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GROWTH AND ANATOMY OF TOMATO (*SOLANUM LYCOPERSICUM* MILL.) CULTIVARS MARMANDE AND ORIA UNDER SALINITY STRESS

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Abstract

This research investigates how irrigation with various salinity levels affects the anatomy and growth of two different tomato cultivars, namely Marmande and Oria. The two cultivars were planted in an outdoor greenhouse under natural conditions in King Abdul-Aziz University from April to May 2014. Compared to the controls the experiments with higher salinity showed significantly reduced fresh weight, dry weight, water content, shoot length, and root length. Salinity had various negative effects on the anatomy of the tomato cultivar Marmande on its xylem parenchyma and surrounding cells' profiles, on its lignification, on its vessels diameter, and on the thickness of its wall in its roots and shoots sections. Salinity had minimal to no effect on tomato cultivar Oria. The tomato cultivar Oria thus showed a higher tolerance to salinity. The highest level of salinity produced greater deleterious effects. The results indicate that the Oria cultivar is tolerant to salinity. This study accordingly the Oria cultivar is recommended for high salinity conditions.

Key words: Anatomy, Tomato, Growth parameters, Salt stress.

Introduction

Salinity stress affects agricultural development in a number of regions, particularly in semi-arid and arid regions (Mousa *et al*., 2014). Tomatoes are significant crops with economic significance (Marsic & Osvald, 2004). Countries such as Saudi Arabia consider high-quality yield an important prerequisite of economic success when in tomato farming (Gerster, 1997; Abdel-Monaim, 2012; Di Cesare *et al*., 2012). In 2011, the Saudi Arabian government dedicated 14,175 hectares of land to tomato cultivation and yielded 483,588 tons of tomatoes during harvest. The country imports approximately 340,000 tons of tomatoes annually, at a cost of approximately 20 million US$ (Anon., 2013). On average, Saudi's consumption rate of processed and fresh tomatoes is approximately 31 kg per capita annually (Statistics, 2007). Tomatoes are considered important as a nutraceutical due to their phytochemical, chemo-preventive, and nutraceutical properties (Ferrari, 2004). Moreover, consumption of the fruit is effective in diseases, particularly ophthalmic, skin, and respiratory diseases (Hasan *et al.*, 2014). Although tomatoes thrive in various climates and soils, their growth may be affected by extremely high temperatures and humidity (Boamah *et al*., 2011). Studies have indicated that tomatoes are either tolerant or sensitive to saline environments based on the cultivar and growth stage (Santa-Cruz *et al*., 2002; Fernandez-Garcia *et al*., 2004; Estan *et al*., 2005). In addition, at the early growth stages, the dry and fresh weights of the shoots and roots can indicate salinity tolerance (Ashraf *et al*., 1999). Al-Tardeh & Iraki (2013) conducted anatomical experiments on the section just below the roots' hypocotyl zone on tomato cultivars from Palestine and found that salt-treated seedlings had roots with reduced vascular tissues. Ceccoli *et al*., (2011) performed anatomical experiments on cross-sections of roots and found that the anatomical parameters of this area reduced with an increase in salinity in *Chloris gayana* Kunth.

This study aims to determine the anatomical and growth factors of two different tomato cultivars in a concentrated saline environment to determine their adaptation process when exposed to salinity.

Materials and Methods

Growth experiment: From April to May of 2014, two tomato cultivars (Marmande and Oria) were grown in a greenhouse under natural light, temperature, humidity, and night/day rhythm. The seeds were grown in perforated plastic, each of which had a 2 kg mixture of acid washed, sieved sand and peat moss soil in the ratio of 2:1, respectively. These seeds were then irrigated with tap water until germination. The perforated pots were divided to form seven different groups. Each group had three pots. Ten seedlings in every pot were left in open ground with temperatures of about 40°C and at soil water potential near field capacity. The seedlings were continuously irrigated using tap water for 14 days. The resultant seedlings were exposed to water with varying salinity levels for a period of three weeks. The salinity levels were 25, 50, 75, 100, 125, and 150 mM. Upon completion of the experiment, the water content, dry and fresh weights, and shoot and root lengths were measured across every pot in the experiment. The various segments of the roots and shoots were treated with formaldehyde and transferred to the University's electronic microscope unit for further anatomical investigation.

Statistical analysis

All the data collected was subject to a one-way variance analysis (ANOVA) using SPSS and Duncan's multiple range test (p<0.05).

Results and Discussion

Fresh and dry weight: Based on the data in Table 1, it is evident that the fresh and dry weights of the shoots and roots of tomato cultivars reduced with increasing salinity levels in comparison to the control seedlings. The lowest root and shoot decreases were reported at a salinity level of 150 mM. According to Hernandez *et al*., (1995), the dry and fresh weights of various parts of the plant, such as the stems, leaves, and roots, had decreased due to salinity stress. The findings of AliDinar *et al*., (1999) and Chartzoulakis & Klapaki (2000) concurred with the results of this study. Satti & Lopez (1994) reported that one of the reasons for the decrease in the dry weights of roots is water stress as a result of salinity. Water stress prevented the plant from undergoing photosynthesis. As a result, the translocation of photosynthates and assimilates failed, thereby affecting growth of the plant. Furthermore, the reduced dry and fresh weight is a result of various factors, including cell membrane destruction, reduced photosynthesis, reduced water within the plant, and the increased presence of sodium ions within the leaf structure inhibiting growth (Sharifi *et al*., 2006).

Water content: Shoot and root water content was negatively affected by salinity levels, to varying degrees, in both cultivars. In Table 1, in Marmande, the results illustrate that the salinity stress in the studied range significantly reduced water content (WC) in both the shoot and the root. The lowest WC percentages were 89.20% and 89.97% in plant shoot and root, respectively. In control plants, WC percentages were 96.28% and 95.33% in shoot and root, respectively.

In Oria, at all studied salinity levels, WC percentages were significantly lower than those of control plants. All Oria shoots had comparable values, and there were no significant differences across shoot measurements. In the Oria roots, no significant differences were observed in WC when applying lower salinity levels (25 mM and 50 mM) in comparisons to control plants. Under salinity levels higher than 50 mM, root WC percentage was gradually reduced by increasing salinity level in the culture media, reaching its lowest value (88.90%) at level 150 mM compared to (96.59%) at control. Some studies were conducted on *Iris lacteal,* and the results indicate that the WC of the plant roots and leaves decreased as the levels of salinity increased. As the concentration of salinity in the medium increased, the plant roots and shoots decreased as salt stress affects the absorption of water in roots and leaves (Wen-Yuan *et al.*, 2012).

The length of the shoot and root: The data in Table 2 indicaotes a marked reduction in shoot and root length due to salinity stress in both cultivars. In Marmande, there was a gradual decrease in shoot and root length compared to the control when increasing salinity. The shortest shoots and roots were 21.93 and 10.67 cm, respectively. These lengths were recorded for the plants grown at a 150 mM salinity level. However, in the control plants, the shoot and root lengths were 32.00 and 16.04 cm, respectively.

In Oria, the shortest shoots and roots were 26.70 and 7.07 cm at 150 and 125 mM, respectively. Under control conditions, shoot and root lengths were 32.03 and 8.87 cm, respectively. Various studies have found that the growth of the roots and shoots in a salinity medium compared to control plants is an effective method of determining the tolerance of tomatoes to salinity stress (Bolarin *et al*., 1991; Foolad, 1996). In order to determine the effect of salinity stress on plants, the length of the roots and shoots of the studied plants are significant parameters because water in the soil is absorbed directly to the plant through the roots. As a result, the effect of salinity stress on a plant can be observed in its roots and shoots (Jamil & Rha, 2004). Ciobanu and Sumalan (2009) conducted a study on *Lycopersicum esculentum* and found that as the levels of salinity increased, the length of shoot and root reduced significantly. However, the root lengths seemed to be more affected than those of the shoots. This finding may be because increased salinity harms the plant and causes nutrient imbalances. According to Werner and Finkelstein (1995), increased salinity stress reduces water uptake in plants. A result of this increased uptake is that root and shoot lengths are reduced.

Anatomy: The results of the microscopic analysis unit illustrate that Marmande root's vascular system was significantly affected by higher salinity (Fig. 1). Salt destroyed the studied plants' xylem parenchyma and the profiles of surrounding cells at various levels of salinity in comparison to control plants. These effects were dependent on salinity concentrations, as seen in Column A of Fig. 1. In addition, increased salinity stress further harms the plant's xylem vessels compared to control seedlings, as seen in Column B of Fig. 1. The roots of plants exposed to salinity stress had lower vascular cell thickness compared to the control plants. Furthermore, increased salinity stress reduced lignin disposition in roots' vascular tissues in studied plants compared to control plants. In Marmande, salt particles were observed between root cells as well as the root's xylem vessels at salinity levels of 150 mM, as shown in Fig. 1, on 150 mM (B and C).

Oria's anatomical investigations show the varying effects of salinity stress on the vascular systems of the studied plant roots (Fig. 2). Generally, salinity levels increased, the roots' xylem parenchyma and profiles of the surrounding cells significantly decreased compared to the control plants, as demonstrated in Column A of Fig. 2. The xylem vessels had the highest lignin disposition at salinity levels of 50 mM. Moreover, at the lowest levels of salinity (50 mM), the studied plants had increased diameter and thickness of xylem vessels compared to control seedlings (Fig. 2, Column B). However, as levels of salinity increased, the lignin deposited in the xylem vessels decreased. Also, vessel sizes decreased as walls became thinner at salinity of 100 mM, as shown in Fig. 2, Column B (100 mM). Salinity stress had a harmful effect on xylem vessels starting at a maximum of 150 mM. At this level, some of the xylem vessels decayed completely, as demonstrated in Fig. 2, Column B (150 mM).

Table 1. The mean values ± SE for tomato cultivars' shoot and root dry weight, fresh weight, and water content (WC) at various levels of salinity.

The different litters are markedly different at $p<0.05$.

	Concentrations	Fresh weight (g/plant)		Dry weight (g/plant)		WC (%)	
		Shoot	Root	Shoot	Root	Shoot	Root
Marmande	Control	24.12 ± 0.18 ^{d}	3.00 ± 0.09 ^{e}	2.24 ± 0.04 ^{f}	0.20 ± 0.01 ^{d}	96.28 ± 0.21 ^{e}	95.33 ± 0.34 ^{d}
	25 mM	21.83 ± 0.81 ^{c}	2.55 ± 0.02 ^{d}	2.17 ± 0.02 ^{f}	0.19 ± 0.00 ^{d}	93.45 ± 0.25 ^{d}	94.93 ± 0.23 ^{d}
	50 mM	20.12 ± 0.66 ^{bc}	1.96 ± 0.08 ^{c}	1.80 ± 0.01 ^{e}	0.16 ± 0.01 ^{c}	91.91 ± 0.21 ^{c}	93.47 ± 0.22 ^{c}
	75 mM	19.87 ± 0.97 ^{b}	1.64 ± 0.06 ^{b}	1.43 ± 0.00 ^{c}	0.14 ± 0.00 ^{b}	90.72 ± 0.25 ^{b}	92.07 ± 0.33 ^{b}
	100 mM	16.70 ± 0.32 ^{a}	1.65 ± 0.11 ^{b}	1.53 ± 0.03 ^{d}	0.13 ± 0.00 ^{b}	90.86 ± 0.10 ^{b}	92.43 ± 0.07 ^{bc}
	125 mM	15.12 ± 0.07 ^{a}	1.42 ± 0.10 ^{ab}	1.20 ± 0.01 ^{b}	0.08 ± 0.01 ^{a}	90.89 ± 0.36 ^{b}	91.80 ± 0.26 ^{b}
	150 mM	14.90 ± 0.50 ^{a}	1.32 ± 0.11 ^{a}	0.56 ± 0.03 ^{a}	0.07 ± 0.00 ^{a}	89.20 ± 0.26 ^{a}	89.97 ± 0.78 ^{a}
	F-value	35.38**	49.73**	525.93**	128.46**	88.87**	24.20**
Oria	Control	17.28 ± 0.04 ^{d}	1.52 ± 0.07 ^{g}	1.16 ± 0.02 ^{d}	0.15 ± 0.00 ^{d}	95.35 ± 0.06 ^{b}	96.59 ± 0.12 ^{d}
	25 mM	15.28 ± 0.27 ^{c}	1.35 ± 0.04 ^{f}	1.08 ± 0.02 ^{cd}	0.08 ± 0.00 ^{c}	92.75 ± 0.34 ^{a}	95.80 ± 0.39 ^{cd}
	50 mM	14.30 ± 0.13 ^{b}	1.32 ± 0.04 ^{e}	1.00 ± 0.07 ^{bc}	0.06 ± 0.00 ^{b}	93.03 ± 0.50 ^{a}	95.79 ± 0.25 ^{cd}
	75 mM	14.48 ± 0.25 ^{bc}	1.18 ± 0.04 ^{d}	0.99 ± 0.03 ^{bc}	0.06 ± 0.00 ^{b}	92.64 ± 0.28 ^{a}	94.70 ± 0.85 ^{bc}
	100 mM	14.02 ± 0.47 ^{b}	1.11 ± 0.01 ^{c}	0.90 ± 0.02 ^{b}	0.05 ± 0.01 ^{a}	93.30 ± 0.13 ^{a}	94.18 ± 0.17 ^{b}
	125 mM	12.25 ± 0.40 ^{a}	0.96 ± 0.04 ^{b}	0.89 ± 0.03 ^{b}	0.05 ± 0.00 ^{a}	92.89 ± 0.43 ^{a}	89.04 ± 0.64 ^{a}
	150 mM	12.21 ± 0.20 ^{a}	0.58 ± 0.05 ^{a}	0.71 ± 0.02 ^{a}	0.04 ± 0.00 ^{a}	92.52 ± 0.08 ^{a}	88.90 ± 0.29 ^{a}
	F-value	37.60**	44.58**	17.67**	125.66**	10.39**	49.74**

ns= Non-significant, *= Significant at $p\leq0.05$, **= Significant at $p\leq0.01$, ***= Significant at $p\leq0.00$

Table 2. The mean values ±SE for shoot and root lengths of tomato cultivars grown at various salinity levels. The different litters are markedly different at *p<0.05*.

	Concentrations	Length (cm/ plant)	
		Shoot	Root
Marmande	Control	32.00 ± 0.49 ^{d}	16.04 ± 0.32 ^{e}
	25 mM	30.65 ± 0.61 ^{cd}	14.52 ± 0.09 ^{cd}
	50 mM	29.91 ± 0.22 ^{c}	14.99 ± 0.50 ^{d}
	75 mM	29.98 ± 0.90 ^{c}	14.27 ± 0.08 ^{cd}
	100 mM	28.23 ± 0.27 ^{b}	13.93 ± 0.26 ^{c}
	125 mM	22.68 ± 0.37 ^{a}	11.73 ± 0.19 ^{b}
	150 mM	21.93 ± 0.43 ^{a}	10.67 ± 0.02 ^{a}
	F-value	59.97**	52.76**
Oria	Control	32.03 ± 0.12 ^{e}	8.87 ± 0.12 ^{d}
	25 mM	30.67 ± 0.52 ^{d}	8.73 ± 0.20 ^{cd}
	50 mM	30.00 ± 0.49 ^{cd}	8.73 ± 0.28 ^{cd}
	75 mM	29.27 ± 0.07 ^{bc}	8.17 ± 0.23 ^{bc}
	100 mM	28.67 ± 0.62 ^{b}	8.00 ± 0.10 ^{b}
	125 mM	26.77 ± 0.18 ^{a}	7.07 ± 0.20 ^{a}
	150 mM	26.70 ± 0.38 ^{a}	7.40 ± 0.10 ^{a}
	F-value	24.84**	13.59**

ns= Non-significant, *= Significant at $p \leq 0.05$, **= Significant at $p \leq 0.01$, ***= Significant at $p \leq 0.001$

Between moderate and high salinity levels of 100 and 150 mM, the negative effects of salinity stress on the anatomy of the vascular tissues of Marmande shoots were clear, particularly at 150 mM salinity. In Fig. 3 (Column A [100 mM] and [150 mM]), the profile of the surrounding cells and xylem vessels was significantly more affected at the two salinity levels compared to those of control plants displayed in Fig. 3 (Column A [Control]). The deposition of lignin in the plant's xylem vessels was not affected by low or moderate levels of salinity. However, the lignin disposition reduced at high levels of salinity compared to the control plants (Fig. 3, Column B). The walls of the xylem vessels began to decay at moderate levels of salinity (100 mM). This effect reaches the maximum at salinity levels of 150 mM (Fig. 3, Column B).

In Fig. 4, the effect of salinity concentrations on the anatomy of Oria shoots' vascular systems from control to salinity levels of 150 mM is shown. Based on the anatomical studies, the Oria shoots' vascular systems showed a relatively high tolerance to salinity stress compared to the Oria roots' vascular systems. Furthermore, the salinity concentrations had no effect on the profiles of surrounding cells and xylem parenchyma at low and moderate salinity levels of 50 mM and 100 mM, respectively. However, few negative effects were observed at high levels of salinity of 150 mM, as shown in Fig. 4 (Column A). Correspondingly, the amount of lignin deposited on the xylem vessels at salinity levels of 150 mM decreased in comparison to that observed in control plants (Fig. 4, Column B). The xylem vessels' diameters exhibited no significant effect in the various salinity levels studied (Fig. 4, Column B).

These results are similar to those found by Al-Tardeh & Iraki (2013). Al-Tardeh & Iraki (2013) studied two Palestinian tomato cultivars and found that the seedlings exposed to salinity stress had reduced vascular functioning in the roots. In addition, the profiles of the phloem and xylem parenchyma were significantly reduced in saline environments. According to Farhana *et al.,* (2014), in parallel studies on maize plants, there were significant changes in the vascular systems of either the roots or stems of the plants exposed to salinity stress. For instance, under saline stress, the maize plant exhibited reduced stem diameters. The vascular tissues and cell sizes of the plants reduced when exposed to salinity. Furthermore, the cross-sectional areas of roots of plants exposed to salinity stress were significantly reduced. The roots of plants under salinity stress exhibited reduced vascular function and cortical parenchyma compared to control plants. These changes in the number and diameter of xylem vessels significantly affected the intake and transport of water (Choat *et al*., 2005).

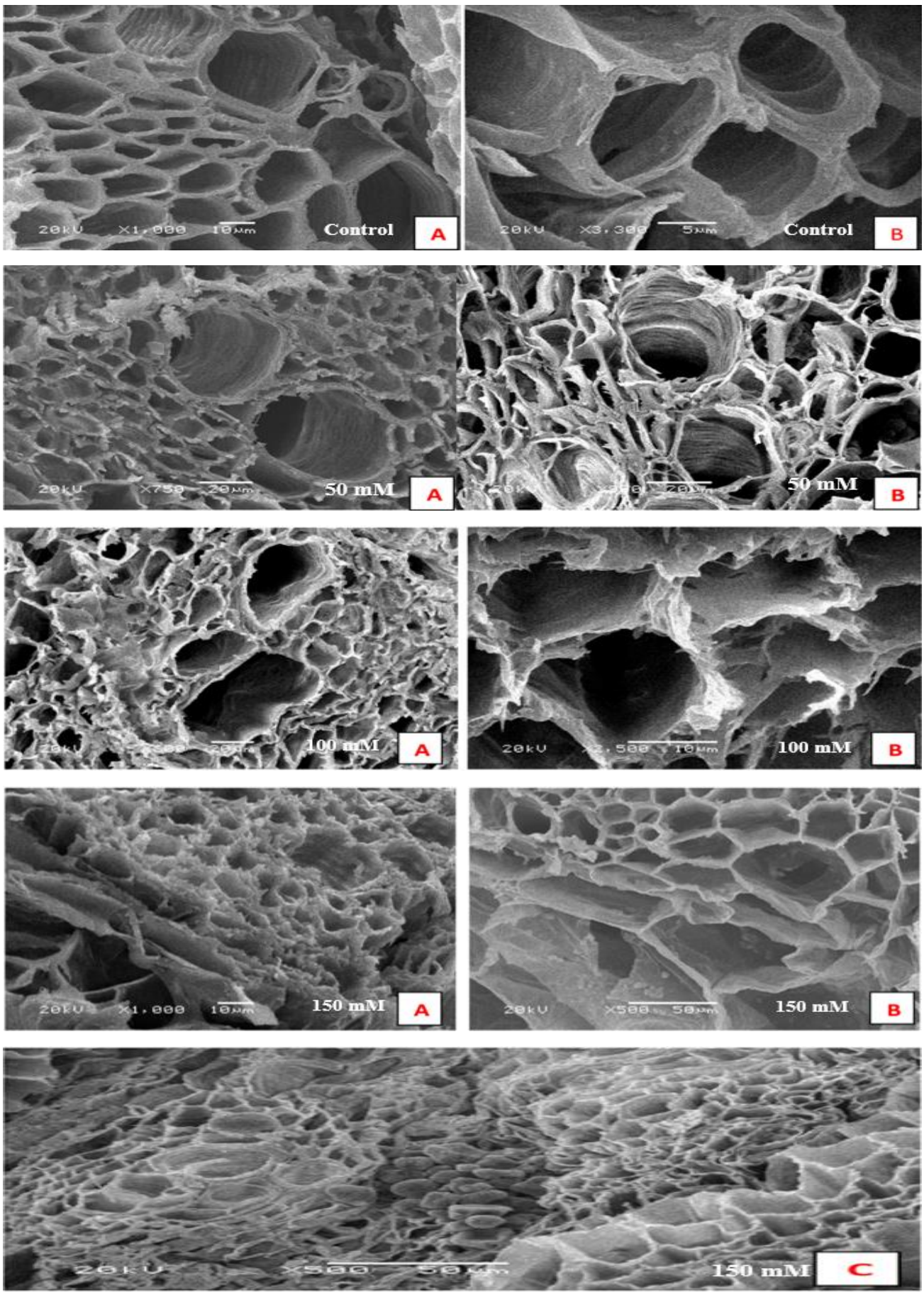

Fig. 1. The electron micrographs of the transverse sections of Marmande root's permanent microscopic specimens as the control plant and those exposed to salinity levels of 50, 100, and 150 mM.

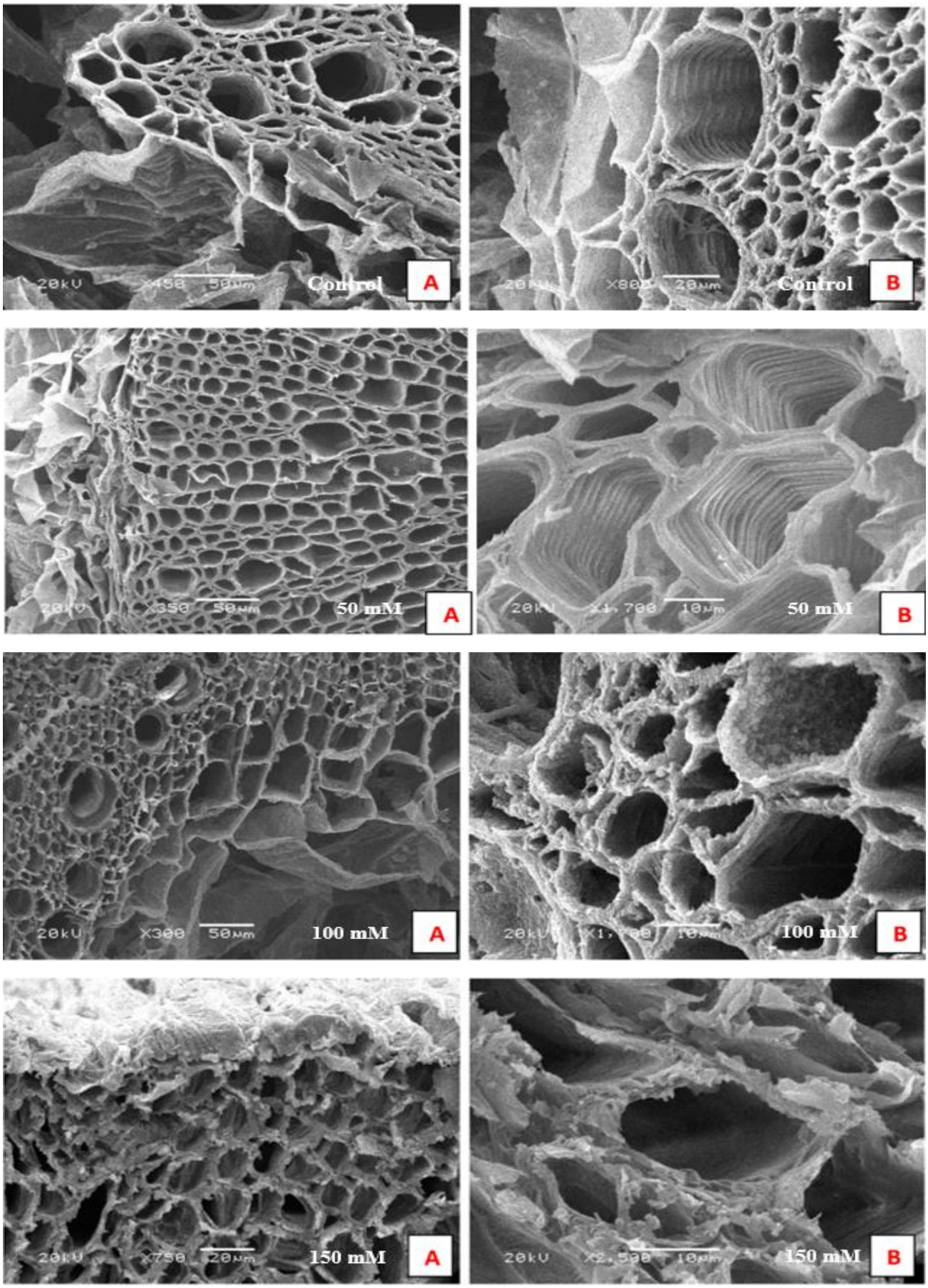

Fig. 2. The electron micrographs of the transverse sections of Oria root's permanent microscopic specimens as the control plant and those exposed to salinity levels of 50, 100, and 150 mM.

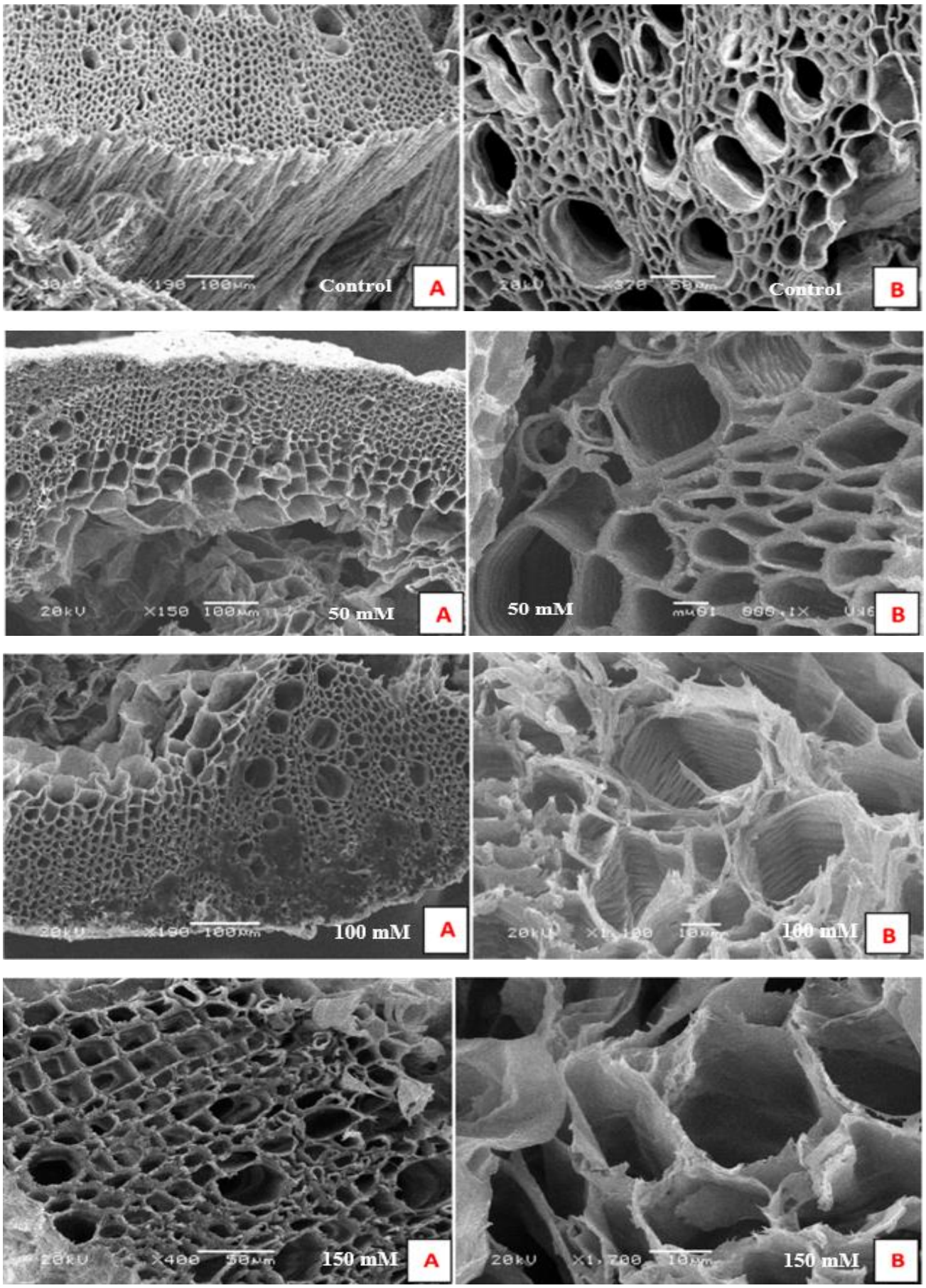

Fig. 3. The electron micrographs of the transverse sections of Marmande shoot's permanent microscopic specimens as the control plant and those exposed to salinity levels of 50, 100, and 150 mM.

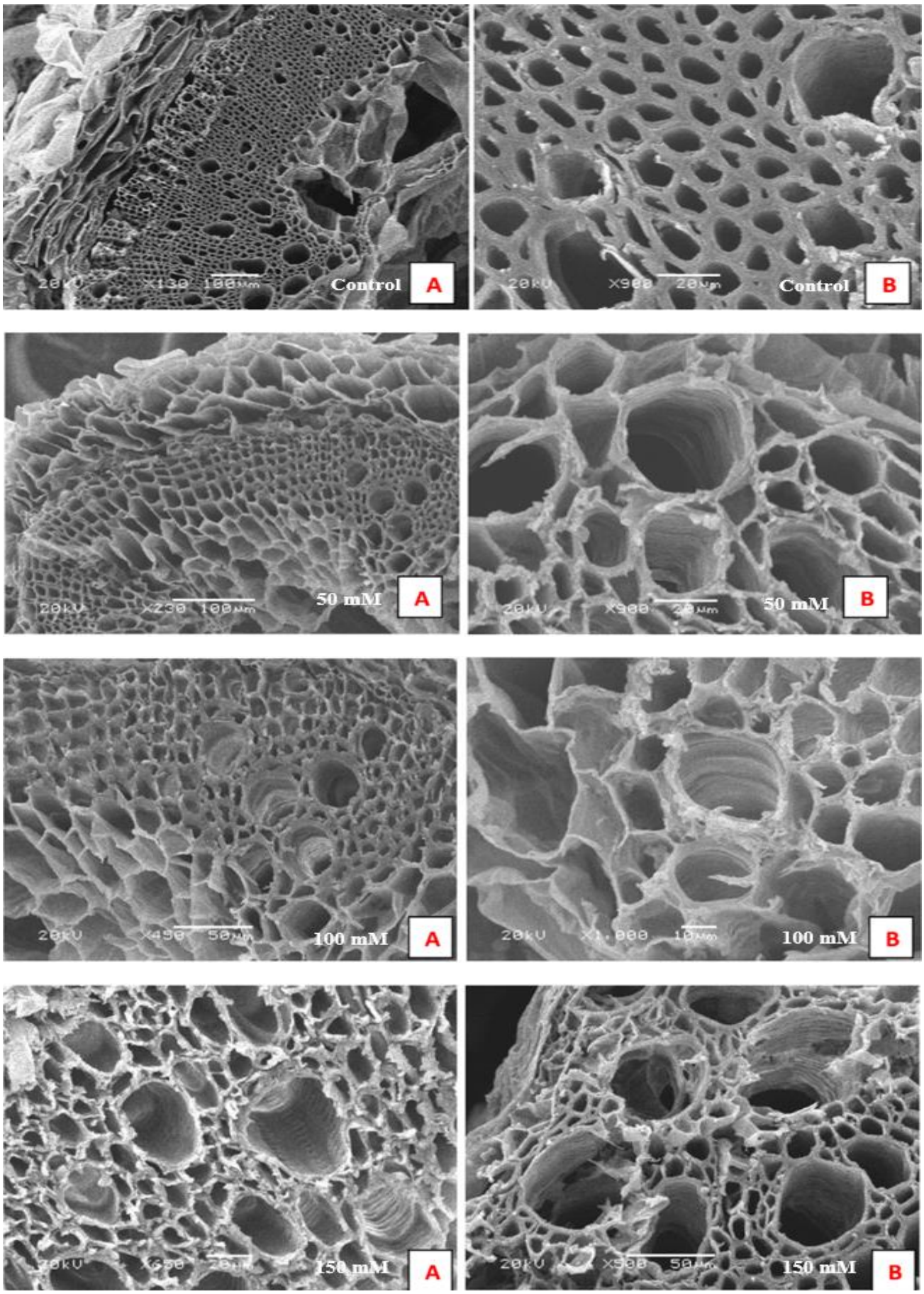

Fig. 4. The electron micrographs of the transverse sections of Oria shoot's permanent microscopic specimens of control plant and those exposed to salinity levels of 50, 100, and 150 mM.

Conclusion

It is evident that the fresh weight, dry weight, water content, and length of shoots and roots of the two tomato cultivars decreased significantly as a result of salinity stress. High levels of salinity had negative effects on the anatomy of both Marmande and Oria roots. However, the roots of Marmande were more sensitive at all levels of salinity. The shoots of both the Marmande and Oria cultivars showed a relatively high tolerance for salinity stress at lower levels of salinity. In particular, in the Oria cultivar, the low and moderate salinity levels had little to no effect. At the highest levels of salinity, both cultivar shoots experienced negative effects. This study recommends using the studied cultivar of Oria under conditions of high salinity, as the Oria cultivar proved relatively salt tolerant and may have the potential for salt adaptation.

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