

1 **Relative salt tolerance of 22 pomegranate (*Punica granatum*) cultivars**

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20

21 **Abstract**

22 A greenhouse experiment was conducted to determine the relative salt tolerance of

23 pomegranate (*Punica granatum*) cultivars. Twenty-two pomegranate cultivars were irrigated

24 weekly with a saline solution at an electrical conductivity (EC) of $10.0 \text{ dS}\cdot\text{m}^{-1}$ for four weeks and
25 subsequently with a saline solution at EC of $15.0 \text{ dS}\cdot\text{m}^{-1}$ for another three weeks (salt treatment).
26 Another group of uniform plants was watered with a nutrient solution without additional salts at
27 EC of $1.2 \text{ dS}\cdot\text{m}^{-1}$ (control). No visual foliar salt damage (leaf burn, necrosis, or discoloration)
28 was observed during the entire experimental period; however, salt treatment negatively impacted
29 pomegranate growth with a large variation among cultivars. Salt treatment reduced shoot length
30 by 25% and dry weight (DW) by 32% on average for all cultivars. Cluster analysis classified the
31 22 tested pomegranate cultivars in two groups. The group consisting of ‘Arturo Ivey’, ‘DeAnda’,
32 ‘Kazake’, ‘Russian 8’, ‘Apseronski’, ‘Purple Heart’, ‘Carolina Venum’, ‘Chiva’, ‘Kunduzski’,
33 ‘Larry Ceballos 1’, ‘ML’, ‘Salavatski’, ‘Spanish Sweet’, and ‘Wonderful’ was more salt tolerant
34 than the group including ‘Al-Sirin-Nar’, ‘Kandahar’, ‘Surh-Anor’, ‘Early Wonderful’, ‘Angel
35 Red’, ‘Ben Ivey’, ‘Utah Sweet’, and ‘Mollar’. The sodium (Na) concentration in the leaf tissue
36 of all 22 pomegranate cultivars was less than $1 \text{ mg}\cdot\text{g}^{-1}$ on a dry weight basis. All pomegranate
37 cultivars in the salt treatment had an average leaf chloride (Cl) content of $10.03 \text{ mg}\cdot\text{g}^{-1}$ dry
38 weight, an increase of 17% from the control. These results indicate that pomegranate plants have
39 strong capability to exclude Na and Cl accumulation in leaf tissue. In conclusion, pomegranate
40 plant is very tolerant to saline water irrigation up to EC of $15 \text{ dS}\cdot\text{m}^{-1}$ with little foliar salt damage
41 and a slight growth reduction. Further, investigation is needed to determine the effects of saline
42 water on the fruit yield and nutritional quality of pomegranate.

43

44 Pomegranate (*Punica granatum*, Lythraceae) is a bushy shrub or small tree native from
45 Iran to the Himalayas in northern India. It has been cultivated since ancient times throughout the
46 Mediterranean region of Asia, Africa, and Europe. The fruit is rich in nutrition with unique

47 flavor, taste, and medicinal properties. Recent scientific findings corroborate the traditional use
48 of the pomegranate as a medical remedy for its antimicrobial properties and for its health
49 benefits such as the ability to reduce blood pressure, and to act against serious diseases such as
50 diabetes and cancer (Holland et al., 2009). Increased public awareness to the benefit of the
51 pomegranate, particularly in the western world, has led to a prominent increase in its
52 consumption. In the U.S., California produces more than 90 percent of the US pomegranates
53 with 26,935 acres, yielding 10.5 tons per acre according to the California Department of Food
54 and Agriculture (Marzolo, 2015).

55 Pomegranate plants adapt to a wide range of environmental and soil conditions but
56 perform best in areas with long, hot, and dry summers (Castle et al., 2011; Holland et al., 2009).
57 Although it is an ancient crop, pomegranate has not been studied systematically regarding
58 cultural practices, fertilization requirements, and salinity and drought tolerance. Salinity is a
59 major environmental constrain in many pomegranate-growing areas such as India, Mediterranean
60 countries, and the southwestern United States. Saline brackish groundwater, treated municipal or
61 industrial effluents, and recycled agricultural runoff water are the major alternative water sources
62 for crop irrigation in many regions of the world including those growing pomegranate (Qadir et
63 al., 2008). These water sources often contain high salt levels that are detrimental to many
64 species. Salt damage depends on the levels of salts and degree of salt tolerance of crops.
65 Therefore, the use of alternative waters for irrigation requires an adequate understanding of how
66 salts impact plant performance and soil characteristics.

67 Limited literature shows that pomegranate is relatively tolerant to salt stress with
68 variations among cultivars (Bhantana and Lazarovitch, 2010; El-Khawaga et al., 2013;
69 Okhovatian-Ardakani et al., 2010). ‘Malas-Saveh’ pomegranate is less tolerant than ‘Shishe-

70 Kab' (Khayyat et al., 2014). Irrigation with saline groundwater at $6.0 \text{ dS}\cdot\text{m}^{-1}$ increased Na and Cl
71 accumulation in leaves, reduced growth, flowering, and yield, and increased incidence of fruit
72 cracking but did not change the total sugar and acidity percentages of fruit in seven-year-old
73 'Manfalouty', 'Wonderful', and 'Nab-Elgamal' pomegranates, with different responses to saline
74 water irrigation among cultivars (El-Khawaga et al., 2013). 'Malas Shirin' pomegranate was
75 tolerant up to 40 mM NaCl in 1:1 sand-perlite medium irrigated with complete Hoagland's
76 solution (Naeini et al., 2006). Okhovatian-Ardakani et al. (2010) compared ten Iranian
77 commercial cultivars in a pot experiment irrigated with saline water at three levels of salinity (4,
78 7, or $10 \text{ dS}\cdot\text{m}^{-1}$) and found that salt tolerance is cultivar dependent based on their vegetative
79 growth and tissue Na and Cl concentration. However, salt tolerance of many existing cultivars in
80 the U.S. is unknown. Identifying salt tolerant cultivars is of great importance in pomegranate
81 production. The aim of this study was to determine the relative salt tolerance of 22 pomegranate
82 cultivars and their morphological and physiological responses to saline water irrigation in
83 greenhouse conditions.

84

85 **Materials and Methods**

86 *Plant materials.* On 12 Mar. 2014, hardwood cuttings (~15 cm) in RL98 Ray Leach
87 Cone-tainersTM (SC10 Super, 3.8 cm in diameter, 21 cm in depth, 164 mL in volume; Stuewe
88 and Sons., Inc., Tangent, OR) were received from Marcelino's Nursery (Tornillo, TX). On 5
89 May 2014, rooted cuttings were transplanted in 5-L treepots (CP512CH, 12.7 cm in width, 30.5
90 cm in height; Stuewe and Sons., Inc.) containing commercial substrate Metro-Mix 902 (50%-
91 60% composted bark, Canadian sphagnum peat moss, vermiculite and coarse perlite, starter
92 nutrient charge with gypsum and slow release nitrogen and dolomitic limestone; SunGro®,

93 Agawam, MA). All plants were grown in a greenhouse in El Paso, TX (lat. 31°41'45"N,
94 long.106°16'54"W, elev.1139 m) for three months and irrigated with a nutrient solution at an
95 electrical conductivity (EC) of $1.2 \pm 0.1 \text{ dS}\cdot\text{m}^{-1}$ (mean and standard deviation). The nutrient
96 solution was prepared by adding 15N-2.2P-12.5K (Peters 15-5-15 Ca-Mg Special; Scotts,
97 Marysville, OH) to reverse osmosis (RO) water at a nitrogen concentration of $150 \text{ mg}\cdot\text{L}^{-1}$.

98 *Treatments.* On 5 Aug. 2014, all plants were pruned to 30 cm tall. One week later (i.e. 11
99 Aug.), uniform plants were chosen and assigned into two groups and treatment was initiated.
100 One group of plants was irrigated weekly with a saline solution at EC of $10.0 \text{ dS}\cdot\text{m}^{-1}$ (actual EC
101 is $9.9 \pm 0.4 \text{ dS}\cdot\text{m}^{-1}$) for four weeks and subsequently with a saline solution at EC $15.0 \text{ dS}\cdot\text{m}^{-1}$
102 (actual EC is $14.9 \pm 0.6 \text{ dS}\cdot\text{m}^{-1}$) for three more weeks (salt treatment). This was because plants
103 irrigated with saline solution did not show any damage. A higher salinity treatment was needed
104 to distinguish the differences among the 22 cultivars. Another group of plants was watered with
105 the aforementioned nutrient solution without additional salts (control). Saline solutions at EC of
106 $10 \text{ dS}\cdot\text{m}^{-1}$ and $15 \text{ dS}\cdot\text{m}^{-1}$ were prepared by adding sodium chloride (NaCl, 57.2 mM) and calcium
107 chloride (CaCl_2 , 28.7 mM), and 86.4 mM NaCl and 43.3 mM CaCl_2 , respectively, to the nutrient
108 solution. This mixture was used because NaCl is the common salt in reclaimed water (Niu and
109 Cabrera, 2010) and CaCl_2 is to forestall potential calcium deficiencies (Carter and Grieve, 2006).
110 Both nutrient and saline solutions were prepared in 100-L tanks with EC confirmed using an EC
111 meter (Model B173; Horiba, Ltd., Kyoto, Japan) before irrigation. Between treatment solutions,
112 plants were irrigated with the nutrient solution whenever substrate surface became dry. Irrigation
113 frequency varied with environmental condition and treatment. For example, plants at high
114 salinity level use less water and need irrigation less often compared to those plants in the control.

115 At each irrigation, plants were irrigated with 1 L treatment solution per plant, resulting in a
116 leaching fraction of approximately $29\% \pm 11\%$.

117 *Greenhouse environmental conditions.* The average air temperature in the greenhouse
118 was 30.9 ± 5.2 °C during the day and 23.0 ± 4.3 °C at night during the entire experimental
119 period. The average daily light integral was 16.3 ± 3.2 mol·m⁻²·d⁻¹, and the average relative
120 humidity was $41.4\% \pm 17.2\%$.

121 *Leachate EC.* The leachate EC was determined following pour-through method according
122 to Cavins et al. (2008). In brief, a saucer was placed under the container which has drained for at
123 least 30 minutes right after treatment solution was applied. A total of 100 mL distilled water was
124 poured on the surface of the substrate to get leachate in the saucer. The leachate solution was
125 collected and tested using an EC meter. One plant per treatment per cultivar was chosen for
126 measurement each time after treatment solutions were applied. Leachate EC readings were
127 averaged across cultivars.

128 *Growth parameters.* At the end of the experiment, plant height (cm) was recorded from
129 the pot rim to the top growing point. New growth of shoots (visibly distinguishable from the old
130 growth before pruning) were harvested, and the length of all new shoots (>5 cm) was measured
131 as shoot length. Then, all leaves of the new shoots were separated from the stems. Both leaves
132 and stems were oven-dried at 70 °C for seven days, and the leaf and stem dry weight (DW) was
133 determined.

134 *Foliar salt damage evaluation.* One week before harvest, foliar salt damage was rated
135 visually using a reference scale from 0 to 5, where 0 = dead; 1 = over 90% foliar damage (leaf
136 burn, necrosis, or discoloration); 2 = moderate (50% to 90%) foliar damage; 3 = slight (less than
137 50%) foliar damage; 4 = good quality with minimal foliar damage; and 5 = excellent with no

138 foliar damage (Sun et al., 2015a). The foliar salt damage visual rating did not account for plant
139 size.

140 *Chlorophyll fluorescence and performance index.* The maximal photochemical efficiency
141 (F_v/F_m) and performance index (PI) were measured according to Strasser et al. (2000, 2004)
142 using a Hansatech Pocket PEA chlorophyll fluorimeter (Hansatech Instruments Ltd., Norfolk,
143 UK) to examine the effect of elevated salinity on leaf photosynthetic apparatus of pomegranate
144 plants one week before harvest. Healthy and fully expanded leaves of three plants per treatment
145 per cultivar were chosen for the measurements. Measurements were taken on sunny days
146 between 900 and 1600 HR, and plants were well watered to avoid drought stress. The leaves
147 were dark acclimated for at least 30 min prior to F_v/F_m and PI measurements. Minimal
148 fluorescence values in the dark-adapted state (F_0) were obtained by application of a low intensity
149 red LED (light emitting diode) light source (627 nm) at 50 μ s, whereas maximal fluorescence
150 values (F_m) were measured after applying a saturating light pulse of 3,500 μ mol·m⁻²·s⁻¹. The
151 parameter F_j is fluorescence intensity at the J step at 2 ms and V_j is relative variable fluorescence
152 at 2 ms calculated as $V_j = (F_j - F_0)/(F_m - F_0)$. M_0 represents the initial slope of fluorescence
153 kinetics, which can be derived from the equation: $M_0 = 4 \times (F_{300 \mu s} - F_0)/(F_m - F_0)$.
154 Maximum quantum use efficiency (F_v/F_m) of photosystem II (PS II) in the dark-adapted state
155 was calculated as $F_v/F_m = (F_m - F_0)/F_m$. Performance index (PI) was calculated as follows
156 (Strasser et al., 2000; Živčák et al., 2008): $PI = \frac{1 - (F_0/F_m)}{M_0/V_j} \times \frac{F_m - F_0}{F_0} \times \frac{1 - V_j}{V_j}$.

157 *Gas exchange.* Leaf net photosynthesis (P_n), stomatal conductance (g_s), and transpiration
158 (E) of three plants per treatment per cultivar were measured one week before harvest using a
159 CIRAS-2 portable photosynthesis system (PP Systems, Amesbury, MA) with an automatic

160 universal PLC6 broadleaf cuvette. A fully expanded leaf at the top of the plant was chosen for
161 measurement. The environmental conditions within the cuvette were maintained at leaf
162 temperature of 25 °C, photosynthetic photon flux (PPF) of 1000 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and CO₂
163 concentration of 375 $\mu\text{mol}\cdot\text{mol}^{-1}$. Data were recorded when the environmental conditions and gas
164 exchange parameters in the cuvette became stable. These measurements were taken on sunny
165 days between 900 and 1600 HR, and plants were well watered to avoid water stress.

166 *Mineral analysis.* Four pomegranate plants per cultivar per treatment were randomly
167 selected to analyze leaf Na, Cl, calcium (Ca), and potassium (K) concentrations. All leaves of
168 each plant were dried and ground to pass a 40-mesh screen with a stainless Wiley mill (Thomas
169 Scientific, Swedesboro, NJ). Powder samples were extracted with 2% acetic acid (Fisher
170 Scientific, Fair Lawn, NJ) to determine Cl using the method described in Gavlak et al. (1994).
171 The concentration of Cl was determined with a M926 Chloride Analyzer (Cole Parmer
172 Instrument Company, Vernon Hills, IL). Powder samples were submitted to the Soil, Water and
173 Forage Testing Laboratory at Texas A&M University (College Station, TX) to determine Na, Ca,
174 and K concentrations. In brief, powder samples were digested in nitric acid following the
175 protocol described by Havlin and Soltanpour (1989). Na, Ca, and K in digested samples were
176 analyzed by inductively coupled plasma-optical emission spectrometry (SPECTRO Analytical
177 Instruments Inc., Mahwah, NJ) and reported on a dry plant basis as described by Isaac and
178 Johnson (1975).

179 *Experimental design and statistical analysis.* A split-plot design with salinity treatment as
180 the main plot and 22 cultivars as the subplot was utilized. Due to plant material availability, 4, 5,
181 or 7 plants (replications) per treatment per cultivar were grown. Analysis of variance (ANOVA)

182 was used to test the effects of soil salinity and cultivar on plant growth. Means separation
183 between treatments was conducted using Student's t-test.

184 Due to large number of cultivars, measurements took two weeks to complete. To
185 minimize differences caused by different days, measurements started by rep number across the
186 cultivars and treatments. Relative shoot DW was calculated for each plant in salt treatment as:
187 $\text{Relative shoot DW (\%)} = \text{shoot DW in salt treatment} / \text{shoot DW in control} \times 100$. Similarly,
188 relative values for height, shoot length, leaf DW, and stem DW were calculated. These relative
189 values and visual scores were used as salt tolerance indices for hierarchical cluster analysis
190 (Zeng et al., 2002). The dendrogram of the 22 pomegranate cultivars is based on the Ward
191 linkage method and squared Euclidian distance on the means of the salt tolerance indices for six
192 multivariate parameters including visual scores and all relative growth data. All statistical
193 analyses were performed using JMP (Version 12, SAS Institute Inc., Cary, NC).

194

195 **Results**

196 *Leachate EC.* The average leachate EC for the control (nutrient solution at EC of 1.2
197 $\text{dS}\cdot\text{m}^{-1}$) ranged from 2.8 to 3.9 $\text{dS}\cdot\text{m}^{-1}$ during the entire experimental period (Fig. 1). For salt
198 treatment, the leachate EC increased from 10.5 to 23.4 $\text{dS}\cdot\text{m}^{-1}$ (for EC values above 20, samples
199 were diluted before the final measurement). The data indicated that more salts accumulated in
200 the root zone of pomegranate plants irrigated with saline solution compared with nutrient
201 solution.

202 *Foliar salt damage and growth parameters.* Regardless of cultivar, all pomegranate
203 plants had no foliar salt damage (leaf burn, necrosis, or discoloration) with a visual score of 5
204 during the entire experimental period (i.e. 66 days) (Tables 1 and 2). Salt treatment affected plant

205 height, shoot length, leaf DW, stem DW, and shoot DW of all pomegranate cultivars, but no
206 interactions between salinity and cultivar were observed (Table 1). This indicates that all
207 pomegranate cultivars responded similarly to saline solution applied in this study. Salt treatment
208 did not inhibit the plant height of all pomegranate cultivars except ‘Mollar’, ‘Purple Heart’, and
209 ‘Russian 8’ (Table 2). Of all tested cultivars, the average reduction in plant height was 6% with
210 ‘Mollar’ having the greatest reduction of 14%. Salt treatment reduced the shoot length of ‘Arturo
211 Ivey’, ‘Al-Sirin-Nar’, ‘DeAnda’, ‘Early Wonderful’, ‘Kandahar’, ‘Purple Heart’, ‘Russian 8’,
212 ‘Surh-Anor’, and ‘Utah Sweet’ pomegranate. ‘Early Wonderful’ pomegranate had the greatest
213 reduction of 46%, whereas ‘ML’ had the least reduction of 10%. The average reduction of shoot
214 length of all cultivars was 25%.

215 Salt treatment decreased the leaf, stem, and shoot DW of ‘Al-Sirin-Nar’, ‘Angel Red’,
216 ‘Aperonski’, ‘DeAnda’, ‘Early Wonderful’, ‘Kandahar’, ‘Kazake’, ‘Purple Heart’, ‘Russian 8’,
217 ‘Salavatski’, ‘Surh-Anor’, and ‘Utah Sweet’ (Table 3). Salt treatment also reduced the leaf DW
218 of ‘Carolina Venum’, and stem and shoot DW of ‘Chiva’. Although no significance differences
219 were observed for the remaining cultivars, salt treatment slightly decreased their leaf, stem, and
220 shoot DW. The reductions of leaf, stem, and shoot DW on average for all cultivars were 32%,
221 32%, and 32%, respectively, with large variations among cultivars. The greatest reduction in leaf
222 DW, stem DW, and shoot DW was 52% for ‘Al-Sirin-Nar’, 49% for ‘Kunduzski’, and 48% for
223 ‘Al-Sirin-Nar’, respectively. The least reduction in leaf DW, stem DW, and shoot DW was 19%
224 for ‘Kunduzski’, 21% for ‘Mollar’, and 25% for ‘ML’, respectively.

225 A dendrogram was developed using the means of the salt tolerance indices for six
226 multivariate parameters including visual scores and relative height, shoot length, leaf DW, stem
227 DW, and shoot DW of all pomegranate cultivars (Fig. 2). Two major clusters were identified.

228 The cluster of ‘Arturo Ivey’, ‘DeAnda’, ‘Kazake’, ‘Russian 8’, ‘Apseronski’, ‘Purple Heart’,
229 ‘Carolina Vernum’, ‘Chiva’, ‘Kunduzski’, ‘Larry Ceballos 1’, ‘ML’, ‘Salavatski’, ‘Spanish
230 Sweet’, and ‘Wonderful’ was more salt tolerant than the other cluster of ‘Al-Sirin-Nar’,
231 ‘Kandahar’, ‘Surh-Anor’, ‘Early Wonderful’, ‘Angel Red’, ‘Ben Ivey’, ‘Utah Sweet’, and
232 ‘Mollar’.

233 *Chlorophyll fluorescence, performance index, and gas exchange.* Salt treatment affected
234 F_v/F_m , PI, P_n , g_s , and E (Table 1). All parameters except F_v/F_m were significant among cultivars,
235 and no interactions occurred between salt treatment and cultivar. Salt treatment reduced the F_v/F_m
236 values of ‘Al-Sirin-Nar’ and ‘Kunduzski’ only (Table 4). The averaged F_v/F_m values for all
237 pomegranate cultivars were 0.80 and 0.78 for the control and salt treatment, respectively. Salt
238 treatment also reduced the PI value of ‘Al-Sirin-Nar’. The mean PI values for all pomegranate
239 cultivars were 3.31 and 2.46 for the control and salt treatment, respectively, with 26% reduction.

240 The P_n , g_s , and E of all pomegranate cultivars irrigated with saline solution were similar
241 to those with nutrient solution with the exception of ‘Apseronski’ (Table 5). On average, the P_n ,
242 g_s , and E of all pomegranate cultivars were $11.2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, $237.2 \text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and 3.8
243 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for plants irrigated with nutrient solution, respectively, and $9.2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, 158.0
244 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and $2.9 \text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for plants irrigated with saline solution, respectively.

245 *Mineral analysis.* Salt treatment significantly increased leaf Na concentration by 3.2, 3.3,
246 5.1, 2.8, 18.8, 6.3, 8, 0.97, and 8.2 times for ‘Al-Sirin-Nar’, ‘Angel Red’, ‘Kazake’, ‘Kunduzski’,
247 ‘Russian 8’, ‘Salavatski’, ‘Surh-Anor’, ‘Utah Sweet’, and ‘Wonderful’, respectively, compared
248 to the control (Table 6). But no significant difference in the leaf Na concentration of the
249 remaining 13 pomegranate cultivars was observed between control and salt treatment. The
250 averaged leaf Na content of all tested pomegranate cultivars was 0.07 and $0.28 \text{mg}\cdot\text{g}^{-1}$ DW for

251 plants in the control and salt treatment, respectively. ‘Angel Red’ pomegranate in salt treatment
252 had the highest Na concentration of 0.71 mg·g⁻¹ DW.

253 Salt treatment also increased the leaf Cl concentration of ‘Al-Sirin-Nar’, ‘Apseronski’,
254 ‘Carolina Vernum’, ‘Kazake’, ‘Kunduzski’, ‘Mollar’, and ‘Russian 8’ pomegranate by 51%,
255 33%, 16%, 32%, 35%, 42%, and 37%, respectively, compared to their respective control (Table
256 6). The averaged leaf Cl concentration of all pomegranate cultivars was 8.56 and 10.03 mg·g⁻¹
257 DW for plants in the control and salt treatment, respectively. ‘Angel Red’ pomegranate in salt
258 treatment showed the highest Cl content of 12.04 mg·g⁻¹ DW.

259 Saline solution prepared with NaCl and CaCl₂ increased the leaf Ca concentration of
260 ‘Purple Heart’, ‘Russian 8’, ‘Salavatski’, and ‘Surh-Anor’ pomegranate by 34%, 64%, 51%, and
261 36%, respectively (Table 6). However, the leaf Ca concentration of ‘Arturo Ivey’, ‘Al-Sirin-
262 Nar’, ‘Angel Red’, ‘Apseronski’, ‘Ben Ivey’, ‘Chiva’, ‘Carolina Vernum’, and ‘Early wonderful’
263 pomegranate was less in salt treatment than in the control. No significant difference in the leaf
264 Ca concentration between control and salt treatment was observed for the remaining ten
265 pomegranate cultivars. The averaged leaf Ca concentration of all pomegranate cultivars was 4.76
266 and 4.49 mg·g⁻¹ DW for plants in the control and salt treatment, respectively.

267 Leaf K concentration decreased significantly with increasing EC in ‘Carolina Vernum’,
268 ‘Kazake’, and ‘Kunduzski’ pomegranate (Table 6). Although the leaf K content of ‘Arturo Ivey’,
269 ‘Al-Sirin-Nar’, ‘Apseronski’, ‘Ben Ivey’, ‘Chiva’, ‘DeAnda’, ‘Early wonderful’, ‘Kandahar’,
270 ‘Larry Ceballos 1’, and ‘ML’ tended to decrease, no significance between control and salt
271 treatment was observed. However, the leaf K content of ‘Purple Heart’, ‘Russian 8’, ‘Surh-
272 Anor’, ‘Utah Sweet’, and ‘Wonderful’ tended to increase, but no significance between control
273 and salt treatment occurred.

274

275 **Discussion**

276

277 *Salt accumulation in the substrate.* To quantify the salinity levels throughout the
278 experiment, we used PourThru method (Cavins et al., 2008) to check the EC of the leachate
279 solution, which is an indication of salt accumulation. More salts accumulated in the root zone of
280 pomegranate plants irrigated with saline solution compared with those with nutrient solution
281 (Fig. 1). El-Khawaga et al. (2013) also observed that saline groundwater irrigation at an EC 1.8
282 $\text{dS}\cdot\text{m}^{-1}$ and 6.0 $\text{dS}\cdot\text{m}^{-1}$ raised the salt accumulation in the root zone at a soil depth of 60-90 cm
283 from 3.7 $\text{dS}\cdot\text{m}^{-1}$ to 4.8 $\text{dS}\cdot\text{m}^{-1}$ and 7.7 $\text{dS}\cdot\text{m}^{-1}$ respectively, when pomegranate plants were grown
284 in sandy clay loam soil. Additionally, salts accumulated less rapidly in this experiment compared
285 to those reported previously (Sun et al., 2015a; Wu et al., 2016), which might result from
286 different substrates used. Metro-Mix 902 with 50%-60% composted bark was used in this
287 experiment, whereas Metro-Mix 360 with 45-55% Canadian sphagnum peat moss was used in
288 others. Metro-Mix 902 may retain lower salts and hold less water compared to Metro-Mix 360
289 because composted bark has lower cation exchange capacity and container capacity than peat
290 moss (Altland et al., 2014; Gabriel et al., 2009). This substrate could be suitable for long-term
291 pomegranate production to prevent salt accumulation.

292 *Salinity effect on growth.* Salinity can inhibit plant growth and cause deleterious effects
293 on plant foliage such as leaf burn, necrosis, or discoloration (Munns, 2002; Wahome et al.,
294 2001). Previous studies have showed that elevated salinity decrease the leaf and shoot biomass in
295 a variety of plant species (Cai et al., 2014; Niu et al., 2013; Niu and Rodriguez, 2006; Sun et al.,
296 2013, 2015 a, b). Salt treatment significantly decreased the leaf, stem, and shoot DW of all

297 cultivars with large variations among cultivars. However, all pomegranate cultivars had no foliar
298 salt damage. In addition, shoot length reduced by 25% on average. These results are in line with
299 previous work that consistently reported the increasing salinity level will inhibit pomegranate
300 growth in term of shoot length, leaf area, shoot biomass or yield. Seven-year-old ‘Manfalouty’,
301 ‘Wonderful’, and ‘Nab-Elgamal’ pomegranate grown in sandy clay loam soil and under
302 environmental conditions in upper Egypt had higher reduction in growth, flowering, and yield
303 with higher fruit cracking when they were irrigated with saline groundwater at an EC of 6.0
304 $\text{dS}\cdot\text{m}^{-1}$ than at an EC of 1.8 $\text{dS}\cdot\text{m}^{-1}$ (El-Khawaga et al., 2013). Naeini et al. (2006) reported that
305 ‘Malas Torsh’ and ‘Alak Torsh’ pomegranate had reduced stem length, internode length and
306 number, and leaf surface when they were irrigated with saline water spiked with 40, 80, or 120
307 Mm NaCl. Net productivity and crop yield of pomegranate would be expected to reduce as
308 growth reduction occurred as a result of saline water irrigation.

309 *Salinity effecct on photosynthetic apparatus.* Salinty also impairs plant photosynthetic
310 apparatus [photosystem II (PS II)] (Taiz and Zeiger, 2015). Salt treatment affected F_v/F_m , PI, P_n ,
311 g_s , and E, and all pomegranate cultivars showed similar responses to salt treatment. Salt
312 treatment decreased the F_v/F_m , PI, P_n , E, and g_s of pomegranate cultivars by 2%, 25%, 18%,
313 34%, and 23%, respectively. This result indicated that salt treatment impacted the photosynthetic
314 apparatus of pomegranate. Khayyat et al. (2016) reported that the photosynthetic efficiency of
315 ‘Malas-e-Saveh’ and ‘Shishe-Kab’ pomegranates reduced under salinity stress. Hasanpour et al.
316 (2015) also observed that salinity treatment decreased the chlorophyll index and chlorophyll
317 fluorescence.

318 *Salinity effect on mineral contents.* Plants can adapt to salt stress through excluding or
319 tolerating Na or Cl accumulation in their shoots (Munns and Tester, 2008). A total of 77%

320 pomegranate cultivars tested in the experiment increased or tended to increase the Na in the leaf
321 tissue when they were irrigated with saline solution; however, Na concentrations of all 22
322 cultivars was less than $1 \text{ mg}\cdot\text{g}^{-1}$. This result is similar to previous works done on pomegranate
323 plants by Karimi and Hassanpour (2014, 2017), Khayyat et al. (2014, 2016), Naeini et al. (2004,
324 2006) and Okhovatian-Ardakani et al. (2010), and they all observed an increase in Na in plant
325 tissue with increasing NaCl concentration in irrigation water. This result indicated that
326 pomegranate plants have high ability to minimize the transport of Na into the shoots to avoid
327 foliar salt damage (Karimi and Hassanpour, 2014, 2017). Leaf Na content in pomegranate is
328 similar to that in rose rootstocks (*Rosa* \times *hybrida* ‘Dr. Huey’, *R.* \times *fortuniana*, *R. multiflora*, and
329 *R. odorata*) that experienced foliar salt damage (Niu and Rodriguez, 2008). But the leaf Na
330 content in pomegranate is lower than other woody plants, for example, *Sophora secundiflora*
331 (Niu and Rodriguez, 2010), and *Jatropha curcas* (Niu et al., 2012).

332 On average, the leaf Cl content of all pomegranate cultivars in salt treatment was 10.03
333 mg g^{-1} DW, or 17% increase compared to that in control. Previous researchers have documented
334 that mineral concentration of Cl in plant tissue increased with increasing salinity (Karimi and
335 Hassanpour, 2014, 2017; Khayyat et al., 2014, 2016; Naeini et al., 2004, 2006; Okhovatian-
336 Ardakani et al., 2010). The Cl contents in pomegranate leaves were also lower than other woody
337 plants, such as rose rootstocks (*Rosa* \times *hybrida* ‘Dr. Huey’, *R.* \times *fortuniana*, *R. multiflora*, and *R.*
338 *odorata*) at EC of $8.2 \text{ dS}\cdot\text{m}^{-1}$ (Niu and Rodriguez, 2008), *Sophora secundiflora* at EC of 6.0
339 $\text{dS}\cdot\text{m}^{-1}$ (Niu and Rodriguez, 2010), and *Jatropha curcas* at EC of $3.0 \text{ dS}\cdot\text{m}^{-1}$ or above (Niu et al.,
340 2012). These results indicate that pomegranate plants are capable to restrict either the uptake or
341 transport of Cl (Karimi and Hassanpour, 2014, 2017).

342 Salinity dominated by Na salt reduces Ca availability, transport, and mobility to growing
343 regions of the plant, which subsequently affects the quality of both vegetative and reproductive
344 organs (Grattan and Grieve, 1999). In our study, 64% of pomegranate cultivars in salt treatment
345 had a significant or a slight decrease of Ca concentration, which agreed with Khayyat et al.
346 (2016). Salinity dominated by Na salts also reduces K acquisition (Grattan and Grieve, 1999;
347 Hasegawa et al., 2000). Thirteen out of 22 pomegranate cultivars in salt treatment had a
348 significant or slight reduction in leaf K content. This is probably a strategy for plants to reduce
349 salt stress as K plays an important role in adjusting the osmotic potential of plant cells as well as
350 activating enzymes related to respiration and photosynthesis (Taiz and Zeiger, 2015). In the
351 study, we observed that 41% of pomegranate cultivars tended to increase leaf K content, which
352 agreed with Karimi and Hassanpour (2014) and Naeini et al. (2004).

353

354 **Conclusions**

355 Pomegranate plants are very tolerant to a saline water up to EC of $15.0 \text{ dS}\cdot\text{m}^{-1}$ with little
356 foliar salt damage and slight growth reduction. Like previous reports, pomegranate plants are
357 capable to restrict either the uptake or transport of Na and Cl to leaves to reduce salt damage.
358 Pomegranate plants can be grown in hot arid and semiarid regions and irrigated with saline
359 groundwater with high salinity. Future research to quantify the effect of salinity on fruit yield
360 and quality is needed.

361

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371

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484 Table 1. A summary of analysis of variance for the effects of salt treatment (Trt), cultivar (Cv),
 485 and their interactions on visual score, height, shoot length, leaf dry weight, stem dry weight, shoot
 486 dry weight, chlorophyll fluorescence (F_v/F_m), performance index (PI), net photosynthesis (P_n),
 487 stomatal conductance (g_s), and transpiration (E) of 22 pomegranate cultivars that were grown and
 488 irrigated with nutrient solution or saline solution in the greenhouse.

| Source | Analysis of variance | | | | | | | | | | |
|----------|----------------------|--------|--------------|------------|------|-------|-----------|-----|-------|-------|-----|
| | Visual score | Height | Shoot length | Dry weight | | | F_v/F_m | PI | P_n | g_s | E |
| | | | | Leaf | Stem | Shoot | | | | | |
| Trt | NS | * | *** | *** | *** | *** | * | *** | *** | *** | *** |
| Cv | NS | *** | *** | *** | *** | *** | NS | ** | *** | ** | *** |
| Trt * Cv | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

489 NS, *, **, ***: nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

490 Table 2. Visual score, height, and shoot length of 22 pomegranate cultivars irrigated with
 491 nutrient solution (Control) or saline solution (Salt). Reduction (%) in height and shoot length
 492 were calculated as a percent of the Control.

| Cultivar | Visual score | | Height (cm) | | | Length of new shoots (cm) | | |
|------------------|--------------|------|---------------------|--------|------|---------------------------|---------|------|
| | Control | Salt | Control | Salt | % | Control | Salt | % |
| Arturo Ivey | 5 | 5 | 72.4 | 71.8 | 0.9 | 384.0 a | 247.3 b | 35.6 |
| Al-Sirin-Nar | 5 | 5 | 95.7 | 85.4 | 10.7 | 383.7 a | 238.3 b | 37.9 |
| Angel Red | 5 | 5 | 76.3 | 71.0 | 6.9 | 308.0 | 266.3 | 13.5 |
| Apseronski | 5 | 5 | 93.4 | 91.1 | 2.4 | 289.1 | 226.7 | 21.6 |
| Ben Ivey | 5 | 5 | 88.1 | 79.9 | 9.4 | 449.6 | 336.3 | 25.2 |
| Chiva | 5 | 5 | 89.4 | 86.0 | 3.8 | 473.2 | 410.4 | 13.3 |
| Carolina Venum | 5 | 5 | 84.6 | 82.6 | 2.4 | 393.0 | 294.4 | 25.1 |
| DeAnda | 5 | 5 | 77.6 | 76.6 | 1.3 | 398.4 a | 269.3 b | 32.4 |
| Early Wonderful | 5 | 5 | 76.4 | 72.2 | 5.5 | 438.0 a | 237.4 b | 45.8 |
| Kandahar | 5 | 5 | 79.0 | 74.1 | 6.1 | 454.9 a | 297.4 b | 34.6 |
| Kazake | 5 | 5 | 81.4 | 79.0 | 2.9 | 401.0 | 296.8 | 26.0 |
| Kunduzski | 5 | 5 | 87.0 | 85.6 | 1.6 | 492.0 | 413.2 | 16.0 |
| Larry Ceballos 1 | 5 | 5 | 83.4 | 83.2 | 0.2 | 355.2 | 311.4 | 12.3 |
| ML | 5 | 5 | 92.6 | 92.0 | 0.6 | 423.8 | 380.2 | 10.3 |
| Mollar | 5 | 5 | 84.7 a ^z | 72.9 b | 14.0 | 584.7 | 426.7 | 27.0 |
| Purple Heart | 5 | 5 | 82.0 a | 78.6 b | 4.1 | 400.6 a | 296.8 b | 25.9 |
| Russian 8 | 5 | 5 | 92.0 a | 82.7 b | 10.1 | 466.8 a | 292.6 b | 37.3 |

| | | | | | | | | |
|---------------|------|------|--------|--------|---------|---------|---------|---------|
| Salavatski | 5 | 5 | 85.0 | 80.4 | 5.4 | 408.7 | 334.8 | 18.1 |
| Spanish Sweet | 5 | 5 | 88.3 | 79.0 | 10.5 | 364.0 | 316.5 | 13.1 |
| Surh-Anor | 5 | 5 | 92.4 | 84.0 | 9.1 | 351.0 a | 244.7 b | 30.3 |
| Utah Sweet | 5 | 5 | 82.8 | 75.6 | 8.7 | 414.4 a | 329.2 b | 20.5 |
| Wonderful | 5 | 5 | 91.4 | 84.6 | 7.4 | 386.2 | 321.2 | 16.8 |
| Mean (CV) | 5 | 5 | 85.3 | 80.4 | 5.7% | 410.1 | 308.5 | 24.5% |
| | (0%) | (0%) | (7.5%) | (7.5%) | (69.7%) | (15.5%) | (18.9%) | (40.4%) |

493 ^z Means with different lowercase letters within a row for the same variable are significantly

494 different between treatments by Student's t-test at $P < 0.05$.

495

496 Table 3. Leaf, stem, and shoot dry weight (DW) of 22 pomegranate cultivars irrigated with

497 nutrient solution (Control) or saline solution (Salt). Reduction (%) in leaf, stem, and shoot DW

498 were calculated as a percent of the control.

| Cultivar | Leaf DW (g) | | | Stem DW (g) | | | Shoot DW (g) | | |
|----------------|---------------------|--------|------|-------------|--------|------|--------------|--------|------|
| | Control | Salt | % | Control | Salt | % | Control | Salt | % |
| Arturo Ivey | 17.6 | 11.0 | 37.5 | 11.6 | 9.0 | 22.0 | 29.2 | 20.1 | 31.4 |
| Al-Sirin-Nar | 23.6 a | 11.4 b | 51.9 | 16.1 a | 9.4 b | 41.4 | 39.7 a | 20.8 b | 47.6 |
| Angel Red | 18.3 a | 12.1 b | 33.6 | 13.5 a | 8.0 b | 40.8 | 31.8 a | 20.1 b | 36.7 |
| Apseronski | 20.8 a | 13.1 b | 36.7 | 12.7 a | 8.7 b | 31.2 | 33.5 a | 21.9 b | 34.7 |
| Ben Ivey | 26.3 | 18.7 | 29.2 | 19.0 | 12.0 | 36.8 | 45.3 | 30.7 | 32.3 |
| Chiva | 27.6 | 21.1 | 23.6 | 22.9 a | 14.8 b | 35.4 | 50.6 a | 35.9 b | 29.0 |
| Carolina Venum | 21.9 a ^z | 13.1 b | 40.1 | 18.0 | 12.1 | 32.6 | 39.9 | 25.2 | 36.7 |

| | | | | | | | | | |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| DeAnda | 20.2 a | 14.8 b | 26.8 | 14.6 a | 10.2 b | 30.0 | 34.8 a | 25.0 b | 28.1 |
| Early Wonderful | 20.3 a | 11.0 b | 45.8 | 15.1 a | 9.7 b | 35.9 | 35.4 a | 20.7 b | 41.6 |
| Kandahar | 12.4 a | 6.9 b | 44.5 | 14.9 a | 9.2 b | 38.1 | 27.2 a | 16.1 b | 40.9 |
| Kazake | 21.4 a | 16.4 b | 23.4 | 16.8 a | 12.2 b | 27.6 | 38.2 a | 28.6 b | 25.2 |
| Kunduzski | 20.1 | 16.4 | 18.5 | 21.9 | 11.3 | 48.5 | 42.0 | 30.6 | 27.0 |
| Larry Ceballos 1 | 23.7 | 18.3 | 22.6 | 16.0 | 11.4 | 28.6 | 39.7 | 29.7 | 25.1 |
| ML | 23.4 | 17.8 | 24.1 | 18.9 | 14.1 | 25.2 | 42.3 | 31.9 | 24.5 |
| Mollar | 24.5 | 14.2 | 41.9 | 14.1 | 11.2 | 20.5 | 38.6 | 25.5 | 34.0 |
| Purple Heart | 21.5 a | 13.8 b | 35.7 | 14.2 a | 10.1 b | 28.6 | 35.7 a | 23.9 b | 32.9 |
| Russian 8 | 21.1 a | 15.4 b | 26.8 | 17.8 a | 12.8 b | 28.1 | 38.9 a | 28.2 b | 27.4 |
| Salavatski | 18.0 a | 14.0 b | 22.3 | 16.3 a | 11.8 b | 27.6 | 34.3 a | 25.8 b | 24.8 |
| Spanish Sweet | 21.0 | 15.7 | 25.7 | 11.4 | 8.1 | 29.4 | 32.4 | 23.7 | 26.9 |
| Surh-Anor | 17.6 a | 10.2 b | 42.1 | 13.5 a | 7.8 b | 42.0 | 31.1 a | 18.0 b | 42.2 |
| Utah Sweet | 20.7 a | 13.7 b | 33.7 | 14.4 a | 9.2 b | 36.4 | 35.1 a | 22.9 b | 34.7 |
| Wonderful | 23.8 | 17.6 | 26.2 | 18.0 | 12.8 | 28.7 | 41.8 | 30.4 | 27.1 |
| Mean | 21.2 | 14.4 | 32.4% | 16.0 | 10.7 | 32.5% | 37.2 | 25.3 | 32.3% |
| (CV) | (15.6%) | (22.8%) | (28.5%) | (18.8%) | (18.5%) | (21.4%) | (14.7%) | (20.0%) | (20.3%) |

499 ^z Means with different lowercase letters within a row for the same variable are significantly

500 different between treatments by student's t-test at $P < 0.05$.

501 Table 4. Leaf chlorophyll fluorescence (F_v/F_m), and performance index (PI) of 22 pomegranate
 502 cultivars irrigated with nutrient solution (Control) or saline solution (Salt). Reduction (%) in
 503 F_v/F_m , and PI were calculated as a percent of the control.

| Cultivars | F_v/F_m | | | PI | | |
|------------------|-----------|--------|-----|---------|--------|------|
| | Control | Salt | % | Control | Salt | % |
| Autora Ivy | 0.80 | 0.80 | 0.0 | 3.65 | 3.26 | 10.8 |
| Al-Sirin-Nar | 0.80 a | 0.78 b | 3.5 | 3.22 a | 1.10 b | 66.0 |
| Angel Red | 0.79 | 0.79 | 0.4 | 3.39 | 2.82 | 16.8 |
| Apseronski | 0.78 | 0.77 | 0.9 | 1.73 | 1.21 | 30.1 |
| Ben Ivy | 0.80 | 0.79 | 1.7 | 4.14 | 3.26 | 21.1 |
| Chiva | 0.80 | 0.78 | 2.5 | 3.62 | 3.05 | 15.8 |
| Carolina Venum | 0.80 | 0.78 | 2.1 | 4.37 | 2.98 | 31.9 |
| DeAnda | 0.80 | 0.79 | 2.1 | 4.00 | 2.18 | 45.5 |
| Early wonderful | 0.79 | 0.78 | 0.8 | 2.46 | 2.21 | 10.2 |
| Kandahar | 0.79 | 0.79 | 0.8 | 3.21 | 2.16 | 32.6 |
| Kazake | 0.81 | 0.81 | 1.6 | 3.50 | 3.44 | 1.8 |
| Kunduzski | 0.81 a | 0.77 b | 4.9 | 2.79 | 1.70 | 38.9 |
| Larry Ceballos 1 | 0.80 | 0.80 | 0.4 | 3.89 | 2.46 | 36.9 |
| ML | 0.80 | 0.79 | 1.3 | 2.95 | 2.37 | 19.8 |
| Mollar | 0.78 | 0.78 | 0.0 | 2.77 | 2.46 | 11.1 |
| Purple Heart | 0.80 | 0.80 | 0.4 | 3.80 | 3.26 | 14.1 |
| Russian 8 | 0.80 | 0.76 | 4.6 | 3.64 | 2.06 | 43.5 |

| | | | | | | |
|---------------|--------|--------|---------|---------|---------|---------|
| Salavatski | 0.79 | 0.79 | 0.4 | 2.39 | 1.91 | 20.2 |
| Spanish Sweet | 0.80 | 0.78 | 2.5 | 3.10 | 1.63 | 47.3 |
| Surh-Anor | 0.79 | 0.78 | 1.7 | 2.66 | 2.24 | 15.8 |
| Utah Sweet | 0.80 | 0.79 | 2.1 | 3.91 | 2.86 | 26.9 |
| Wonderful | 0.81 | 0.79 | 1.7 | 3.60 | 3.70 | 2.7 |
| Mean (CV) | 0.80 | 0.78 | 1.7 | 3.31 | 2.46 | 25.4 |
| | (1.1%) | (1.2%) | (81.9%) | (19.8%) | (28.7%) | (63.5%) |

504 ^z Means with different lowercase letters within a row for the same variable are significantly

505 different between treatments by student's t-test at $P < 0.05$.

506 Table 5. Leaf net photosynthesis (P_n), stomatal conductance (g_s), and transpiration (E) of 22
 507 pomegranate cultivars irrigated with nutrient solution (Control) or saline solution (Salt).
 508 Reduction (%) in P_n , g_s , and E were calculated as a percent of the control.

| Cultivars | P_n ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) | | | g_s ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) | | | E ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) | | |
|------------------|---|-------|------|---|---------|------|---|-------|------|
| | Control | Salt | % | Control | Salt | % | Control | Salt | % |
| Autora Ivy | 12.2 | 8.9 | 26.9 | 248.3 | 123.5 | 50.3 | 4.0 | 2.6 | 36.0 |
| Al-Sirin-Nar | 8.5 | 8.5 | 0.7 | 149.4 | 138.8 | 7.1 | 2.8 | 2.7 | 2.5 |
| Angel Red | 13.0 | 11.2 | 13.8 | 332.7 | 213.3 | 35.9 | 4.8 | 3.7 | 22.3 |
| Apseronski | 10.1 a ^z | 7.1 b | 29.8 | 213.8 a | 112.0 b | 47.6 | 3.6 a | 2.3 b | 37.0 |
| Ben Ivy | 11.2 | 8.2 | 26.7 | 203.3 | 127.0 | 37.5 | 3.6 | 2.6 | 26.2 |
| Chiva | 12.3 | 9.5 | 22.4 | 319.5 | 146.7 | 54.1 | 4.5 | 2.9 | 35.5 |
| Carolina Venum | 11.5 | 9.8 | 15.0 | 284.7 | 159.0 | 44.1 | 4.1 | 3.2 | 21.9 |
| DeAnda | 12.5 | 10.3 | 17.6 | 272.0 | 171.3 | 37.0 | 4.4 | 3.2 | 26.4 |
| Early wonderful | 12.1 | 10.0 | 17.9 | 319.0 | 146.3 | 54.1 | 4.6 | 2.9 | 37.0 |
| Kandahar | 10.2 | 9.8 | 3.9 | 210.0 | 138.0 | 34.3 | 3.5 | 2.9 | 17.0 |
| Kazake | 8.5 | 6.2 | 27.9 | 154.0 | 92.0 | 40.3 | 2.9 | 2.1 | 26.9 |
| Kunduzski | 11.7 | 11.5 | 1.1 | 247.3 | 217.0 | 12.2 | 3.9 | 3.7 | 6.7 |
| Larry Ceballos 1 | 12.2 | 11.7 | 3.7 | 233.3 | 231.0 | 1.0 | 3.9 | 3.9 | 1.0 |
| ML | 11.7 | 11.2 | 3.7 | 266.7 | 251.2 | 5.8 | 3.9 | 3.8 | 1.9 |
| Mollar | 14.9 | 12.2 | 18.0 | 343.8 | 258.5 | 24.8 | 4.7 | 4.0 | 16.6 |
| Purple Heart | 12.5 | 9.8 | 21.7 | 250.4 | 176.3 | 29.6 | 4.2 | 3.1 | 26.6 |
| Russian 8 | 8.1 | 5.4 | 33.7 | 139.6 | 66.7 | 52.2 | 2.7 | 1.6 | 41.5 |

| | | | | | | | | | |
|---------------|-----------------|----------------|-----------------|------------------|------------------|-----------------|----------------|----------------|-----------------|
| Salavatski | 11.4 | 9.1 | 20.1 | 217.2 | 153.3 | 29.4 | 3.8 | 2.9 | 25.0 |
| Spanish Sweet | 10.0 | 6.7 | 33.0 | 185.4 | 91.5 | 50.6 | 3.2 | 2.1 | 34.8 |
| Surh-Anor | 13.8 | 9.6 | 30.5 | 328.7 | 189.0 | 42.5 | 4.8 | 3.3 | 31.0 |
| Utah Sweet | 8.6 | 6.3 | 27.0 | 163.3 | 96.0 | 41.2 | 3.1 | 2.1 | 33.0 |
| Wonderful | 9.6 | 9.2 | 4.4 | 163.7 | 150.3 | 8.2 | 3.1 | 2.9 | 9.2 |
| Mean (CV) | 11.2 (16.0%) | 9.2 (20.8%) | 18.1 (60.6%) | 238.4 (27.1%) | 156.8 (33.7%) | 33.6 (50.4%) | 3.8 (17.3%) | 2.9 (22.1%) | 23.4 (53.4%) |

509 ^z Means with different lowercase letters within a row for the same variable are significantly

510 different between the treatments by student's t-test at $P < 0.05$.

511 Table 6. Leaf Na, Ca, Cl, and K concentrations of pomegranate cultivars irrigated with nutrient
 512 solution (Control) or saline solution (Salt).

| Cultivars | Mineral concentration (mg/g DW) | | | | | | | |
|------------------|---------------------------------|--------|---------|---------|---------|--------|---------|---------|
| | Na | | Cl | | Ca | | K | |
| | Control | Salt | Control | Salt | Control | Salt | Control | Salt |
| Arturo Ivey | 0.12 | 0.11 | 10.07 | 11.39 | 5.14 a | 3.16 b | 21.35 | 20.48 |
| Al-Sirin-Nar | 0.13 b ^z | 0.52 a | 7.74 b | 11.69 a | 5.83 a | 3.18 b | 17.86 | 16.24 |
| Angel Red | 0.17 b | 0.71 a | 9.33 | 12.04 | 4.54 a | 3.60 b | 21.55 | 22.06 |
| Apseronski | 0.10 | 0.25 | 8.02 b | 10.67 a | 5.08 a | 3.72 b | 18.51 | 16.82 |
| Ben Ivey | 0.08 | 0.19 | 8.12 | 8.79 | 4.26 a | 3.04 b | 20.67 | 19.09 |
| Chiva | 0.07 | 0.07 | 9.31 | 9.30 | 5.70 a | 4.03 b | 21.51 | 20.62 |
| Carolina Venum | 0.04 | 0.05 | 8.95 b | 10.34 a | 4.75 a | 2.31 b | 22.12 a | 18.61 b |
| DeAnda | 0.07 | 0.06 | 9.32 | 9.27 | 4.63 | 4.08 | 22.41 | 21.07 |
| Early Wonderful | 0.07 | 0.06 | 10.72 | 9.75 | 4.26 a | 2.73 b | 22.46 | 20.92 |
| Kandahar | 0.02 | 0.39 | 8.47 | 10.21 | 4.78 | 3.73 | 21.03 | 17.94 |
| Kazake | 0.11 b | 0.65 a | 7.03 b | 9.29 a | 5.38 | 3.88 | 18.32 a | 14.57 b |
| Kunduzski | 0.12 b | 0.45 a | 7.70 b | 10.37 a | 4.34 | 5.35 | 18.39 a | 16.03 b |
| Larry Ceballos 1 | 0.07 | 0.13 | 7.93 | 9.57 | 4.26 | 4.23 | 20.44 | 19.95 |
| ML | 0.02 | 0.10 | 9.88 | 9.93 | 4.42 | 3.13 | 23.43 | 21.20 |
| Mollar | 0.01 | 0.07 | 7.63 b | 10.80 a | 4.87 | 4.93 | 15.94 | 16.36 |
| Purple Heart | 0.05 | 0.34 | 7.86 | 9.40 | 4.06 b | 5.42 a | 19.82 | 21.59 |
| Russian 8 | 0.02 b | 0.45 a | 7.34 b | 10.03 a | 4.37 b | 7.19 a | 17.52 | 18.33 |

| | | | | | | | | |
|---------------|---------|---------|---------|--------|---------|---------|---------|---------|
| Salavatski | 0.05 b | 0.35 a | 7.74 | 8.38 | 4.46 b | 6.71 a | 17.30 | 17.37 |
| Spanish Sweet | 0.15 | 0.61 | 9.31 | 10.36 | 4.74 | 6.60 | 17.21 | 17.69 |
| Surh-Anor | 0.04 b | 0.34 a | 7.63 | 9.51 | 4.55 b | 6.18 a | 16.88 | 18.13 |
| Utah Sweet | 0.08 b | 0.15 a | 9.54 | 9.50 | 5.55 | 4.94 | 22.46 | 24.01 |
| Wonderful | 0.02 b | 0.21 a | 8.75 | 10.12 | 4.78 | 6.73 | 20.74 | 22.47 |
| Mean (CV) | 0.07 | 0.28 | 8.56 | 10.03 | 4.76 | 4.49 | 19.90 | 19.16 |
| | (61.6%) | (73.8%) | (11.7%) | (9.0%) | (10.4%) | (32.4%) | (11.1%) | (12.8%) |

513 ^z Means with different lowercase letters within a row for the same variable are significantly

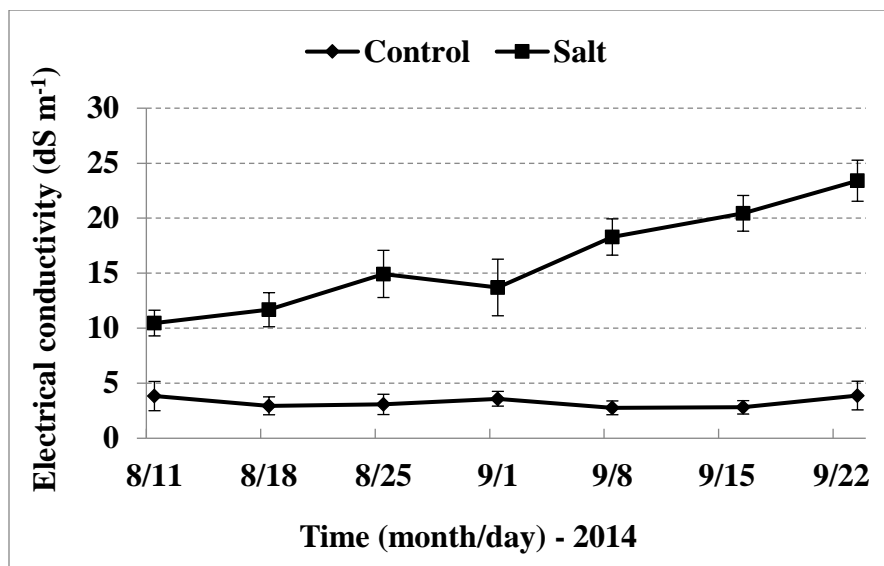
514 different between treatments by student's t-test at $P < 0.05$.

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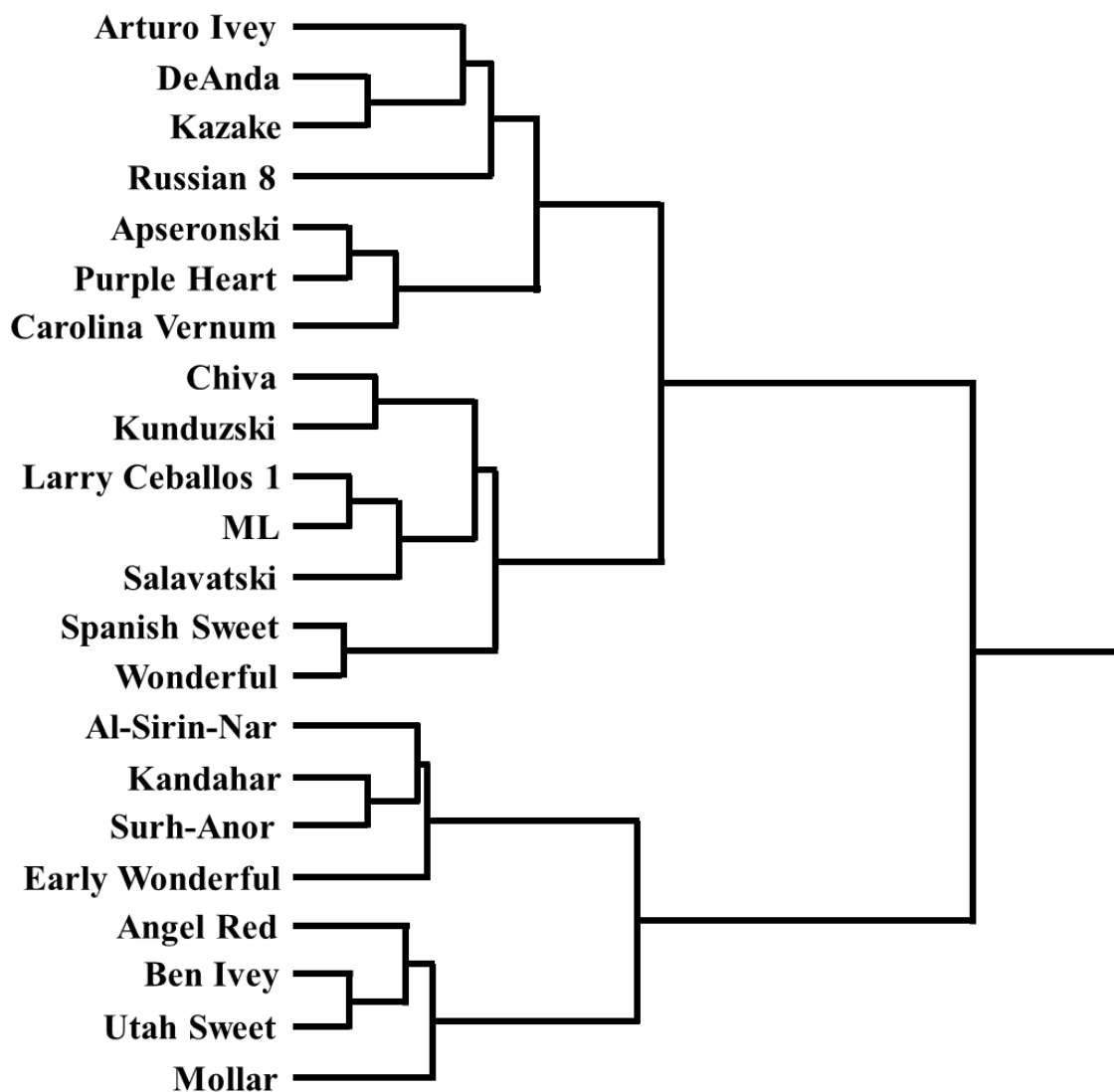
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520 **Fig. 1.** Leachate electrical conductivity (EC) taken using PourThru technique during the

521 experimental period. Control represents a nutrient solution at EC of $1.2 \text{ dS}\cdot\text{m}^{-1}$, whereas salt

522 represents saline solution at EC of $10.0 \text{ dS}\cdot\text{m}^{-1}$ for the first four weeks and $15.0 \text{ dS}\cdot\text{m}^{-1}$ for the
523 latter three weeks. Vertical bars represent standard deviations of twenty-two samples (cultivar)
524 per treatment.

525



526

527

528 **Fig. 2.** The dendrogram of cluster analysis of 22 pomegranate cultivars based on the Ward
529 linkage using squared Euclidian distance on means of multivariate parameters including visual
530 scores and relative height, shoot length, leaf dry weight, stem dry weight, and shoot dry weight.