26 Comparative Study on the Response of Several Tomato Rootstocks to Drought and Salinity Stresses

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26.1 INTRODUCTION

Soil and water salinity are major problems affecting several parts of the world, and the affected areas are on the increase due to brackish groundwater overexploitation, sea water intrusion, misuse of fertilizers and climate change (Valipour 2014; Elhag 2016). However, there is a great potential in using salt-affected lands and waters by adopting several practices that alleviate the negative impact of salinity on crops, yield and farmer's income (Dasgupta et al. 2015; Wichelns and Qadir 2015). Increasing the salt tolerance of crops through plant breeding could improve the sustainable management of saline water by reducing the leaching requirement of irrigated soils and enabling the selection of tolerant varieties that can grow under saline conditions (Ashraf and Wu 1994; Flowers and Yeo 1995).

Tomato is the most cultivated vegetable crop in the world. According to FAOSTAT (2014), the cultivated area of tomato is 6 Mha, around 20% of total area cultivated for vegetables, while production is equal to 223 million tonnes, accounting for ~50% of the total amount of vegetable production. Due to the importance of tomato

production, the enhanced use of rootstocks under different growing conditions, both in the field and in the greenhouse, is essential.

Grafting is currently regarded as a rapid technique aimed at increasing the environmental stress tolerance of fruit vegetables as well as maximizing yield (Schwarz et al. 2010; Al-Harbi, 2017a; 2018). It is used to reduce infections by soil-borne pathogens as well as enhance tolerance against abiotic stresses (Louws et al. 2010). The selection of a commercial rootstock is often carried out either by experienced farmers based on the recommendations of extension advisors or by the seed companies, based on their breeding and development programs. The most adopted selection criterion is plant vigor, including stem diameter (SD) (Navarrete et al. 1997). Other criteria used to select the best rootstock include root weight, shoot weight, and sodium concentration in shoots or leaves (Zijlstra et al. 1994; Santa-Cruz et al. 2002). Under saline conditions, the most suitable rootstock for tomato is the one that best excludes sodium from the root system, as long-term damage caused by salinity in tomato has been mainly related to high accumulation of Na^+ and Cl^- . Therefore, salt-tolerant rootstocks should slow or prevent the accumulation of toxic levels of sodium and chloride in the leaves (Estañ et al. 2005).

Grafting has been used to increase the salinity tolerance of trees and recently grafting has been used for vegetables, in particular tomato (Santa-Cruz et al. 2002; Al-Harbi et al. 2017b,c). However, tomato rootstocks were initially used to increase resistance of tomato to soil diseases, as tomato was mainly grown with fresh water irrigation.

Taking into account facts that tomato is one of the most important horticultural crops in the world, and its production is concentrated in semi-arid regions, where salinity and drought are major problems, it is of great interest to know whether the grafting technique is a valid strategy for improving tomato salt tolerance. The objective of this study was to evaluate the responses to both water- and salinity-stress of twelve commercial rootstocks and one wild *Solanum* species.

26.2 MATERIALS AND METHODS

Twelve commercial tomato varieties (DR9011TV, Emperador, Empower, APIT 0919, King Kong, Maxifort, Optifort, Silex, Sousspro, Superpro, Unifort, Arazi) and two wild genotypes (*S. pimpinellifolium* and *S. chesmanii*) were tested in a field trial using four salinities in the irrigation water (EC_w values of 1.5, 4, 7 and 10 dS/m) and three irrigation levels (100, 50 and 25% of the full irrigation requirement) using low saline water (1.5 dS/m). The field trial was conducted between February and May 2016 in the experimental station of the International Center for Biosaline Agriculture, Dubai, UAE. Plants were first sown into a nursery and then transplanted into the field after 4 weeks. For plant fertilization, a modified Hoagland solution was supplied to the plants (Hoagland and Arnon 1950; Cooper 1988; Hochmuth and Hochmuth 2001).

Salinity treatments were applied using four tanks filled with saline groundwater mixed with fresh water to achieve the required level of salinity. Irrigation treatments were applied using drippers with different flows. Drippers with 2, 4 and 8 L/hr flow rates were used to irrigate treatments at 25, 50 and 100% of full fresh irrigation

TABLE 26.1
Fresh and Groundwater Analysis

Water Type	pH	Electrical Conductivity (dS/m)	Ca+Mg (mg/L)	Na (mg/L)
Fresh water	8.35	0.495	122	63
Groundwater	7.15	24.70	6462	4864

requirement (FI). Irrigation amounts were determined using the ET_o approach, as described by Allen et al. (1998) for 100% full irrigation requirement. All salinity treatments received full irrigation. Analyses of fresh and saline groundwater are presented in [Table 26.1](#).

SD, root, shoot and biomass weight, and sodium and potassium concentrations in leaves were determined. SD was measured using digital calipers at 5 cm above the ground. Fresh root weight (FRW), fresh shoot weight (FSW), fresh biomass weight (FBW), root to shoot ratio (R/S ratio) were measured at the end of the growth period. Plants were first weighed as a whole, then roots and shoots weights were determined separately. Sodium and potassium concentrations of leaves were analyzed using a flame photometer after digestion of dried tissue in 10 mM H_2NO_3 , using the standard procedures (Negrao et al. 2017).

Differences in the response of the plants to the applied treatments were assessed with a general linear model in the StatSoft STATISTICA 8.0.550 software. Comparison of means was performed using analysis of variance with two factors (ANOVA2). A Tukey test was used to statistically identify the homogeneous groups. All statistical differences were considered significant at $\alpha = 0.05$ or lower.

26.3 RESULTS

26.3.1 BIOMASS PARTITIONING AND MINERAL CONCENTRATIONS

The fourteen rootstocks were studied under drought or saline stress conditions in order to assess their tolerance levels. Growth and biomass as well as macronutrients were determined under different stress levels. The results of this study showed significant differences in the measured characteristics: rootstock, stress level and their interaction according to the factors ($P<0.05$) ([Tables 26.2](#) and [26.3](#)). Except for root/shoot ratio (R/S) under drought stress, both drought and saline stress treatments significantly reduced all growth and biomass parameters (FRW, FSW, R/S ratio, SD and FBW) for all rootstocks ($P<0.05$); this decrease was greater under the 25% FI and 10 dS/m treatments respectively, compared to the 100% FI non-saline control.

Under drought stress conditions, Na^+ concentrations increased significantly with increasing stress intensity (especially under 25% FI), while Na/K ratio decreased ($P<0.05$). However, no statistical difference was recorded for K ([Table 26.2](#)). These both ions and their ratio (Na/K) changed significantly depending on the saline stress level ($P<0.05$) ([Table 26.3](#)). In comparison with the control, Na/K ratio significantly decreased, while both Na and K increased, where the highest concentrations were found at 10 dS/m and 7 dS/m, respectively. Furthermore, all studied

TABLE 26.2

The Variation among the Monitored Parameters of Investigated Rootstocks under Drought Treatments and ANOVA Analysis Results (P-Values)

	FRW	FSW	FBW	R/S ratio	SD	Na	K	Na/K ratio
		(g/plant)		-	cm	mg/g of DM*		-
Rootstock								
AIPT0919	102.25a	381.42a	483.68a	0.27abc	1.14abc	0.58b	17.84a	36.43abc
ARAZI	94.83a	354.83ab	449.67ab	0.32abc	1.28a	0.52b	20.22a	45.22a
<i>S. Cheesmanii</i>	16.71c	51.13d	67.83e	0.33ab	0.51f	1.93a	20.70a	13.24c
DR9011TV	98.54a	302.29abc	400.83abc	0.33ab	1.18abc	0.58b	18.77a	34.46abc
EMPERADOR	65.50ab	325.50abc	391.00abcd	0.23abc	1.11abcd	0.42b	18.51a	47.94a
EMPOWER	62.92ab	355.50a	418.42abc	0.23abc	1.16abc	0.50b	17.81a	38.91ab
KING KONG	62.04ab	253.08abc	315.13bcd	0.26abc	1.01bcd	0.57b	17.28a	34.86abc
MAXIFORT	96.17a	385.08a	481.25a	0.26abc	1.29a	0.58b	18.25a	34.52abc
OPTIFORT	88.37a	292.25abc	380.63abcd	0.37a	1.16abc	0.49b	18.78a	40.93ab
<i>S. Pimpinilifolium</i>	94.13a	300.17abc	394.29abcd	0.32abc	0.90de	1.46a	19.54a	18.47bc
SILEX	64.46ab	217.25bc	281.71cd	0.31abc	0.97cde	0.40b	18.29a	50.71a
SOUSSPRO	73.75ab	347.54ab	421.28abc	0.21bc	1.19ab	0.44b	17.54a	41.56ab
SUPERPRO	62.46ab	363.33a	425.79abc	0.18bc	1.19ab	0.53b	16.97a	42.12ab
UNIFORT	32.87bc	198.71c	231.58d	0.17c	0.79e	0.70b	15.56a	26.72abc
Drought Treatment								
100 % FI	113.62a	434.65a	548.26a	0.29a	1.13a	0.55b	17.91a	42.68a
50 % FI	55.46b	261.96b	317.42b	0.25a	1.09a	0.66b	17.36a	34.36b
25 % FI	48.43b	187.98c	236.41c	0.28a	0.97b	0.87a	19.61a	31.41b
ANOVA (P-values)								
Rootstock	<.001	<.001	<.001	<.001	<.001	<.001	ns	<.001
Drought	<.001	<.001	<.001	ns	<.001	<.001	ns	0.003
Rootstock x Drought	0.042	0.030	0.024	0.018	ns	ns	ns	Ns

*: dry matter

Abbreviations: FRW: fresh root weight, FSW: fresh shoot weight, FBW: Fresh biomass weight, R/S: Root to shoot ratio, SD: Stem diameter, Na: Sodium concentration, K: Potassium concentration, Na/K: sodium to potassium ratio.

Note: Means within a column accompanied by the same letter are not significantly different (5% probability level, the Tukey test).

parameters had significant statistical differences between rootstocks, except K⁺. Under drought stress, both AIPT0919 and MAXIFORT rootstocks showed high values of FRW, FSW and FBW, where MAXIFORT and ARAZI had the highest SD values among all rootstocks. We also noted that high values of RW were found in ARAZI, DR9011TV, OPTIFORT and *S. Pimpinilifolium*; while high values of SW were observed in EMPOWER and SUPERPRO. In addition to its high RW value, OPTIFORT had the highest R/S ratio.

Under saline conditions, the highest RW values were with DR9011T, whereas MAXIFORT, AIPT0919 and SUPERPRO had the highest SW values. ARAZI had

TABLE 26.3
The Variation among the Monitored Parameters of Investigated Rootstock under Salinity Treatments and ANOVA Analysis Results (P-Values)

	FRW	FSW	FBW	R/S ratio	SD	Na	K	Na/K ratio
	(g/plant)			-	cm	mg/g of DM*		-
Rootstock								
AIPT0919	113.69abcd	457.12a	570.86a	0.25abcde	1.12abc	0.98c	17.69a	25.45ab
ARAZI	116.69abc	394.72abc	511.41a	0.32a	1.29a	1.17c	20.34a	30.22a
<i>S. Cheesmanii</i>	10.97g	39.34d	50.30c	0.26abcd	0.47f	5.06a	15.85a	6.56c
DR9011TV	135.78a	425.91ab	561.69a	0.32a	1.21ab	1.17c	19.10a	21.94abc
EMPERADOR	78.75cdef	375.22abc	453.97ab	0.21bcde	1.10abcd	0.84c	19.45a	31.13a
EMPOWER	66.94ef	432.88ab	499.81ab	0.18cde	1.17abc	0.87c	16.82a	25.24ab
KING KONG	84.81bcdef	349.66abc	434.47ab	0.23abcde	1.08bcd	1.21c	18.84a	24.50ab
MAXIFORT	110.22abcde	459.88a	570.11a	0.23abcde	1.29a	0.98c	19.48a	24.99ab
OPTIFORT	116.88abc	404.09abc	520.95a	0.29ab	1.21ab	1.05c	18.92a	25.66ab
<i>S. Pimpinilifolium</i>	126.41ab	413.34ab	539.74a	0.32a	0.91de	2.64b	17.43a	10.46bc
SILEX	70.59def	260.56c	331.17b	0.28abc	0.98cde	0.75c	17.66a	31.77a
SOUSSPRO	70.53def	370.75abc	441.28ab	0.18bcde	1.14abc	0.89c	18.20a	26.71ab
SUPERPRO	68.94def	447.34a	516.28a	0.16de	1.15abc	0.85c	17.91a	27.89a
UNIFORT	42.16fg	293.97bc	336.13b	0.14e	0.84e	1.19c	15.44a	19.20abc
Salinity Treatment								
Control	113.62a	434.65a	548.26a	0.29a	1.13a	0.55c	17.91b	42.68a
4 dS/m	109.35a	463.71a	573.04a	0.26ab	1.09a	1.00c	18.12b	24.76b
7 dS/m	83.96b	343.66b	427.62b	0.24b	1.07a	1.76b	21.10a	17.77b
10 dS/m	39.75c	222.20c	261.97c	0.18c	0.98b	2.31a	15.19c	9.56c
ANOVA (P-values)								
Rootstock	<.001	<.001	<.001	<.001	<.001	<.001	Ns	<.001
Salinity	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Rootstock x Salinity	ns	Ns	ns	Ns	ns	<.001	Ns	ns

*: dry matter

Abbreviations: FRW: fresh root weight, FSW: fresh shoot weight, FBW: Fresh biomass weight, R/S: Root to shoot ratio, SD: Stem diameter, Na: Sodium concentration, K: Potassium concentration, Na/K: sodium to potassium ratio.

Note: Means within a column flanked by the same letter are not significantly different at 5% (probability level, the Tukey test).

high values of both R/S ratio and SD. Similar values of R/S ratio were observed in both DR9011TV and *S. pimpinilifolium* and of SD in MAXIFORT. Among all studied rootstocks, seven rootstocks (AIPT0919, ARAZI, DR9011TV, MAXIFORT, OPTIFORT, *S. pimpinilifolium*, and SUPERPRO) had highest FBW values. However, under drought and saline conditions, the lowest values of FRW, FSW, SD and FBW were recorded for *S. cheesmanii*, whereas UNIFORT showed the lowest R/S ratio values. Regarding to the minerals under both drought and saline

TABLE 26.4

Correlation Coefficients between Studied Parameters under Drought Conditions for the 14 Rootstocks

	FRW	FSW	R/S Ratio	SD	FBW	Na	K	Na/K Ratio
FRW	1							
FSW	0.59	1						
R/S ratio	0.46	-0.23	1					
SD	0.18	0.47	-0.24	1				
FBW	0.76	0.97	-0.05	0.43	1			
Na	-0.24	-0.32	0.00	-0.46	-0.33	1		
K	0.12	-0.10	0.05	-0.04	-0.07	0.20	1	
Na/K ratio	0.23	0.24	0.02	0.31	0.26	-0.57	0.47	1

Note: All correlations were significant at $P = 0.05$.

conditions, *S. cheesmanii* had highest Na^+ and lowest Na^+/K^+ ratio. Nonetheless, the highest significant values of Na^+/K^+ were found in ARAZI, EMPERADOR and SILEX rootstocks ($P < 0.05$). According the ANOVA analysis, a significant rootstock $\times$ drought interaction was observed for FRW, FSW, R/S ratio and FBW under drought conditions, while the rootstock $\times$ salinity interaction was only significant for Na^+ ($P < 0.05$).

Significant positive correlations were recorded between FRW, R/S ratio and FBW, between RW and SW, and between K^+ and Na^+/K^+ ratio, under both stress conditions ($P < 0.05$) (Tables 26.4 and 26.5). However, significant negative correlations were observed between Na^+ and the studied growth and biomass traits (FRW, FSW, SD and FBW) and between Na^+ and Na^+/K^+ ratio ($P < 0.05$) (Tables 26.4 and 26.5).

TABLE 26.5

Correlation Coefficients between Studied Traits under Saline Conditions for the 14 Rootstocks

	FRW	FSW	R/S Ratio	SD	FBW	Na	K	Na/K Ratio
FRW	1							
FSW	0.68	1						
R/S ratio	0.60	-0.06	1					
SD	0.22	0.47	-0.15	1				
FBW	0.82	0.98	0.12	0.43	1			
Na	-0.23	-0.34	-0.06	-0.45	-0.33	1		
K	0.18	0.10	0.11	0.14	0.13	-0.02	1	
Na/K ratio	0.15	0.16	0.07	0.20	0.17	-0.38	0.41	1

Note: All correlations were significant at $P = 0.05$.

26.3.2 CANONICAL DISCRIMINANT ANALYSIS

In order to discriminate between the fourteen studied rootstocks, we performed canonical discriminant analysis (CDA) using all studied traits as predictors of membership in the diagnostic group (fourteen rootstocks) under drought stress conditions (CDAd) and under saline stress conditions (CDAs). These traits allowed us to separate the best groups of individuals and provide graphical representations to highlight this separation. The results obtained from CDA affirmed the existence of differences in the global characteristics of the studied rootstocks. Wilks’s lambda showed a high significance of the differences (Wilks’s $\lambda = 0.169$ for CDAd and Wilks’s $\lambda = 0.203$ for CDAs) and the calculated F value also indicated significant differences at $P \leq 0.001$. The null hypothesis of discriminant functions generated in this study is tested using χ^2 test. The latter demonstrated a significant discriminatory power for all the functions in both analyses ($P < 0.001$). For CDAd, the first two discriminant functions (DF1 and DF2), with high eigenvalues (1.43 and 0.57, respectively), accounted for most of the total variance (87.8%) and their canonical correlations were $r_1 = 0.77$ and $r_2 = 0.60$, respectively (Table 26.6). Regarding the CDAs, the high eigenvalues of the first two functions (1.65 and 0.55, respectively) allowed them to explain most of the total variance (84.7%) and the corresponding canonical correlations were $r_1 = 0.79$ and $r_2 = 0.60$ for DF1 and DF2, respectively (Table 26.6).

The 2D canonical plots (Figures 25.1 and 25.2) showed the distribution of the fourteen rootstocks spanned by the first two functions. According to the standardized coefficients of the canonical discriminant functions (Table 26.7), SD and R/S ratio were highly weighted in the positive part of DF1 (CDAd), whereas Na^+ and

TABLE 26.6
Statistical Characteristics of the Discriminant Functions Extracted from Canonical Discriminant Analysis (CDA)

	Discriminant Function	Eigenvalue	Variance (%)	Cumulative Variance (%)	Canonical Correlation
Drought Stress	1	1.43	62.7	62.7	0.77
	2	0.57	25.0	87.8	0.60
	3	0.19	8.4	96.2	0.40
	4	0.05	2.1	98.3	0.21
	5	0.02	0.9	99.2	0.14
	6	0.01	0.5	99.7	0.11
	7	0.01	0.3	100.0	0.08
Saline Stress	1	1.65	63.6	63.6	0.79
	2	0.55	21.1	84.7	0.60
	3	0.22	8.5	93.2	0.43
	4	0.11	4.1	97.3	0.31
	5	0.03	1.3	98.6	0.18
	6	0.03	1.1	99.7	0.17
	7	0.01	0.3	100.0	0.10

TABLE 26.7
Standardized Canonical Discriminant Function Coefficients of the Studied Parameters under Both Drought and Saline Stress, according to CDA

	Drought Stress		Salinity Stress	
	Function 1	Function 2	Function 1	Function 2
RW	-0.12	0.38	0.41	0.32
SW	0.15	0.10	-0.02	0.08
R/S ratio	0.37	0.47	-0.09	0.62
SD	0.70	0.59	0.67	0.37
TB	0.19	0.13	-0.02	0.10
Na	-0.63	0.34	-0.57	0.68
K	0.04	0.53	0.14	0.07
Na/K ratio	0.05	-0.65	-0.17	-0.32

FIGURE 26.1 2D scatterplot showing the distribution of the fourteen rootstocks according to the two discriminant function gradients obtained by CDA for the studied traits under drought stress conditions (CDAd).

FIGURE 26.2 2D scatterplot showing the distribution of the fourteen rootstocks according to the two discriminant function gradients obtained by CDA for the studied traits under saline stress conditions (CDAs).

RW in the negative part. SD and K⁺ were highly weighted in the positive part of DF2 (CDAd), while Na⁺ was the only trait most weighted to the negative part of CDAd. Regarding DF1 of CDAs, SD and FRW exhibited the highest standardized coefficients in the positive part, whereas Na⁺ and Na⁺/K⁺ ratio were highly weighted in the negative part. Na⁺ and R/S ratio were highly weighted in the positive part of DF2 (CDAs), while Na⁺/K⁺ ratio was highly weighted in the negative part as for DF2 of CDAd. The DF1 of CDAd allowed a clear separation of DR9011TV, ARAZI, OPTIFORT, MAXIFORT, SUPERPRO, EMPERADOR, EMPOWER and SILEX from the other rootstocks, where ARAZI, MAXIFORT and DR9011TV were characterized by the highest SD and RW. According to the DF2, both *S. Cheesmanii* and *S. pimpinilifolium* were distinguished from other rootstocks especially by having highest Na⁺ concentration and low levels of biomass. Compared to CDAd, DF1 of CDAs separated DR9011TV, ARAZI, OPTIFORT, MAXIFORT, EMPERADOR, EMPOWER, KING KONG and APIT0919 from others, where DR9011TV was distinguished by the highest RW. Similar to CDAd, both ARAZI and MAXIFORT

were discriminated by the highest SD. Yet again, both *S. cheesmanii* and *S. pimpinellifolium* were clearly discriminated from other rootstocks by having highest Na⁺ concentration and highest R/S ratio, respectively.

26.4 DISCUSSION

The study found a limited variation in salt tolerance within the cultivated species. However, there are several wild species within *Lycopersicon* that present a potential source of useful genes for breeding to salt tolerance (Mousa et al. 2013). Researchers have also identified salt-tolerant accessions within the wild tomato species *L. pimpinellifolium*, *L. peruvianum*, *L. cheesmanii*, *L. hirsutum*, and *L. pennellii* which can be of interest in breeding programs under salinity conditions (Rush and Epstein 1976; Cuartero and Fernández-Muñoz 1998; Foolad 2007; Rzepka-Plevnes et al. 2007).

The differential accumulation and re-distribution of dry matter biomass among the study tomato genotypes with respect to root and shoot tissues, under a range of water and salt treatments, suggested a negative linear relationship between biomass accumulation and increased stress. Increased salinity and stress led to reduction in root and shoot weight with more pronounced effects on shoots. *S. pimpinellifolium* has an extremely efficient system for the re-distribution of photosynthates from the source (shoot) to the sink (root), thus, enabling aggressive root production under salinity. Several reports indicate that *S. pimpinellifolium* is a salt-tolerant wild relative of tomato. Bolarin et al. (1991) found that *S. pimpinellifolium* was the most tolerant genotype to salinity based on slope value of the shoot weight vs salinity relationship curve compared to other wild tomato relatives (*L. pennellii*, *L. hirsutum* and *L. peruvianum*). Our results show that under high salinity stress (10 dS/m) *S. pimpinellifolium* had the highest root and shoot weight compared to commercial varieties. This was confirmed by Rao et al. (2013) who reported that shoot dry weight of *S. pimpinellifolium* accessions was less affected under salt stress than *S. lycopersicum*.

It has been shown that Arazi showed the thickest SD under both water and salt stress. Several studies have suggested that SD has positive effects on a rootstock's vigorous root system which helps absorb water and nutrients more efficiently (Oztekin and Tuzel 2011; Wahb-Allah et al. 2011) and may also serve as a supplier of endogenous plant hormones (Albacete et al. 2008; 2014). Rootstock diameter is, therefore, an important criterion for rootstock selection. Vigorous rootstocks have high water and nutrient uptake due to their well-developed xylem structure (Klepper et al. 1971). Bletsos et al. (2003) indicated that depending on the increase in plant development, the grafted plants showed a better vigor compared to non-grafted plants with regard to the plant length and SD.

It has been suggested that commercial crop yield should be the ultimate agronomic criterion for establishing the salt tolerance of crops. However, as salinity affects a wide range of physiological, biochemical and molecular functions and processes in plant growth and development, the enhancement of crop salt tolerance requires a combination of several physiological traits, not simply those directly influencing yield (Rao et al. 2013). There is considerable evidence that salt exclusion (specifically Na⁺ exclusion) is the mechanism of survival for most species of agricultural importance when they are exposed to saline conditions (Walker 1986; Schachtman et al. 1991; Reimann 1992;

Fortmeier and Schubert 1995; Hauser and Horie 2010). This study clearly suggests that *S. pimpinellifolium* was the most suitable rootstocks under high saline conditions in terms of root and shoot development; however, this genotype accumulated more sodium in the leaves compared to commercial varieties and thus had an increased Na^+/K^+ ratio. This was confirmed by Rush and Epstein (1981) who showed that, under high salt conditions (50–100 mM NaCl), the salt-tolerant tomato genotype freely accumulated Na^+ in the shoot, while the salt-sensitive cultivar excluded it from the leaves. It appears that Silex rootstock tends to exclude Na^+ from the leaf tissue, while *S. pimpinellifolium* freely accumulates Na in the leaf with no toxic effects. Potassium levels in Silex rootstock remained high in the leaves, indicating that K^+ was being selectively accumulated even at these high Na^+ solution levels where the Na^+/K^+ ratio was greater than 15. From this, it appears that the inability of *S. pimpinellifolium* to withstand salinity is linked to its limited efficiency in keeping Na^+ in the leaf tissue below toxic levels and compensating for the lower water potentials associated with salinity by increasing tissue levels of organic solutes (Rush and Epstein 1976). According to the ANOVA and CDA analysis of the studied traits, we can suggest a classification of the studied rootstocks according to their tolerance degree. DR9011TV, ARAZI, OPTIFORT, MAXIFORT seem to be more tolerant to drought stress, whereas both DR9011TV and ARAZI also perform better under saline stress. However, *S. cheesmanii* appears to be the most sensitive to both drought and saline stress.

26.5 CONCLUSION

With the rising of the groundwater salinization problem, there is an urgent need to explore alternative practices to use saline water to grow vegetable cash crops. Grafting use salt-tolerant rootstocks potential solution to producing good yields under saline conditions. However, the screening of suitable rootstocks is not an easy task as it depends on several parameters. Root development as well as sodium exclusion is the main criteria for the selection of suitable rootstocks. This study has shown that both water and salinity stress affected negatively rootstock biomass production with less effect observed for SD. Water stress slightly increased sodium accumulation in rootstock leaves, however, salinity stress greatly increased sodium accumulation and consequently increased the Na^+/K^+ ratio. Our results have shown that there is a great potential for using rootstocks in tomato grafting under saline conditions. Arazi and *S. pimpinellifolium* had highest root development; however, the latter accumulated more sodium in the shoot. Nevertheless, the use of *S. pimpinellifolium* for tomato grafting under saline conditions needs to be studied. Silex, Empower, Sousspro, Maxifort and Emperador rootstocks had the lowest Na^+ concentration in their leaves, which means that they exclude sodium in their root system and this makes them potentially useful rootstocks to be used for tomato grafting under saline conditions.

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