Response of Hot Pepper Yield, Fruit Quality, and Fruit Ion Content to Irrigation Water Salinity and Leaching Fractions

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Abstract. It has been proved that irrigation with high saline water and leaching fraction (LF) affect crop yield, but the effects of irrigation water salinity (EC_{iw}) and LF on fruit quality remain largely elusive. We therefore investigated the effects of EC_{iw} and LF on the yield, fruit quality, and ion content of hot peppers. An experiment using irrigation water with five levels of salinity (EC_{iw} of 0.9, 1.6, 2.7, 4.7, and 7.0 dS·m⁻¹) and two LFs (0.17 and 0.29) was conducted in a rain shelter. The experiment took the form of a completely randomized block design, and each treatment was replicated four times. We increased the salinity of the irrigation water by adding 1:1 milliequivalent concentrations of NaCl and CaCl₂ to a half-strength Hoagland solution. The plants were irrigated for 120% and 140% evapotranspiration, corresponding to an LF of 0.17 and 0.29. Results showed that the total fruit yield decreased significantly with an increase in the EC_{iw} as a result of reduction both in the fresh weight of fruit and the number of fruit per plant. An increase in the EC_{iw} also led to a decrease in the total dry biomass of fruit and plant, as well as decreasing water use efficiency (WUE_F). Salinity reduced the appearance of the fruit by both decreasing the length (F_L) and maximum width (F_{MW}) of the fruit. However, increased EC_{iw} also improved the taste of the hot peppers by increasing the total soluble solid (TSS) content, as well as adding to their nutritional quality with a higher content of Vitamin C (VC). Their storage quality was also improved because of an improvement in the firmness of the fruit (F_n) as well as a reduction in the fruit water content (F_{WC}). An increase in the LF led to an increase in the total fruit yield, total dry biomass of fruit and plant, and WUE_F; it also increased the F_{WC} and VC content, and decreased the F_{MW} and fruit shape index (F_{SI}). The threshold-slope linear response and sigmoidal-sharp models were both a good fit for the measured total fruit yield, and the LF had no significant effect on the model parameters. The relative TSS and F_n increased linearly as the electrical conductivity (EC) of soil-saturated paste extract (EC_e) increased, whereas they decreased linearly as the relative seasonal evapotranspiration (ET_r) increased regardless of the LFs. The relative F_W, F_L, and F_{MW} decreased linearly with the increased EC_e, and increased linearly with the increased ET_r, regardless of the LFs. The relative fruit Na⁺ concentration increased linearly as the EC_e increased. The regression correlations between the total fruit yield, fruit quality parameters, ion contents, and EC_e or ET_r could provide important information for salinity and irrigation water management with a compromise between the hot pepper yield and fruit quality.

In many parts of the world, saline water collected from field drainage has been successfully used for irrigation (Grattan et al., 1994). However, plants may suffer from osmotic stress, ionic imbalance, and the inhibition of nutrient absorption when irrigated with saline water, with an adverse effect on fruit yield (Ben-Gal et al., 2008; Munns, 2002). To alleviate the effects of salinity stress on plants, the application of extra water for the leaching of salts (e.g., Na⁺, Ca²⁺, and Mg²⁺) from the root zone is a common

method of reducing the salt content in the surface soil (Chen et al., 2016). An appropriate LF will maintain tolerable root-zone salinity (Dudley et al., 2008), in turn, enhancing the fruit yield.

Peppers (*Capsicum annuum* L.) are considered moderately sensitive to salt stress (Rameshwaran et al., 2016). The threshold-slope linear response model (Maas and Hoffman, 1977) and the sigmoidal-sharp salinity response model (Van Genuchten and Hoffman, 1984) are commonly used to describe

yield–salinity relationship. The LF may affect the yield of peppers, but whether the LF also has an effect on the parameters of these models is unclear.

Irrigation with saline water may in many cases improve fruit quality. The fruit quality parameters of tomatoes (*Solanum lycopersicum* L.) including total acidity, TSS, sugar content, pigment content, and organic acid content were improved by saline water irrigation (Gough and Hobson, 2015; Plaut and Yehezkel, 2004). It also improved the quality of the melons (*Citrullus vulgaris* L.) by increasing F_n, dry matter, acidity, TSS, and total sugar content (Colla et al., 2006; Navarro et al., 1999). For peppers, however, there is limited literature that is mainly concerned with sweet peppers or bell peppers, and it is not inconclusive. Navarro et al. (2010) and Rubio et al. (2009) found that irrigation with saline water (3.0 dS·m⁻¹ NaCl) had no effect on the TSS, F_n, and pH of sweet peppers. However, Navarro et al. (2002) found that saline water irrigation (from NaCl or Na₂SO₄) decreased the quality of sweet peppers by reducing pulp thickness, F_n, TSS, and fructose, glucose, and amino acid contents. On the other hand, saline water irrigation improved the fruit quality of bell peppers giving higher TSS, VC content (ascorbic acid), total sugar content, and acidity (Patil et al., 2014), and improved the quality of sweet peppers causing a higher myoinositol, fructose, and glucose content (Rubio et al., 2009). The quantitative relationship between the fruit quality parameters of hot peppers and the EC_e or evapotranspiration, which are useful relationship to know for the management of saline irrigation for high-quality hot pepper production, have not been documented. In addition, we studied Na⁺, K⁺, and Ca²⁺ concentrations and K⁺/Na⁺ ratio in hot peppers to further understand the mechanisms causing the effects of the EC_{iw} and LF on yield and quality.

The objectives of this study are 1) to assess the effects of EC_{iw} and LF on the yield, fruit quality, and ion content of hot peppers; 2) to study the responses of a total yield of hot peppers to salinity and to calibrate the yield indices of both a threshold-slope linear response model and sigmoidal-shape model; and 3) to establish the quantitative relationships between fruit quality, ion content, and EC_e or seasonal evapotranspiration.

Materials and Methods

Experimental setup. The experiment was conducted from Apr. 28 to July 22, 2015, in a rain shelter at the Agro-Meteorology Research Station in Nanjing City, Jiangsu Province, China. The white plastic pots (top diameter 26 cm × bottom diameter 22 cm × height 27 cm), with a 2-cm hole in the bottom of each pot to allow for drainage were used. Each pot was filled with 11 kg of air-dried soil with a sandy loam texture sifted through a 5-mm sieve. The bulk density of the soil was 1.47 g·cm⁻³, the field water capacity was

Table 1. Effects of irrigation water salinity (EC_{iw}) and leaching fraction (LF) on yield parameters and water use efficiency (WUE_F) of hot pepper using two-way analysis of variance (ANOVA).

Factors	Number of fruits per plant	Fresh fruit wt (g)	Total fruit yield (g/plant)	Total fruit dry biomass (g/plant)	Plant dry biomass (g/plant)	WUE_F (kg·m ⁻³)
EC_{iw} (dS·m ⁻¹)						
0.9	23.5 a	28.2 a	656.1 a	48.5 a	88.0 a	26.1 a
1.6	21.0 ab	27.9 a	577.7 b	42.6 b	80.5 b	23.4 b
2.7	19.6 b	24.6 b	481.9 c	41.2 b	72.5 c	21.4 c
4.7	17.8 b	21.8 c	385.3 d	36.3 c	62.6 d	20.6 c
7.0	13.6 c	19.1 c	257.3 e	25.9 d	44.1 e	15.4 d
LF						
0.17	18.4	24.0	449.2 b	37.2 b	66.3 b	20.9 b
0.29	19.9	24.7	494.1 a	40.6 a	72.8 a	22.4 a
ANOVA						
LF	NS	NS	*	*	*	*
EC_{iw}	***	***	***	***	***	***
$EC_{iw} \times LF$	NS	NS	NS	NS	NS	NS

*, **, and *** represent significant differences between means at 0.05, 0.01, and 0.001 level of probability, respectively; NS, nonsignificant. Different letters within a column for each experimental factor indicate significant difference at $P < 0.05$ by Duncan's multiple range tests.

0.27 (cm³·cm⁻³), the wilting point was 0.04 (cm³·cm⁻³), and the soil pH was 7.4. The available N, P, and K contents of the soil were 28.0, 16.3, and 47.7 mg·kg⁻¹, respectively, and soil organic matter content was 7.3 g·kg⁻¹.

Hot pepper plants (cultivar Bocuiwang) of a similar height were selected and transplanted into plastic pots on Apr. 28, 2015, one plant per pot. Before transplanting, all the pots were saturated with tap water. Each plant was irrigated using tap water at 5 d after transplanting (DAT) with an irrigation amount of 0.9 L per plant. Saline water treatments with two LFs commenced 10 DAT.

Irrigation water with five levels of salinity (i.e., 0.9, 1.6, 2.7, 4.7, and 7.0 dS·m⁻¹) and two LFs (i.e., 0.17 and 0.29) was included in the experiment. The experiment was a completely randomized block design comprising 10 treatments with each treatment being replicated four times. A half strength Hoagland solution [in mmol·L⁻¹: 2.0 Ca(NO₃)₂ × 4H₂O, 2.0 KNO₃, 0.5 NH₄NO₃, 0.5 MgSO₄ × 7H₂O, 0.25 KH₂PO₄; in μmol·L⁻¹: 40 Fe-EDTA, 25 H₃BO₃, 2.0 MnCl₂ × 4H₂O, 2.0 ZnSO₄ × 7H₂O, 0.5 CuSO₄ × 5H₂O, 50 KCl, 0.075 (NH₄)₆Mo₇O₂₄ × 4H₂O, 0.15 CoCl₂ × 6H₂O] at EC of 0.9 dS·m⁻¹ was added to the irrigation water that was used as a nonsaline treatment (Heeg et al., 2008). Saline water was produced by adding 1:1 milliequivalent

Table 2. Effects of irrigation water salinity (EC_{iw}) and leaching fraction (LF) on total soluble solids (TSS), Vitamin C content (VC), fruit firmness (F_n), fruit water content (F_{WC}), fruit length (F_L), maximum fruit width (F_{MW}), and fruit shape index (F_{SI}) of hot pepper using the two-way analysis of variance (ANOVA).

Factors	TSS (%)	VC (mg/100 g FW)	F_n (kg·cm ⁻²)	F_{WC} (%)	F_L (mm)	F_{MW} (mm)	F_{SI}
EC_{iw} (dS·m ⁻¹)							
0.9	3.4 d	64.0 b	14.4 c	92.83 a	95.7 a	36.3 ab	0.383 b
1.6	3.5cd	80.2 ab	15.0 bc	92.31 b	93.0 a	36.3 ab	0.395 b
2.7	3.7 c	76.7 ab	15.7 b	91.38 c	87.7 b	37.2 a	0.430 a
4.7	4.1 b	74.0 ab	16.8 a	90.44 d	83.0 c	34.9 bc	0.433 a
7.0	4.5 a	95.1 a	17.6 a	89.87 e	81.3 c	33.7 c	0.421 a
LF							
0.17	3.9	65.3 b	15.5	91.57 b	88.2	36.4 a	0.423 a
0.29	3.7	88.9 a	15.6	91.91 a	90.2	35.5 b	0.398 b
ANOVA							
LF	NS	**	NS	*	NS	*	**
EC_{iw}	***	*	***	***	***	***	***
$EC_{iw} \times LF$	NS	NS	NS	NS	*	NS	**

*, **, and *** represent significant differences between means at 0.05, 0.01, and 0.001 level of probability, respectively; NS, nonsignificant. Different letters within a column for each experimental factor indicate significant difference at $P < 0.05$ by Duncan's multiple range tests.

concentrations of NaCl and CaCl₂ to the half strength Hoagland solution.

The amount of saline irrigation water applied was 120% and 140% of evapotranspiration (ET, g), corresponding to an LF of 0.17 and 0.29. The ET of each pot was determined by using the water balance method:

$$ET = W_n - W_{n+1} + (I - D) \times \rho \quad [1]$$

where W_n and W_{n+1} are the pot weights before the n th and $(n + 1)$ th irrigation (g), I and D are the amounts of irrigation and drainage water applied, respectively (L), and ρ is the water bulk density (1000 g·L⁻¹).

A glass bottle was placed underneath each pot to collect the drainage water, and the amount collected was measured after each irrigation event. Immediately before each irrigation event, each pot was weighed, and the ET and irrigation amounts were calculated. Throughout the experiment, the irrigation interval was 2–5 d, and in total, there were 24 irrigations.

Measurements and method

Yield, dry biomass, and WUE_F . The hot pepper fruits were harvested during their whole growth stages five times in total, starting on 8 June 2015. The weight of each

fruit and the number of fruits per plant were measured at each harvesting to evaluate the mean weight of the fresh fruit and the total fruit yield. The fruit gathered at each harvesting was then dried in an oven at 70 °C to obtain a constant dry weight. The same procedure was performed at the end of the experiment on the roots, stems, and leaves of each plant. WUE_F was calculated as the ratio between the total fruit yield and the seasonal ET.

Fruit quality parameters. The fruit quality parameters were measured during the fruit maturation and harvesting stages. The TSS of the hot peppers was measured using a handheld refractometer (WZ-108; Beijing Wancheng Beizen Precise Instruments Co., Ltd., China). The F_n was detected using a fruit firmness tester (GY-3; Sanhe Instruments Co., Ltd., China) and applying a cylindrical probe to the fruit shoulder. The content of VC was determined using the 2, 6-dichloroindophenol titrimetric method (AOAC, 1984). The water content of the fruit (F_{WC}) was determined using the oven-drying method described previously at each harvesting. The F_L and F_{MW} of each fruit were also measured using a digital vernier caliper (PD 151; Prokit's Industries Co., China),

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Table 3. Effects of irrigation water salinity (EC_{iw}) and leaching fraction (LF) on ion content of hot peppers using the two-way analysis of variance (ANOVA).

Factors	Ca^{2+} (mg·g ⁻¹ DW)	K^{+} (mg·g ⁻¹ DW)	Na^{+} (mg·g ⁻¹ DW)	K^{+}/Na^{+}
EC_{iw} (dS·m ⁻¹)				
0.9	1.48	20.80	0.114 c	192.56 a
1.6	1.31	22.25	0.143 c	146.48 b
2.7	1.37	21.75	0.266 bc	97.55 c
4.7	1.28	21.11	0.303 b	72.87 cd
7.0	1.75	21.61	0.585 a	39.80 d
LF				
0.17	1.44	21.7	0.27	110.58
0.29	1.45	21.4	0.29	104.80
ANOVA				
LF	NS	NS	NS	NS
EC_{iw}	NS	NS	***	***
$EC_{iw} \times LF$	NS	NS	NS	NS

*** represents significant differences between means at 0.001 level of probability; NS, nonsignificant. Different letters within a column for each experimental factor indicate significant difference at $P < 0.05$ by Duncan's multiple range tests.

Fig. 1. Calculated threshold-shape linear response salinity model and sigmoidal-shape salinity response model based on irrigation water salinity (EC_{iw} , A), EC_e of soil saturated paste extract (EC_e , B) and drainage water salinity (EC_{dw} , C) regardless of the leaching fractions (LFs); the values of EC_{dw} and EC_e that are used were measured at the end of the experiment.

Fig. 2. Relationship between the relative total fruit yield (Y_r) and relative seasonal evapotranspiration (ET_r); LF is the leaching fraction.

and the F_{SI} that is defined as the ratio of F_{MW} to F_L was calculated.

The Na^{+} , K^{+} , and Ca^{2+} content of the hot peppers. The dried fruits were mixed and then ground into powder and stored at room

temperature before digestion. The dried samples (0.1 g) were digested in high-purity HNO_3 at a 5% (v/v) HNO_3 concentration that was heated using a heating block. The Na^{+} , K^{+} , and Ca^{2+} concentrations in the digestion were measured using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES, Perkin Elmer Optima 8000). For quality control, procedural blanks, standard reference materials, and sample replicates were randomly inserted.

Yield response functions. In this study, the data of the relative total fruit yield (Y_r) were fitted to the yield reduction models. One was the threshold-slope linear response model proposed by Maas and Hoffman (1977):

$$Y_r = \frac{Y_i}{Y_m} = \begin{cases} 1 & 0 \leq EC_e \leq EC_t \\ 1 - b(EC_e - EC_t) & EC_t < EC_e < EC_o \\ 0 & EC_e > EC_o \end{cases} \quad [2]$$

where Y_m is the maximum total fruit yield, mainly represented by an EC_{iw} of 0.9 dS·m⁻¹;

Y_i is the observed total fruit yield for the saline treatment; EC_t (dS·m⁻¹) is the threshold EC , and b (m·dS⁻¹) is the slope parameter, indicating the yield loss per unit increase in the EC_e beyond the threshold value; EC_o is the root-zone salinity above which the yield is zero.

Another model was the sigmoidal-sharp salinity response model proposed by Van Genuchten and Hoffman (1984):

$$Y_r = \frac{1}{1 + (EC_e/EC_{e50})^s} \quad [3]$$

where EC_{e50} represents the EC_e value when $Y_r = 0.5$; and s is a dimensionless empirical parameter.

We applied these two models to analyze the effect of salinity on the Y_r . We also used EC_{iw} and drainage water salinity (EC_{dw}) instead of EC_e in Eqs. [2] and [3] to assess the effects of EC_{iw} and EC_{dw} on the Y_r .

Water stress caused by salinity. Stewart and Hagan (1973) proposed a model to predict the yield from ET. The publication FAO 33 introduced a relationship between the relative yield decrease for water stress combining a yield response factor (K_y) and relative seasonal ET ($ET_r = ET_i/ET_m$, where ET_i and ET_m are observed seasonal ET values for saline treatments and maximum ET, respectively) to assess plant tolerance to water stress (Doorenbos and Kassam, 1979). This model has already been used to analyze salinity in many previous studies (Heidarpour et al., 2009; Kiremit and Arslan, 2016) and was used in this study:

$$1 - Y_r = K_y(1 - ET_r) \quad [4]$$

Statistical analysis. SPSS (Version 21.0; IBM Corp., Armonk, NY) was used to give two-way analyses of variance using the general linear model-univariate procedure to determine the effects of the EC_{iw} and LF on the following characteristics of the hot peppers: number of fruit per plant; fresh fruit weight; total fruit yield; total fruit dry biomass; plant dry biomass; WUE_F ; TSS; VC; F_n ; F_{WC} ; F_L ; F_{MW} ; F_{SI} ; and the Na^{+} , K^{+} , and Ca^{2+} concentrations and K^{+}/Na^{+} ratios of hot peppers. The correlations between hot pepper fruit quality parameters, ion contents, and ET or EC_e were analyzed by linear regression, as were the relationship between relative yield and relative seasonal ET, and the yield response function proposed by Maas and Hoffman (1977). The yield response function suggested by Van Genuchten and Hoffman (1984) was analyzed using nonlinear regression in SPSS.

Results

Effects of the EC_{iw} and LF on fruit yield parameters and WUE_F . The hot pepper yield parameters and WUE_F are given in Table 1. They were markedly restricted by the EC_{iw} . Across the LFs, the number of fruit per plant and the weight of fresh fruit decreased significantly by 16.5% to 42.0% and 12.7% to 32.3%, respectively, when the EC_{iw} was higher than 1.6 dS·m⁻¹, whereas the total fruit

Fig. 3. Relationships between relative fruit quality parameters [total soluble solid (A); firmness (B); fruit water content (C); maximum fruit width (D); fruit length (E); fruit sharp index (F) and Vitamin C (G)] and EC of soil saturated paste extract (EC_e) regardless of the leaching fractions (LFs).

yield decreased by 12.0% to 60.8% in the EC_{iw} of 1.6–7.0 $dS \cdot m^{-1}$, compared with the EC_{iw} of 0.9 $dS \cdot m^{-1}$.

The dry biomass of both the fruit and plants decreased significantly with an increase in the EC_{iw} , with the highest values obtained from the EC_{iw} of 0.9 $dS \cdot m^{-1}$ and the lowest from the EC_{iw} of 7.0 $dS \cdot m^{-1}$. The EC_{iw} led to a reduction of 10.3% to 41.0% in WUE_F when the plants were subjected to the EC_{iw} of 1.6–7.0 $dS \cdot m^{-1}$.

Across the different EC_{iw} , a high LF significantly increased the total fruit yield, the dry biomass of the fruit and plants, and the WUE_F , whereas it had no effect on the number of fruits per plant and the weight of the fresh fruit. There was no interaction between the EC_{iw} and LF in terms of yield parameters and WUE_F .

Effects of the EC_{iw} and LF on quality parameters. Hot pepper quality is a comprehensive index and consists of interactions among varying single quality attributes. The

taste quality (TSS), nutritional quality (VC), storage quality (F_n and F_{WC}), and external quality (F_L , F_{MW} , and F_{SI}) were all analyzed in this study. Table 2 shows fruit quality parameters using different levels of EC_{iw} and LFs. The EC_{iw} showed a marked influence on fruit quality parameters across the LFs. The TSS content in the EC_{iw} of 2.7–7.0 $dS \cdot m^{-1}$ increased significantly by 8.8% to 29.7% when compared with the EC_{iw} of 0.9 $dS \cdot m^{-1}$, whereas a significant increase in the VC content was only observed in the EC_{iw} of 7.0 $dS \cdot m^{-1}$. A higher EC_{iw} led to a higher F_n value. However, if the EC_{iw} was increased from 0.9 to 7.0 $dS \cdot m^{-1}$, the F_{WC} decreased significantly from 92.83% to 89.87%. Increases in the EC_{iw} correspond to an increase in the F_{SI} , but to a reduction in the F_L and F_{MW} .

Across the EC_{iw} , there were no significant differences in the F_L , TSS, and F_n between the two LFs, whereas an increase in the LF led to an increase in the VC and F_{WC} , and

a decrease in the F_{MW} and F_{SI} . The EC_{iw} and LF had no interactions in terms of the TSS, VC, F_n , F_{WC} , and F_{MW} , whereas there were interactions with respect to the F_L and F_{SI} .

Effects of the EC_{iw} and LF on the ion content in the fruit. Change in the EC_{iw} showed no effect on the Ca^{2+} and K^+ contents of the fruit (Table 3). However, as the EC_{iw} increased, the Na^+ content in the fruit increased, whereas the K^+/Na^+ ratio decreased. Change in LF showed no significant differences in the ion content in the fruit.

Salinity response models and water stress caused by salinity. Figure 1 shows the Y_r data plotted against the EC_{iw} , EC_e , and EC_{dw} , respectively. Values of Y_r data decreased as the EC_{iw} , EC_e , or EC_{dw} increased, with these data falling into a curve regardless of the LFs. Figure 1 also shows the fitted threshold-slope linear model and sigmoidal-shape model curves. Both models seem to accord reasonably well with the measured Y_r data within our EC_{iw} treatments, with the LF having no significant effect on these model parameters.

The relationship between the Y_r and the ET_r of the hot peppers is shown in Fig. 2. There was a significant ($P < 0.001$) linear correlation between the Y_r and the ET_r with a slope of 1.65 (K_y value) regardless of the LFs, indicating that hot peppers are highly sensitive to water stress caused by salinity.

The quantitative relationship between fruit quality parameters and the EC_e and ET_r . Figure 3 shows the relationship between the fruit quality parameters of the hot peppers and the EC_e across the LFs. The relative TSS and F_n show a significant positive linear correlation with the EC_e (Fig. 3A and B). A significant negative linear correlation was observed between the relative F_{WC} , F_L , F_{MW} , and the EC_e (Fig. 3C–E). However, there was no significant ($P > 0.05$) correlation between the relative F_{SI} and VC and the EC_e (Fig. 3F and G). The LF had no effect on the parameters of these correlations.

Figure 4 shows the relationship between the fruit quality parameters of the hot peppers and the ET_r across the LFs. An increase in the ET_r leads to a significant linear decrease in the relative TSS and F_n (Fig. 4A and B), whereas there is a significant linear increase in the relative F_{WC} , F_L , and F_{MW} (Fig. 4C–E). No significant ($P > 0.05$) correlations were found between the relative F_{SI} and VC and the ET_r (Fig. 4F and G). The LF had no effect in terms of the parameters of these relationships.

The quantitative relationships between the ion content of the fruit and the EC_e and ET_r . The relative Na^+ content in the fruit increased linearly with the EC_e but decreased linearly with the ET_r regardless of the LFs (Fig. 5A and C). Increases in the EC_e led to a significant linear decrease in the relative K^+/Na^+ (Fig. 5B), whereas it increased linearly as the ET_r increased irrespective of the LFs (Fig. 5D). There was no correlation between the K^+ or Ca^{2+} content in the fruit and the EC_e or ET_r (figure not shown).

Fig. 4. Relationships between relative quality parameters [total soluble solid (A); firmness (B); fruit water content (C); maximum fruit width (D); fruit length (E); fruit sharp index (F) and Vitamin C (G)] and relative seasonal evapotranspiration (ET_r (%)) regardless of the leaching fractions (LFs).

Discussion and Conclusions

Water is a crucial factor affecting the hot pepper yield and fruit quality. A salt-induced water deficit (as reflected by the high K_y of 1.65 in Fig. 2) is one of the major constraints in the way of plant growth, inhibiting the crop yield. However, a water deficit caused by high salinity may also improve fruit quality (Adams and Ho, 2015; Chen et al., 2016; Rubio et al., 2009). The simultaneous control of yield and fruit quality is usually a challenge, however, as a result of the inverse relationship between yield and fruit quality (Wang et al., 2011).

The total fruit yield and dry biomass of the plants both decreased significantly as a result of an increase in the EC_{iw} (Table 1). A reduction in the number of fruits per plant contributed nearly as much to a reduced total fruit yield as a result of salinity as did the weight of the fresh fruit (Table 1). The reduction in the weight of the fresh fruit through the EC_{iw} was because of a reduction

in the F_{WC} rather than in the mean dry biomass of the fruit (Table 2, data for the mean dry biomass of the fruit are not shown). The reduction of the total fruit yield under saline irrigation could be explained as a salt-induced water deficit, the accumulation of Na^+ in plants and the inhibited uptake of K^+ (Chen et al., 2016; Garcia-Legaz et al., 2005). These changes have an adverse effect on gas exchange and plant growth, in turn affecting yield. The WUE_F of hot peppers was remarkably restricted by the EC_{iw} because salinity reduces total fruit yield more than it reduced water loss.

A high yield, in conjunction with high-quality fresh fruit, is crucial for increasing the economic benefits for farmers (Chen et al., 2016). In this study, except for the external quality (reflected as F_L , F_{MW} , and F_{SI}), the storage quality (F_n and F_{WC}), taste quality (TSS), and nutritional quality (VC) increased significantly with increased EC_{iw} . The lower ψ_s of soil water and consequently, the lower availability of soil water for the fruit caused

by salinity leads to a reduction in cell size and intercellular volume and in turn reduce the F_{WC} , F_L , and F_{MW} . The F_{SI} value was increased with the increase in the EC_{iw} because salinity reduced the F_L more than it reduced the F_{MW} (Table 2). The decrease in the F_{WC} might imply the occurrence of osmotic adjustment (Johnson et al., 2006). F_n is one of the main attributes determining the storage capacity of fruits: a higher F_n could reduce the mechanical damage and improve the storage durability of fruits (Flores et al., 2003). In this study, the F_n increased significantly by 9.0% to 22.2% in the EC_{iw} of 2.7–7.0 $dS\cdot m^{-1}$, compared with the EC_{iw} of 0.9 $dS\cdot m^{-1}$ across the LFs. The possible reasons are that 1) as a small fruit tends to have a high F_n , the increased cellular density due to the reduction in fruit size under saline treatment increases the F_n (Wang et al., 2011); 2) the increased water stress caused by salinity during fruit enlargement and maturity enhances the F_n (Chen et al., 2013; Patanè and Cosentino, 2010); and 3) Belakbir et al. (1998) showed that the F_n in peppers is related to the level of Ca^{2+} in the fruit, and that salinity is able to reduce F_n by reducing the availability of Ca^{2+} in the fruits. However, in this study, the Ca^{2+} in fruit was unaffected by salinity, indicating that the Ca^{2+} in the fruits is not the reason for the increased F_n in saline irrigation. High F_n and low F_{WC} in salinity treatment indicate the fact that irrigation with saline water is able to improve the quality of fruit storage.

Unlike Navarro et al. (2010) and Rubio et al. (2009), who found that low levels of EC_{iw} (less than 3 $dS\cdot m^{-1}$) did not increase the TSS content in sweet peppers, in this study, the EC_{iw} promoted the TSS content in hot peppers (Table 2). A reduced water uptake in plants irrigated using saline water leads to an increase in soluble concentrations and in turn increases the TSS content (Malash et al., 2008). The reduction of the F_{WC} in hot pepper fruits undergoing salinity treatment (Table 2) might also have contributed to the increased TSS content.

A higher VC content was observed in hot pepper fruits (Vanderslice et al., 1990). VC is considered to be an important nutritional quality owing to its antioxidant characteristics (Wang et al., 2011). The VC content in the EC_{iw} of 7.0 $dS\cdot m^{-1}$, in this study, was increased significantly by 48.6%, compared with the EC_{iw} of 0.9 $dS\cdot m^{-1}$ across the LFs. The possible reasons are that 1) the salinity reduced water uptake by roots, resulting in water stress (as reflected by K_y in Fig. 2), consequently increasing the VC content (Patanè et al., 2011); and 2) the leaf area reduced by the salinity could increase the light intensity and duration, in turn, promoting the accumulation of VC (Chen et al., 2013; Wang et al., 2011).

To provide an important basis for salinity irrigation and management, the quantitative relationship between yield, fruit quality, fruit ion content, and EC_e or ET_r should be investigated. The response of a total yield of fresh hot peppers to salinity can be represented

Fig. 5. Relationships between relative fruit ion content (Na^+ and K^+/Na^+) and the EC of soil saturated paste extract (EC_e ; A and B), and relative seasonal evapotranspiration (ET_r ; C and D); LF is the leaching fraction.

effectively by using a threshold-slope linear model or sigmoidal-shape model in terms of EC_{iw} , EC_e , or EC_{dw} within our experimental range regardless of the LFs. The b parameter for the threshold-slope linear model based on EC_{iw} was 0.096 (9.6%), which fell within the range of 8.4% to 11.7% as suggested by Chartzoulakis and Klapaki (2000), whereas the EC_t was much lower than their 1.8. The b and EC_t parameters for the threshold-slope linear model based on EC_e were 0.051 (5.1%) and 1.1 $\text{dS}\cdot\text{m}^{-1}$, respectively, i.e., lower than the 7.0% to 16.0% and 1.2–4.0 $\text{dS}\cdot\text{m}^{-1}$ found in previous studies, as listed by Rameshwaran et al. (2016). The differences in the parameters across studies may be as a result of the varieties of pepper used, the irrigation method, soil fertilizer, climatic conditions, and the growth season (Chartzoulakis and Klapaki, 2000; Heidarpour et al., 2009; Rameshwaran et al., 2016). The b and s parameters for the threshold-slope linear model and sigmoidal-sharp model based on the EC_{dw} were lower than those based on the EC_{iw} and EC_e , whereas the $\text{EC}_{\text{dw } 0}$ and $\text{EC}_{\text{dw } 50}$ were higher for the higher concentrations of EC_{dw} than those of the EC_{iw} and EC_e .

Many chemical reactions take place and are ultimately responsible for the high quality of hot peppers at the onset of fruit ripening. The relative TSS and F_n were found to decrease linearly with the ET_r , which is in line with the findings of Chen et al. (2013) for tomatoes grown in greenhouse. No data for the F_w , F_L , and F_{MW} were analyzed in their study; however, in this study, the relative F_w , F_L , and F_{MW} decreased linearly with the ET_r and increased linearly with the EC_e , because the ET_r was reduced linearly with the EC_e .

Rubio et al. (2009) showed that Ca^{2+} was lower in the fruits of salinized plants than in the fruits of plants irrigated with salt-free water. The fruit Ca^{2+} and K^+ concentrations in this study were unaffected by the EC_{iw} , however, indicating that the uptake of mineral nutrition was not limited to the sufficient mineral nutrition (half strength Hoagland solution) supply in the irrigation water. Insufficient Ca^{2+} results in blossom end rot, a physiological disorder afflicting hot peppers that reduces the market yield and quality of the fruits (Chen et al., 2016; Rubio et al., 2009). No blossom end rot was observed in this study, which also reflected the fact that Ca^{2+} of the fruit was not limited. The Na^+ concentration in the fruits increased as EC_{iw} increased, in line with the findings of Azuma et al. (2010). A linear positive correlation between the relative Na^+ concentration in fruits and EC_e and linear negative correlation between relative K^+/Na^+ ratio and EC_e suggest that Na^+ caused salt toxicity including an ion imbalance and water deficit in the tissue of the fruit (Azuma et al., 2010).

An increase in the LF was observed to lead to an increase in the total fruit yield because of an increase in the total dry biomass of the fruit, whereas the LF had no effects on the number of fruits per plant and the weight of the fresh fruit (Table 1). Neither did the LF affect the total fruit yield, number of fruits per plant, and weight of the fresh fruit before the fifth harvesting, indicating that the LF needs sufficient time to affect the total fruit yield. The WUE_F of hot peppers was high in the high LF because it increased the total fruit yield more than it increased the seasonal ET. No significant differences in the TSS, F_n , and F_L were observed across the two

LFs, whereas an increase in the LF was found to lead to a significant decrease in the F_{MW} and F_{SL} , whereas the F_{WC} and VC content increased. The increased F_{SL} in the lower LF was mainly as a result of a greater F_{MW} . The low F_{WC} in the low LF would indicate that a low LF could improve the storage quality of the fruit. However, the mechanism of a high content of VC in the high LF remains elusive and merits further investigation. The LF had no effect in terms of the parameters using the threshold-slope linear and sigmoidal-sharp models as well as the K_y value using the yield–moisture stress relationship (Fig. 2) and the correlation between quality parameters and EC_e or ET_r , indicating that the LF is not the main factor governing the difference in the parameter values for models across studies, neither did the LF effect on the correlation between the ion content of the fruit and the EC_e or ET_r .

In summary, the threshold-slope linear and sigmoidal-sharp models both suited the measured Y_r reasonably well within our EC_{iw} range. The relative TSS and F_n increased linearly with the EC_e and decreased linearly with the ET_r , whereas the relative F_w , F_L , and F_{MW} decreased linearly with the EC_e and increased linearly with the ET_r . The relative Na^+ concentration in the fruit increased linearly, whereas the relative fruit K^+/Na^+ ratio decreased linearly with an increased EC_e . Interestingly, the LF had no effect on these correlations with respect to fruit yield, quality, ion content, and EC_e or ET_r .

The total fruit yield and WUE_F decreased significantly as the EC_{iw} increased. Increased salinity reduced the external quality of hot peppers, whereas improved the taste, nutritional and storage quality of the hot peppers, and led to a higher accumulation of Na^+ in the fruit. High LF increased the total fruit yield, WUE_F , and nutritional quality but decreased in the F_{MW} and F_{SL} . Therefore, it is suggested that high LF can be applied to obtain high yield and better-quality fruit when hot peppers are irrigated with water having a high level of saline content.

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