LSD test (at $P \leq 0.05$). All statistical analyses were performed using SPSS (Statistical Package for Social Sciences) version 11.

Effect of different salinity levels on tomato VW severity and plant growth

The root-dip method is used for tomato seedling inoculation. Seedlings at the two to three-leaf stages were uprooted, their roots washed with tap water, rinsed in SDW and dipped for 30 min in pathogen spore suspension (10^7 spores/ml). Seedlings dipped in SDW served as the uninoculated control.

All the seedlings were transplanted, immediately after inoculation, to pots (16 cm diameter) filled with a mixture of peat and perlite (75%: 25%), previously sterilized at 107°C for 1 h, and maintained under unheated greenhouse conditions where the temperature ranged between 9 and 23°C.

During the 15 first days following inoculation, plants were watered regularly with tap water to favor revival following transplanting. Thereafter, pots were watered, every 2 days, with water amended or not with NaCl. The added quantity of water was adequate to replenish the water level in the culture substrate to pots capacity. Six NaCl doses were tested: 0, 2, 4, 6, 8 and 10 g/l. Plants uninoculated with *V. dahliae* were included in the experiment to provide an assessment of the effect of the salinity on plants in the absence of the pathogen. Five plants were used per elementary treatment.

VW severity was estimated 62 days post-planting (DPP), via the leaf damage index (LDI) and according to a 0-4 scale which depends on symptom severity on leaves (Jabnoun-Khiareddine *et al*. 2007).

Plant height and LDI were recorded weekly. At the end of the assay, the root and stem dry and fresh weights (DW and FW, respectively), and the fruit weight were noted for all tomato plants.

Statistical analyses were performed, for all measured parameters, following a completely randomized factorial design where fungal treatments (inoculated or non with *V. dahliae*) and NaCl doses were the fixed factors. Five replicates per elementary treatment were used and means were separated according Fisher's protected LSD test (at $P \leq 0.05$).

RESULTS

Effect of NaCl on *V. dahliae* mycelial growth *in vitro*

The effects of six saline levels added to PDA on the mean diameter of *V. dahliae* colonies, formed after 7 days of incubation at 25°C, was shown to be insignificant at $P \leq 0.05$. Otherwise, pathogen colony development under diverse salt stresses is statistically comparable to those of the untreated control after 7 days (**Fig. 1**) and 15 days of incubation. However, some microscopic observations showed that the increasing NaCl doses in the growth medium, did not negatively affect pathogen sporulation. With highest NaCl doses such as 8 and 10 g/l, *V. dahliae* colonies showed reduced aerial mycelium production and consequently hyphal density and produced more microsclerotia than the unamended controls (**Fig. 2**).

Effect of NaCl on tomato Verticillium wilt severity

The effects of salt stress on the intensity of leaf damage caused by *V. dahliae* on tomato plants were elucidated. Since uninoculated control plants were symptomless under all stress conditions, only data of inoculated plants are presented. **Fig. 3** shows that increasing NaCl dose (from 2 to 10 g/l) to inoculated tomato plants enhanced the development of VW disease and resulted in a significant increase in the LDI recorded from 35 to 62 DPP. Hence, higher LDI was noted at 8 and 10 g/l salinity levels (**Fig. 4**).

At the end of the assay i.e., 62 days post-inoculation, the LDI recorded depended on the fungal treatment and the NaCl dose tested; a significant interaction was noted between both fixed factors at $P \leq 0.05$. **Fig. 5** shows that ino-

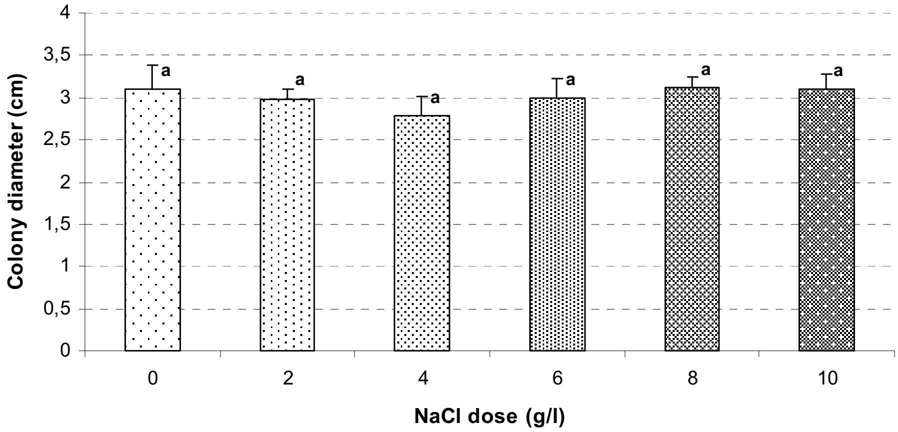

Fig. 1 Effect of different NaCl-based treatments on *V. dahliae* radial growth noted on PDA after 7 days of incubation at 25°C. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

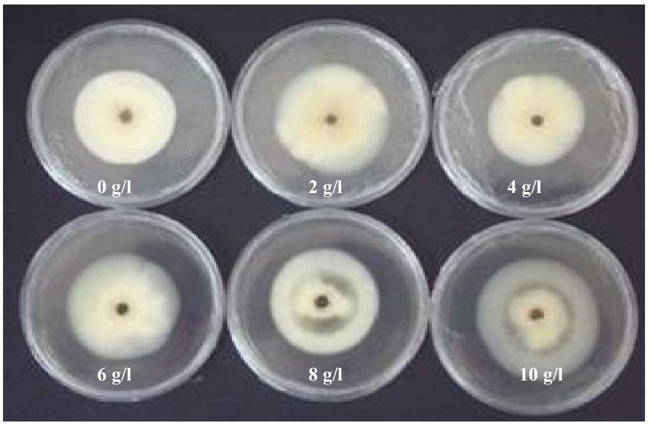

Fig. 2 Effect of different NaCl-based treatments on *V. dahliae* mycelial growth and microsclerotia abundance on PDA noted after 7 days of incubation at 25°C.

Fig. 4 Disease severity of tomato cv. 'Ventura' plants inoculated with *V. dahliae* and watered with saline water (10 g of NaCl/l), compared with uninoculated control recorded 56 days post-planting.

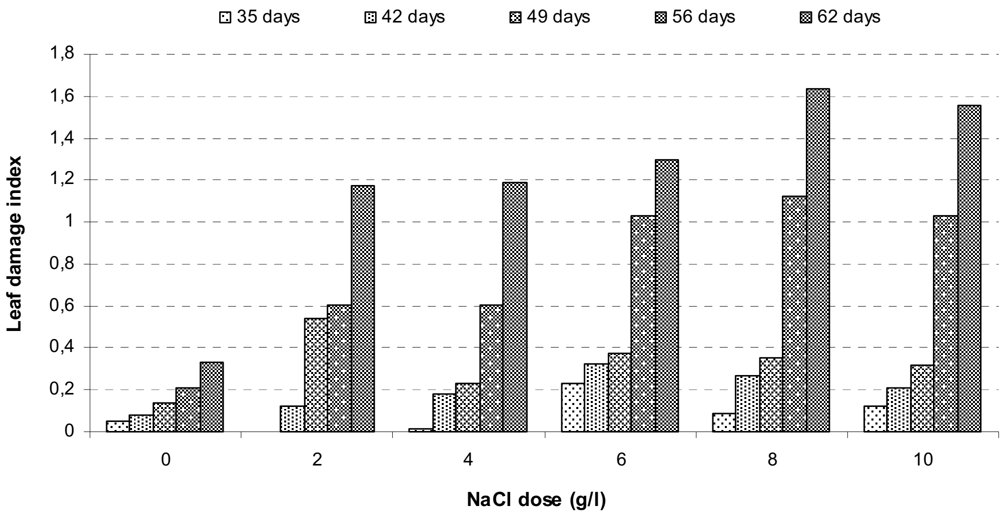

Fig. 3 Effect of increasing water salinity on the disease severity of tomato cv. 'Ventura' plants inoculated with *V. dahliae* recorded 35 to 62 days post-planting.

culated plants watered with increasing water salinity significantly enhanced wilt severity compared to plants watered with non-saline water. LDI on plants under highest salt stress (8 and 10 g of NaCl/l) was more than four times higher than that recorded at 0 g/l. NaCl doses such as 2, 4 and 6 g/l caused a significant increase in LDI compared to the unstressed control.

Effect of NaCl on tomato growth and production

1. Plant height

Plant height increase, from 35 to 62 DPP, was related to NaCl dose and fungal treatment, independently, as interaction between both fixed factors was statistically insignificant. In fact, salinity treatment in watering cv. 'Ventura' tomato plants from 15 DPP until the end of the assay nega-

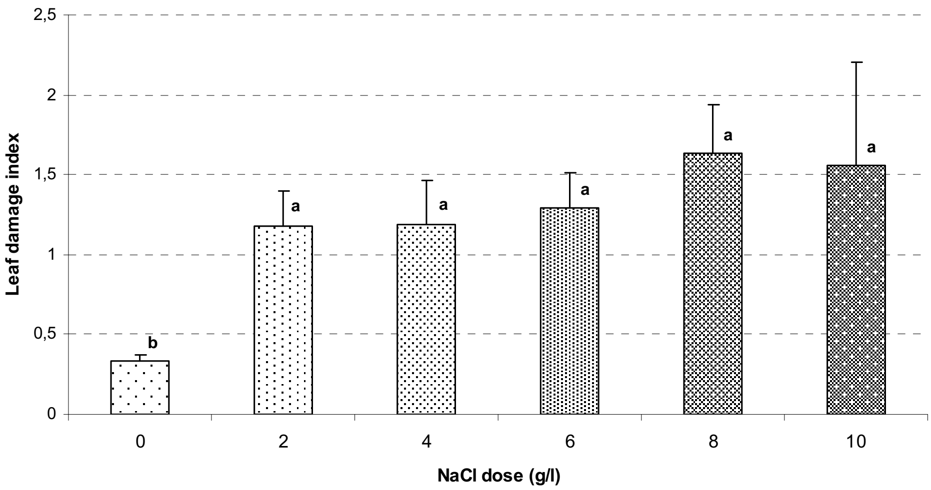

Fig. 5 Effect of increasing water salinity on the disease severity of tomato cv. 'Ventura' plants inoculated with *V. dahliae* recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

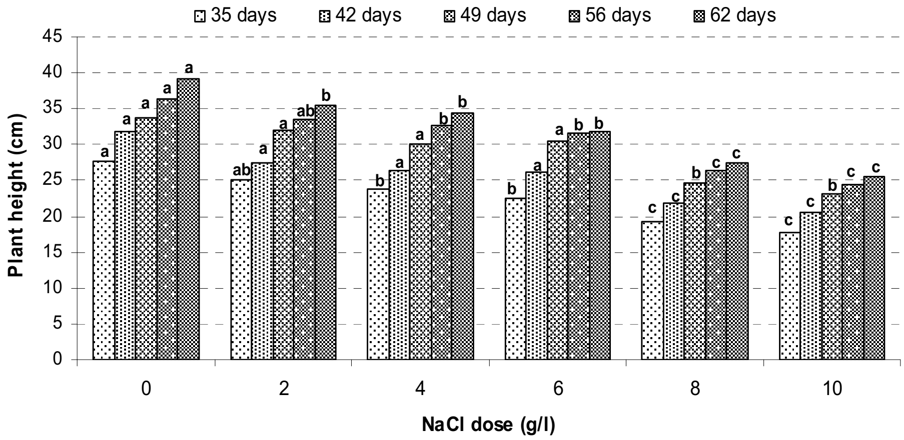

Fig. 6 Effect of increasing water salinity on the plant height of tomato cv. 'Ventura' plants recorded 35 to 62 days post-planting. For each recorded date (i.e days post-planting), bars (for NaCl doses) with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

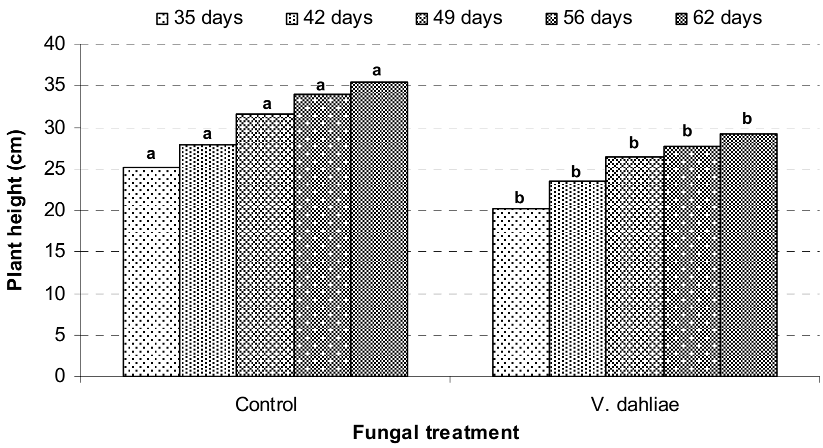

Fig. 7 Plant height of tomato cv. 'Ventura' plants inoculated or non with *V. dahliae* recorded 35 to 62 days post-planting. For each recorded date (i.e days post-planting), bars (for fungal treatments) with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

tively affected plant growth as height decreased with increasing salinity level (**Fig. 6**). The increase in plant height over time was greatest in the case of plants irrigated with non-saline water. In contrast, under highest salt treatments (8 and 10 g of NaCl/l), plant growth was strongly reduced compared to unstressed plants (0 g/l). The rate of increase in plant height, which was related to the fungal treatment, slowed down on inoculated plants compared with the uninoculated control (**Fig. 7**). The same observation was noted with saline water irrigation.

Plant height, noted at 62 DPP, depended significantly (at $P \leq 0.05$) on NaCl dose (**Fig. 8**). The decrease in this growth parameter varied between 10 and 35% when NaCl dose increased from 2 to 10 g/l. Also, plant height decreased after inoculation by the fungus (about 17% less that the uninoculated control, **Fig. 9**).

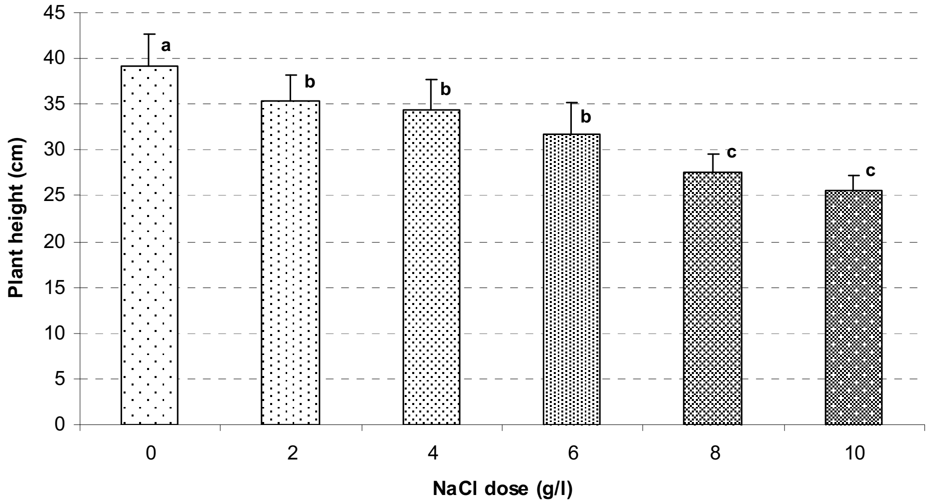

Fig. 8 Effect of increasing water salinity on the plant height of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

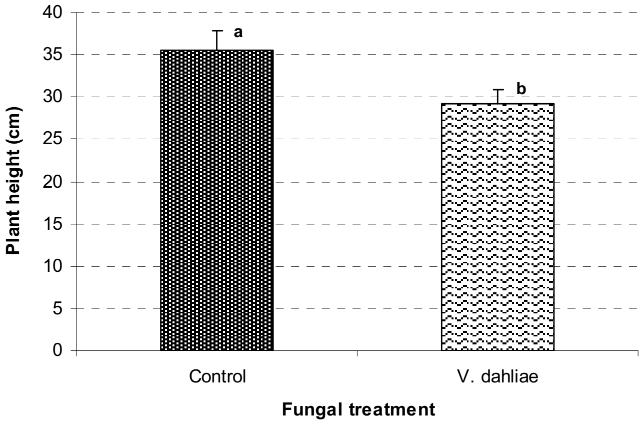

Fig. 9 Plant height of tomato cv. 'Ventura' plants inoculated or non with *V. dahliae*, recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

2. Aerial part weight

The aerial part FW and DW, noted 62 DPP, depended significantly (at $P \leq 0.05$) on salinity levels tested only as fungal treatments were shown to have an insignificant effect on both these growth parameters.

Data presented in **Fig. 10** shows that salinity adversely affected the vegetative growth of cv. 'Ventura' tomato plants. The aerial part FW was generally lowered as salinization level increased; this parameter was reduced by more than 50% with higher salt treatments tested (8 and 10 g of NaCl/l) compared to the non-saline water (0 g/l).

Similarly, the aerial part DW was also negatively affected by increasing salinity levels (**Fig. 11**) and the reduction, compared to the control plants watered with unsalinized water, ranged between 9 and 43% when NaCl dose varied from 2 to 10 g/l.

3. Root weight

The root FW and DW, noted 62 DPP, were significantly related (at $P \leq 0.05$) to the salinity level and fungal treatment, independently. The interaction between both fixed factors was statistically insignificant. In fact, for all salt treatment doses, the root FW and DW increased about 28% on inoculated tomato plants compared to uninoculated ones. However, under salt stress, both these parameters decreased when NaCl doses increase.

The reduction ranged between 12 and 73% (**Fig. 12**) for root FW when salinity levels increased from 2 to 10 g of NaCl/l, compared to the control plants irrigated with non-saline water. Significant decreases, compared to the control, were recorded with the 4, 6, 8 and 10 g/l salt treatments.

However, data presented in **Fig. 13** shows that the root DW decreased by 9 to 57% when NaCl dose varied from 2 to 10 g/l, respectively. A significant negative effect, compared to the unstressed control, was obtained with 6, 8 and 10 g/l salt treatments.

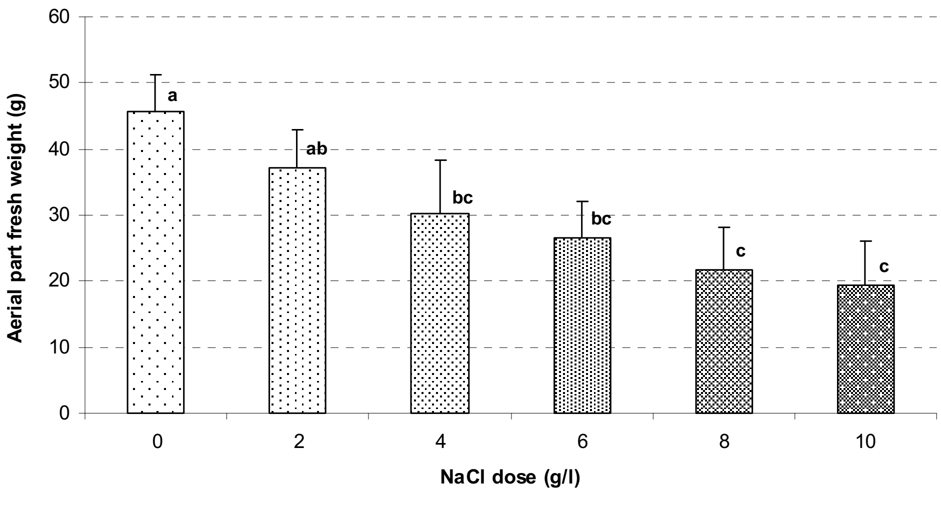

Fig. 10 Effect of increasing water salinity on the aerial part fresh weight of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

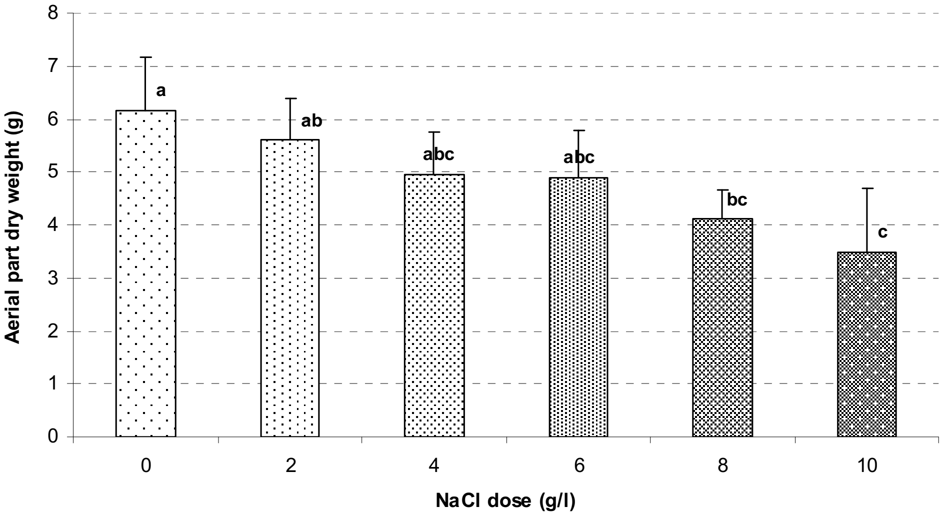

Fig. 11 Effect of increasing water salinity on the aerial part dry weight of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

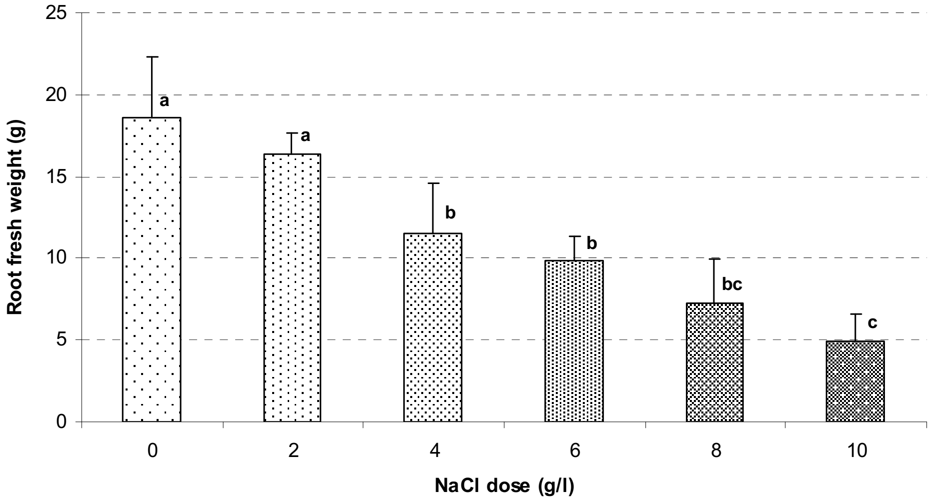

Fig. 12 Effect of increasing water salinity on the root fresh weight of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

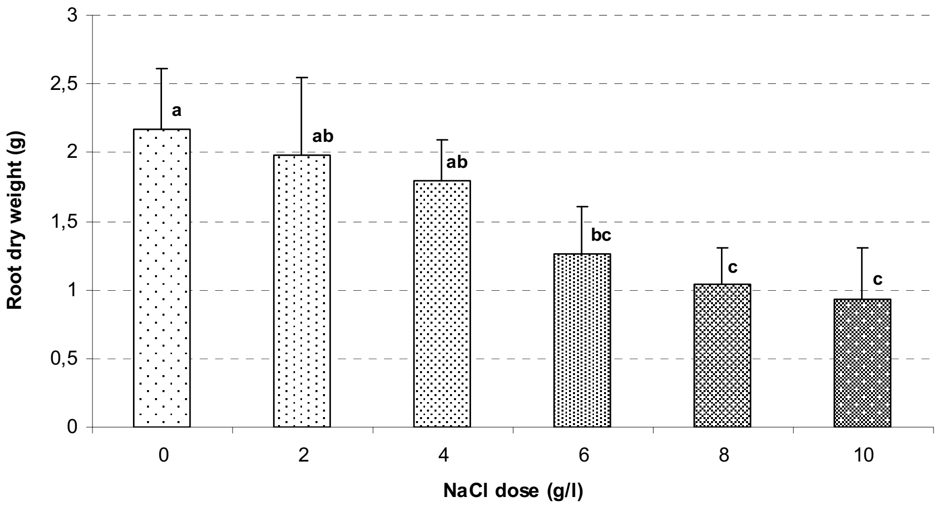

Fig. 13 Effect of increasing water salinity on the root dry weight of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

4. Fruit weight

The fruit FW, noted 62 DPP, depended significantly ($P \leq 0.05$) only on the salinity level. In fact, as shown in **Fig. 14**, this parameter was adversely affected by the highest NaCl doses tested (8 and 10 g/l); it was reduced by 38 and 72% when compared to non-saline water. The reduction recorded with less than 8 g of NaCl/l varied between 21 and 28%, but was not statistically significant.

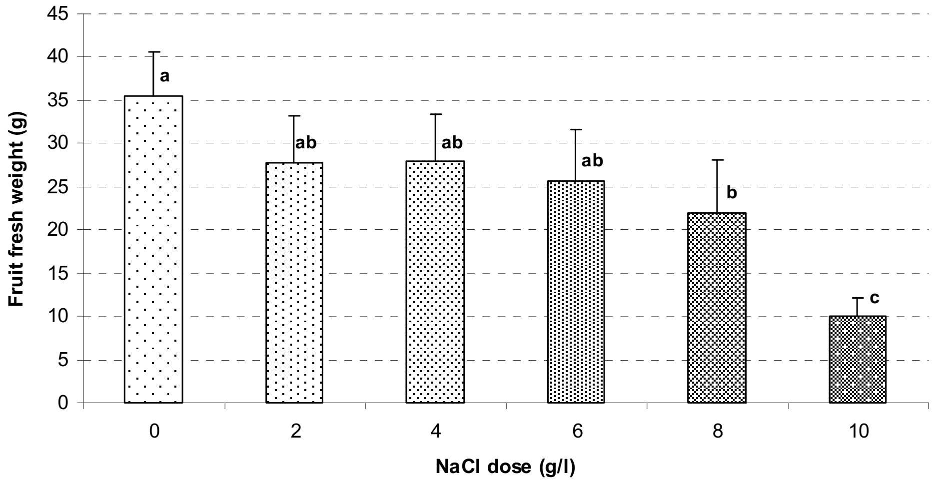

Fig. 14 Effect of increasing water salinity on the fruit fresh weight of tomato cv. 'Ventura' plants recorded 62 days post-planting. Bars with the same letter are not significantly different according to Fisher's protected least significant difference LSD test ($P \leq 0.05$).

DISCUSSION

Two decades ago, a third of all irrigated lands in the world were affected to a greater or lesser degree by salinity (Pasternak 1987) which has become currently one of the most severe abiotic factors limiting agricultural production.

Tomato is considered to be moderately sensitive to salinity (Ayers and Westcot 1985; Katerji *et al.* 2000) but is adversely affected by irrigation with saline water at levels exceeding 1.7 g/l (i.e. 2.5 dS/m) of total salts (Mass 1986; Cuartero and Fernández-Muńoz 1999). This and higher levels are evident in many surface wells in coastal Tunisian regions where tomato is intensively cultured under greenhouse or field conditions (Askri 2001). In addition to this abiotic stress, tomato has been shown to be severely affected by many soil-borne pathogens under saline conditions such as FORL (Woltz *et al.* 1992; Jones *et al.* 1993; Triky-Dotan *et al.* 2005), FOL (Besri 1980; Daami-Remadi *et al.* 2009), *V. dahliae* (Besri 1980; 1981; Regragui *et al.* 2003), and *Phytophthora parasitica* (Snapp *et al.* 1991).

Interactions between plants, nutrients, and disease pathogens are very complex and not completely understood. Work reported in the present study is the first describing the combined interactive effect of water salinity and *V. dahliae* on tomato cv. 'Ventura', and quantifying the effect of this abiotic stress on VW severity, plant growth and subsequent yield loss. Thus, this study provides additional information on VW epidemiology under conditions of salinity stress when susceptible cultivars were used.

The pathogen × salinity interaction was evaluated *in vitro*. Although the radial colony growth did not take into account changes in hyphal density or specific growth rate as mentioned by Subbarao *et al.* (1993), it is usually a reliable parameter to measure the effect of an environmental variable on the fungi growth. Moreover, Cook (1973) mentioned that this kind of *in vitro* experiments may reflect the pathogen behavior *in vivo*, inside plant tissues.

The present results showed that the different salinity levels tested did not negatively affect *V. dahliae* radial growth. Several pathogens other than *V. dahliae* were reported to be tolerant to salts in culture, including *Aspergillus*, *Penicillium* and *Fusarium* spp. (Tresner and Hayes 1971), *Pythium aphanidermatum* (Rasmussen and Stanghellini 1988), *Phytophthora* spp. (MacDonald 1982; Blaker and MacDonald 1985), *Fusarium oxysporum* f. sp. *lycopersici* (Besri 1980; Daami-Remadi *et al.* 2009), and *F. oxysporum* f. sp. *vasinfectum* (Ragazzi and Vecchio 1992). However, NaCl was shown to cause greater reductions of *in vitro* growth of charcoal rot causal agent than KCl or sucrose. NaCl caused the greatest negative effects on *Macrophomina phaseolina* development, morphology and sclerotinization due to reduced pigment synthesis and increased aerial mycelium production (Cervantes-García *et al.* 2003).

The *in vitro* salinity × *V. dahliae* interaction studies, reported in the present work, showed insignificant effect of salt treatments tested on pathogen sporulation and an important increase in resting structures formation under higher salinity levels associated with a slight reduction in hyphal density. Thus, the interaction of pathogens with salinity seemed to be quite specific, complex and can not be extrapolated for all soil-borne fungi even if they occupied the same ecological niche and are submitted to the same abiotic stress.

The salinity × *V. dahliae* interaction studies on tomato cv. 'Ventura' showed that plants inoculated with *V. dahliae* and watered with increased saline water concentrations were severely affected by VW. This finding is in accordance with previous reports on *V. dahliae*: Besri (1990), Livescu *et al.* (1990) and Nachmias *et al.* (1993). In fact, the interaction between *V. dahliae* and saline irrigation water was observed on potato where disease expression and colonization levels of the fungus were found to be more severe in *V. dahliae*-tolerant cultivars irrigated with saline water compared with plots irrigated with fresh water (Nachmias *et al.* 1993). In the same way, *V. albo-atrum* has been isolated from alfalfa growing in a region of the Mojave desert of California (Erwin *et al.* 1988, 1989) where soil salinity is typically high (Backlund and Hoppes 1984). Experimentally, the addition of salinity stress (3.0 or 5.0 dS/m) to inoculated NK-89786 alfalfa plants enhanced the progression of VW disease (Howell *et al.* 1994).

Soil exposed to salinity has been also reported to increase the susceptibility of some crops to soil-borne fungi such as *Phytophthora* spp. (MacDonald 1982; Blaker and MacDonald 1986; Bouchibi *et al.* 1990; Snapp *et al.* 1991; Sanogo 2004), *Pythium ultimum* (Martin and Hancock 1981), FOL (Daami-Remadi *et al.* 2009) and FORL (Woltz *et al.* 1992; Jones *et al.* 1993). The incidence and severity of crown and root rot disease of tomato increased significantly under irrigation with saline water; the pathogen build-up at the root zone in soil was faster, the disease onset came earlier, and yield was significantly reduced (Triky-Dotan *et al.* 2005). Moreover, salinity stress may weaken the genetic resistance of plants to disease by inducing changes in susceptibility of root tissue to pathogen concentration (MacDonald *et al.* 1984).

The present results showed that the majority of growth parameters, i.e., plant height, aerial part and root FW and DW were negatively affected by water salinity levels. Only the highest NaCl concentrations affected all of the considered parameters and caused a significant reduction in root and shoot growth. These findings equals that of several authors who found that salinity adversely affected the vegetative growth of tomato, and it reduced plant length and

DW (Adler and Wilcor 1987) and also the FW and DW of shoots and roots (Omar *et al*. 1982; Shannon *et al*. 1987; Hajer *et al*. 2006; Daami-Remadi *et al*. 2009). Increasing NaCl concentration in nutrient solution adversely affected tomato shoot and roots, and plant height (Al-Karaki 2000). Furthermore, the leaf and stem DWs of tomato were also significantly reduced in plants irrigated with saline nutrient solution in contrast with control plants (Satti and Al-Yahyai 1995). Reduction of DWs due to increased salinity may be a result of a combination of osmotic and specific ion effects of Cl and Na (Al-Rwahy 1989).

These growth parameters were reduced by more than 50% with higher salt treatments i.e., 8 and 10 g/l doses tested. Thus, cultivation of susceptible tomato cultivars such as cv. 'Ventura' may lead to increased plant growth inhibition associated with increased VW severity.

Moreover, the fruit FW was adversely affected by higher NaCl doses tested (8 and 10 g/l); it was reduced by 38 and 72% compared to non-saline water. Similarly, greater yield losses were caused by salinity stress submitted to tomato cv. 'Ventura' plants infested with FOL and alfalfa plants already inoculated with *V. albo-atrum* (Howell *et al*. 1994; Daami-Remadi *et al*. 2009). In the same way, the use of saline water for irrigation increases the salt concentration in the soil and thereby affects plant development by reducing plant growth, yield, and quality (Akilan *et al*. 1997).

The effect of salinity on plant disease may result from its effect on one or more biotic components involved in the disease: the pathogen, the host resistance or susceptibility, the microbial activity in the soil, or the abiotic components of the soil (Triky-Dotan *et al*. 2005). In fact, increasing salt in the root zone induces osmotic changes and interferes with nutrient uptake (Cornillon and Palloix 1997; Halperin *et al*. 2003). Nutrient imbalances resulted from the effect of salinity on nutrient availability, competitive uptake, transport or partitioning within the plant (Grattan and Grieve 1994). Moreover, irrigation water containing NaCl contributes to the direct effects of excess salt on plant growth that may be described as an osmotic stress, reducing water availability; ion imbalance stress, caused by antagonistic effects on nutrient elements; and specific toxicity of Cl^-, Na^+, or both (Víllora *et al*. 2000).

Our findings concerning the interaction of VW disease of tomato with salinity correspond to studies in similar or different pathosystems and indicated that the use of even lower salinity waters (as is the case of the dose 4 g/l and to a lesser degree 2 g/l) can affect plant health and growth. Moreover, based on this pot experiment, it is possible that for tomato cultivars growing in areas where water salinity already causes a problem, an increase in susceptibility to VW can amplify the yield reduction more.

Consequently, an effective management of *V. dahliae* in fields with high level of salinity should include, in the future, the selection of resistant cultivars with tolerance to salinity for limiting eventual yield losses due to concomitant biotic and abiotic stresses. However, further studies on comparative behavior of available resistant and susceptible tomato cultivars under salt stress are needed to be planned firstly.

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