

Article

Effects of Fruit-Setting Saline Irrigation on Fruit Ion Content and Quality Indicators of Two Tomato Cultivars Under Substrate Culture

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Abstract

To evaluate the effects of saline water on the yield and quality of tomatoes, a late fruit-setting stage irrigation experiment was conducted in a greenhouse using two cultivars: medium-fruited, tasty *Strawberry tomato* (fresh-eating) and large-fruited *Maofen tomato* (fresh/processing). For this, plants were grown in pots containing substrate, and five irrigation water electrical conductivity (EC) levels (1.0 as control, 2.6, 4.2, 5.8, and 7.4 dS m⁻¹) were applied for each cultivar, resulting in a 2 × 5 factorial design with 10 treatments in total. Then, tomato growth, fruit ion composition, and quality attributes were evaluated. The results showed that 1.0–7.4 dS m⁻¹ saline water had no significant impact on the plant height, stem diameter, single-fruit weight, or total yield of either cultivar. However, *Strawberry tomato*'s marketable yield decreased by 23.5% at 7.4 dS m⁻¹. The yield per plant of *Maofen tomato* was 2.7 times that of *Strawberry tomato*. Fruit Na⁺ content increased with EC for both cultivars; *Maofen tomato* had higher Na⁺ and a lower K⁺/Na⁺ ratio, with greater ion content responses to salinity. Regression analysis revealed distinctly nonlinear responses in key yield, ion, and quality parameters across the salinity gradient. The fruit comprehensive quality score (CQS) rose with EC, and *Strawberry tomato*'s average CQS increase (109%) was significantly higher than *Maofen tomato*'s. In conclusion, saline irrigation initiated when the fourth-cluster fruits attained 60% of the final harvested diameter, at EC ≤ 5.8 dS m⁻¹ for *Strawberry tomato* and ≤ 7.4 dS m⁻¹ for *Maofen tomato*, improved fruit quality without compromising yield. *Strawberry tomato* is recommended for quality-oriented production, whereas *Maofen tomato* is better suited for yield-oriented production, providing scientific support for saline water utilization in greenhouse soil-less cultivation.

Keywords: brackish water; ions accumulation; fruit quality; soilless culture; *Solanum lycopersicum*



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1. Introduction

Global freshwater scarcity and soil salinization have become core constraints on the sustainable development of protected horticulture [1,2]. Unlike episodic stresses such as heat waves, salinization is cumulative and often irreversible in its impacts on soil health and crop productivity. Salinity, in particular, has been explicitly identified as a priority stressor in modern greenhouse crop production systems under climate change [3]. In this context, the rational utilization of saline water for irrigation represents an important strategy for broadening agricultural water resources [4,5]. Tomato (*Solanum lycopersicum* L.) is a major vegetable crop worldwide [6], and mild saline water irrigation at the appropriate growth stage has been proven to improve fruit quality without significant yield loss [7–9], as evidenced by increased amounts of soluble solids, organic acids, soluble sugars, and ascorbic acid [10,11]. Based on a meta-analysis of 56 relevant studies, Wang et al. [7] further clarified that slightly saline water ($EC \leq 3 \text{ dS m}^{-1}$) and moderately saline water ($3 < EC \leq 8 \text{ dS m}^{-1}$) can balance yield stability and quality improvement in tomato cultivation, which provides a feasible technical path for water-saving and quality-improving tomato production [12,13].

Previous study has clarified the suitable saline water EC threshold ($\leq 5.8 \text{ dS/m}$) for substrate-grown *Strawberry tomato* at the late fruiting stage, confirming that saline water irrigation can improve fruit quality and reduce freshwater consumption [14]. However, that work was confined to a single fresh-eating cultivar and did not examine fruit ion accumulation or the underlying ion homeostasis mechanisms. The maintenance of ion homeostasis is central to salt stress physiology. Ca^{2+} and K^{+} play irreplaceable roles in preserving cell membrane integrity and sustaining normal growth [15–17]. Under high-salinity conditions, excess Na^{+} competes with Ca^{2+} for uptake sites [18,19], gradually reducing the $\text{Ca}^{2+}/\text{Na}^{+}$ ratio with increasing irrigation water EC [20] and impairing transmembrane transport efficiency [21]. Meanwhile, excessive Cl^{-} accumulation inhibits K^{+} and Mg^{2+} accumulation [22,23], breaks dynamic ion equilibrium [24], and ultimately induces nutritional imbalance and physiological salt injury [25]. A higher $\text{K}^{+}/\text{Na}^{+}$ ratio is generally associated with stronger salt tolerance in plants [26]. Critically, these physiological disturbances do not scale linearly with increasing external salinity [27]. Instead, plant performance follows a continuous physiological continuum: mild-to-moderate salinity can activate endogenous adaptive mechanisms to sustain yield and even enhance fruit quality, while severe salinity exceeds plant regulatory thresholds, triggering irreversible metabolic dysfunction and marked yield reduction. Accordingly, salinity should be regarded as a continuous stress-intensity gradient, allowing different EC levels to be rationally positioned along this continuum to strike an optimal balance between yield stability and quality improvement. In addition, there are significant genotypic differences in tomato salt tolerance, fruit quality characteristics [28] and ion absorption capacity among cultivars with different fruit types and market orientations [29,30]. However, the differential responses of medium-fruited fresh-eating and large-fruited dual-purpose cultivars to late-fruiting-stage saline irrigation have not been systematically characterized, constraining the development of precision irrigation strategies tailored to distinct production goals (high yield or high quality).

To fill the above gaps, this study takes two typical tomato cultivars (*Strawberry tomato*, a medium-fruited fresh-eating cultivar with superior flavor, and *Maofen tomato*, a large-fruited cultivar for fresh consumption and processing) as test materials, and carries out a substrate cultivation experiment of saline water irrigation at the late fruiting stage in a greenhouse. A core scientific hypothesis is proposed in this study: Under saline water irrigation, the two cultivars differ in their capacity to maintain ion homeostasis, with cultivar-specific patterns of ion accumulation and selective partitioning—particularly of

K^+/Na^+ ratios in fruit tissues—jointly shaping the divergent quality responses along the salinity gradient.

The objectives of this study were: (1) to compare the differences in growth, yield, fruit ion content and quality characteristics; (2) to perform a comprehensive evaluation of the quality of different varieties of tomato fruit; (3) to determine cultivar-specific EC thresholds and propose a differentiated saline irrigation scheme tailored to distinct production goals (high yield or high quality).

2. Materials and Methods

2.1. Experimental Design

The cultivation experiment was carried out from January to May 2021. It was conducted in a solar greenhouse at Weike Seed Industry ($36^{\circ}54'4.34''$ N, $118^{\circ}47'1.05''$ E), Weifang City, Shandong Province, China. “*Strawberry tomato*” (a medium-fruited fresh-eating cultivar with superior taste) and “*Maofen tomato*” (a large-fruited cultivar suitable for both fresh consumption and processing), hereafter referred to as S and P, were used as test materials. Soil-less cultivation was adopted. Tomato seedlings were grown in pots (31 cm in height and 27.5 cm in diameter) placed in the solar greenhouse. Each of the 10 treatment combinations (2 cultivars $\times$ 5 EC levels) consisted of 20 pots (one plant per pot), with all pots arranged in rows oriented north–south to minimize positional effects from light and temperature gradients within the greenhouse. The substrate, composed of peat, vermiculite, and perlite, was filled into the pots at a bulk density of 0.3 g/cm^3 , with a filling height of 27 cm. This composition was selected to provide adequate water-holding capacity and aeration for tomato root development under soil-less conditions. One tomato seedling was planted per pot, with a plant spacing of 40 cm and a row spacing of 80 cm. Topping was performed after the 4th cluster of flowers set fruit. To reduce water evaporation from the substrate surface, black plastic film was applied to all treatments at the time of transplanting.

All plants were irrigated with freshwater ($EC = 1.0 \text{ dS m}^{-1}$; Table 1) supplemented with a nutrient solution (Yamazaki formula) before the fourth-cluster fruits reached 60% of the diameter of fully mature harvestable fruits. Once this developmental threshold was reached (in order to ensure a certain yield), five irrigation water EC levels (1.0 as control, 2.6, 4.2, 5.8, and 7.4 dS m^{-1}) were applied for each cultivar, following a 2×5 factorial design with 10 treatments in total. These EC levels were set according to the salinity range of local underground brackish water and related studies on tomato salt tolerance under protected substrate cultivation [8], covering non-saline control (1.0 dS m^{-1}) and low- (2.6 dS m^{-1}), moderate- ($4.2\text{--}5.8 \text{ dS m}^{-1}$), and high (7.4 dS m^{-1}) -salinity gradients, which can fully reveal the response patterns of tomato to increasing salinity during the late fruit-setting stage. For the two cultivars, these treatments were labeled as S1–S5 (for *Strawberry tomato*) and P1–P5 (for *Maofen tomato*), resulting in a total of 10 treatments. Irrigation water with salinity $\geq 2.6 \text{ dS m}^{-1}$ was prepared by mixing sea salt with local groundwater. The concentrations of major salt ions in different salinity treatments are shown in Table 1. All treatments were irrigated with water supplemented with a nutrient solution prepared according to the Yamazaki formula for tomato, consisting of Stock A ($\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ 70.8 g L^{-1} , KNO_3 80.8 g L^{-1}), Stock B ($\text{NH}_4\text{H}_2\text{PO}_4$ 15.4 g L^{-1} , $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ 49.2 g L^{-1}), and Stock C ($\text{EDTA} \cdot 2\text{Na}$ 27.8 g L^{-1} , $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 37.2 g L^{-1} , H_3BO_3 2.86 g L^{-1} , $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ 2.13 g L^{-1} , $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ 0.22 g L^{-1} , $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ 0.08 g L^{-1} , $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$ 0.02 g L^{-1}). To prevent or mitigate blossom-end rot (BER) (caused by Ca^{2+} deficiency induced by high temperature and salt stress), all treatments were sprayed with a 0.3% calcium nitrate solution on the foliage at appropriate intervals, totaling 6 sprays, with a dosage of 20 mL per plant per spray [31].

Table 1. Ion concentration of irrigation water salinity.

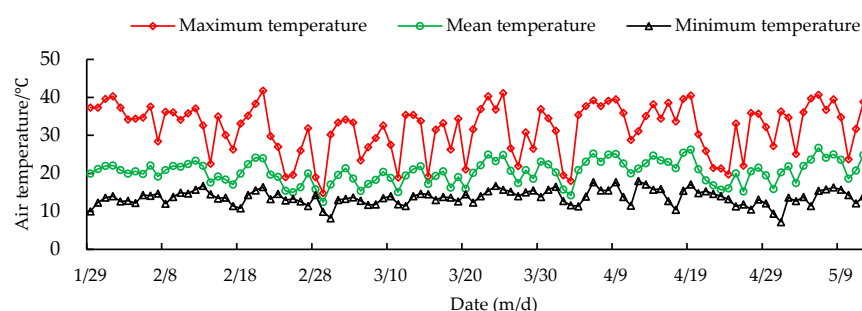
Treatment	Irrigation Water Salinity (dS m ⁻¹)	Ion Concentration/(mg L ⁻¹)						
		Na ⁺	Ca ²⁺	Mg ²⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻
S1/P1	1.0	53.0	54.4	45.2	5.5	104.2	311.1	44.3
S2/P2	2.6	431.4	60.1	46.1	10.0	683.9	316.0	62.6
S3/P3	4.2	809.8	65.8	47.0	14.5	1263.6	320.9	80.9
S4/P4	5.8	1188.2	71.5	47.9	19.0	1843.3	325.8	99.2
S5/P5	7.4	1566.6	77.2	48.8	23.5	2423.0	330.7	117.5

Note: S1–S5 and P1–P5 represent the saline water irrigation treatments for *Strawberry tomato* and *Maofen tomato*, respectively, with EC values of 1.0, 2.6, 4.2, 5.8, and 7.4 dS m⁻¹.

2.2. Determination Indicators and Methods

(1) Air Temperature

An air temperature and humidity recorder (Benetech GM1365, Shenzhen Jumaoyuan Technology Co., Ltd., Shenzhen, China) was installed at the crop canopy inside the greenhouse to monitor the temperature conditions in the greenhouse during the experiment. The monitoring frequency was set at 1 h per interval, and the accuracy of the monitoring probe for temperature was ± 0.3 °C. During the experiment, the average temperature, maximum temperature, and minimum temperature were 20.4 °C, 31.9 °C, and 13.7 °C, respectively (Figure 1).

**Figure 1.** Air temperature in the greenhouse.

(2) Irrigation Amount

As shown in Table 2, the total irrigation amount per plant was 59 L for both tomato cultivars across all treatments, among which the amount of saline water irrigation accounted for 47.9% of the total irrigation amount.

Table 2. Irrigation water amount and irrigation time during the experiment.

Treatment	Fresh Water Irrigation Amount (L)	Saline Water Irrigation Amount (L)	Saline Water Irrigation Amount/Total Water Irrigation Amount (%)	Fresh Water Irrigation Duration (d)	Saline Water Irrigation Duration (d)
S1/P1	59	0	0	123	0
S2/P2–S5P5	31	28	47.9	66	57

Note: S1–S5 and P1–P5 represent the saline water irrigation treatments for *Strawberry tomato* and *Maofen tomato*, respectively, with EC values of 1.0, 2.6, 4.2, 5.8, and 7.4 dS m⁻¹.

(3) Growth Indicators

After the second fruit cluster was harvested, plants with extremely vigorous or weak growth were excluded. From the remaining uniform population, three plants per treatment were randomly selected as independent biological replicates. Each selected plant

originated from a separate pot to ensure independence. Plant height (cm) was measured with a ruler, and stem diameter (mm) was determined using a vernier caliper (Model 0–150, Shanghai Tool Works Co., Ltd., Shanghai, China). Each treatment included three independent biological replicates. During the period from fruit ripening initiation to the end of harvest, each fruit was picked individually by plant, and diseased fruits were recorded simultaneously. Diseased fruits specifically referred to BER fruits, which were identified based on the criteria: depression and browning at the fruit apex, accompanied by flesh hardening. Each fruit was weighed individually using an electronic balance (Model MA104, Mettler Toledo, Zurich, Switzerland; accuracy, 0.001 g), and the obtained data were used to calculate single-fruit weight, yield per plant, and marketable fruit (disease-free fruit) yield.

(4) Fruit Ion Content

Fifteen fruits of uniform maturity were sampled from the second fruit cluster (counted from bottom to top) of tomato plants under each treatment. Prior to sampling, plants exhibiting excessively vigorous or weak growth, as well as fruits that were abnormally large or small, were excluded to minimize non-treatment variability. From the remaining uniform population, one or two fruits were collected per plant, ensuring that the sampled fruits originated from at least eight distinct individuals per treatment. After cleaning and drying the freshly fruit surface, each fruit was cut longitudinally, and a 1/4 portion was excised. The portions from all 15 fruits were randomly assigned to four groups; each group was independently homogenized to yield four composite homogenates per treatment (the total volume of homogenate prepared per treatment was no less than 80 mL). The homogenates were flash-frozen in liquid nitrogen and stored at -70°C until further analysis. The ion content in the fruits was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Agilent 7900, Agilent Technologies, Santa Clara, CA, USA) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, PerkinElmer Optima 8300, PerkinElmer Inc., Shelton, CT, USA) for NO_3^- , Cl^- , K^+ , Na^+ , Ca^{2+} and Mg^{2+} . The results were expressed in $\text{mg}\cdot\text{kg}^{-1}$ dry weight (DW). Each treatment included three independent biological replicates.

(5) Fruit Quality

Vitamin C content: Determined by the 2,6-dichlorophenol indophenol titration method [32]. Soluble sugar content: Measured using the anthrone colorimetric method [33]. Organic acid content: Determined by acid–base titration [32]. The results were expressed as citric acid equivalent, given that citric acid is the predominant organic acid in tomato fruit. Lycopene content: Assayed via the extraction colorimetric method [34]. The extraction was performed under cold conditions and protected from light, followed by filtration to obtain the clear extract for analysis. Soluble solids content: Determined using a digital refractometer (Model PAL-1, ATAGO, Tokyo, Japan) [35]. Each treatment included four independent biological replicates.

The comprehensive quality score (CQS) can more clearly reflect the quality changes of the two cultivars under saline water irrigation. The CQS of fruits in the P1 treatment was defined as a relative value of 100, and the CQS of other treatments was calculated as the ratio of each quality indicator value to that of S1/P1, specifically expressed as follows:

$$q_r = \frac{q_i}{q_1} \quad (1)$$

where q_i represents the relative score of the i -th quality index (including lycopene content, soluble sugar content, sugar–acid ratio, soluble solids content, and VC content). q_1 is the observed value of the same i -th quality indicator specifically measured from the fruits of the reference S1/P1 treatment. w_i denotes the weight coefficient. Each of the five

quality indicators was assigned an equal weight ($w_i = 0.2$), as there is no established consensus in the literature on the relative importance of these individual traits to overall tomato fruit quality. This equal-weighting approach provides an objective and transparent means of integrating multiple quality attributes into a single comparative index. Thus, the comprehensive quality score (Q) of tomato fruits can be expressed as follows:

$$Q = \sum_{i=1}^5 \left(w_i \times \frac{q_i}{q_1} \right) \quad (2)$$

2.3. Data Analysis

Microsoft Office Excel 2020 and Origin 2024 Data Processing software were used for data processing and graph creation. SPSS Statistics 26 software was employed to perform significance difference analysis and correlation analysis across all treatments. Prior to ANOVA, normality was visually inspected using Q–Q plots, and homogeneity of variances was confirmed using Levene’s test. A two-way analysis of variance (two-way ANOVA) was then conducted with cultivar and EC level as fixed factors. When significant effects were detected ($p \leq 0.05$), means were separated using Duncan’s multiple range test. For key response variables, linear and quadratic regression analyses were performed with EC as the independent variable to examine continuous response patterns along the salinity gradient; model fit was evaluated using R^2 .

3. Results

3.1. Effects of Irrigation Water Salinity on the Mean Values of Tomato Growth Indicators

As shown in Figure 2, at the harvest period, no significant difference ($p > 0.05$) in stem diameter was observed between the two cultivars. However, plant height differed significantly ($p \leq 0.05$), with *Strawberry tomato* being 22.3% taller than *Maofen tomato* on average. Saline water irrigation was initiated after the completion of major vegetative growth. Therefore, it did not retroactively affect stem diameter or plant height in either cultivar. The observed height difference between the two cultivars reflects their inherent genetic differences in growth habit rather than a response to the salinity treatments.

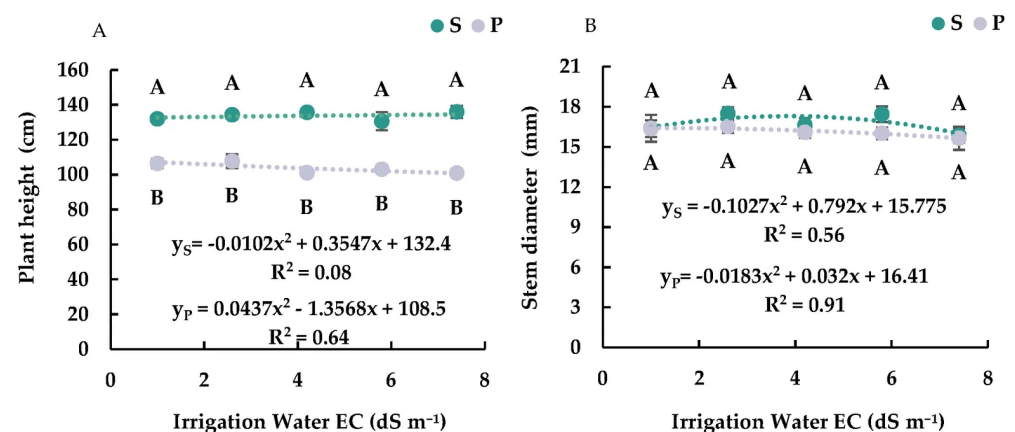


Figure 2. Plant height (A) and stem diameter (B) of two tomato cultivars under different treatments at the harvest period. Note: The x-axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5). Data points represent means ± SE of three biological replicates. Dashed curves represent the quadratic regression fits. Different uppercase letters indicate statistically significant differences among treatments within each cultivar according to two-way ANOVA with cultivar and salinity as factors, followed by Duncan’s multiple range test ($p \leq 0.05$). Regression equations and R^2 values are shown in the figure panels. (See Figures 3–6 below).

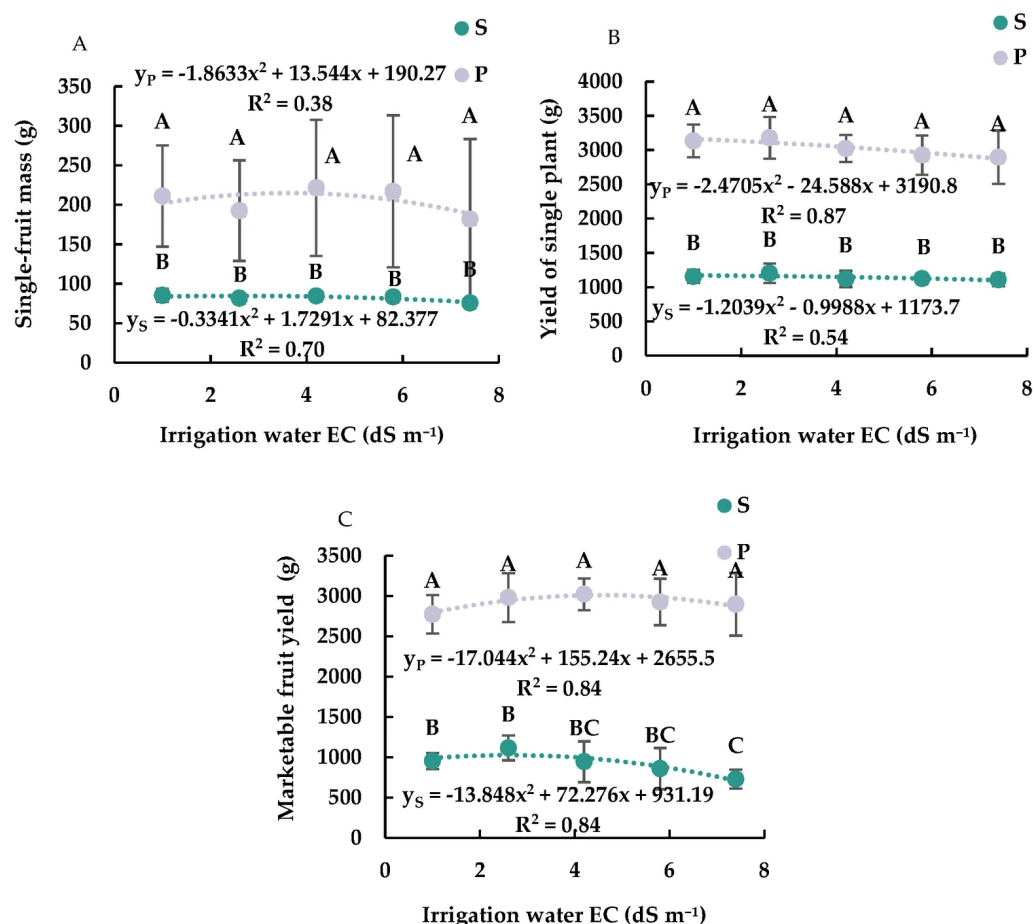


Figure 3. Single-fruit mass (A), yield per plant (B), and marketable fruit yield (C) of two tomato cultivars under different treatments at the conclusion of the fruit harvesting process are presented. Note: The x -axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5).

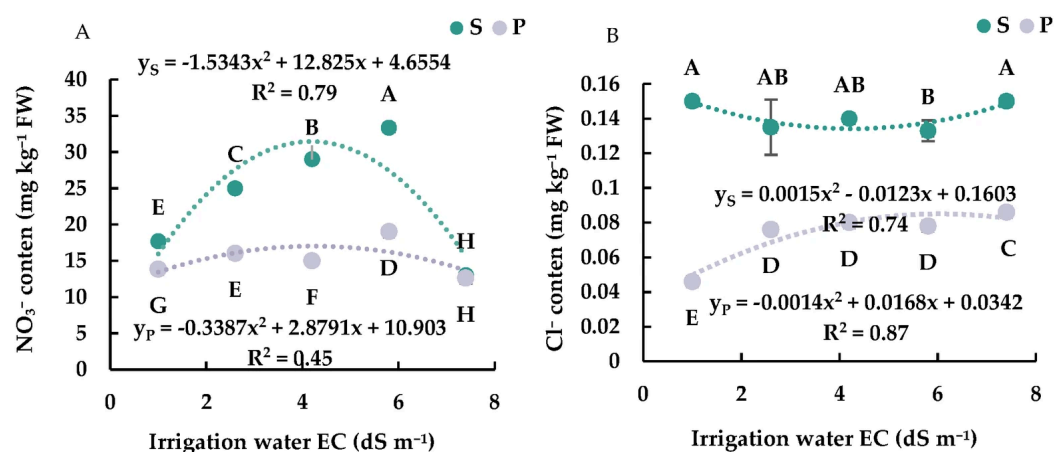


Figure 4. Nitrate (NO₃⁻) content (A) and chloride (Cl⁻) content (B) in two tomato cultivars under different saline irrigation treatments. Note: The x -axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5).

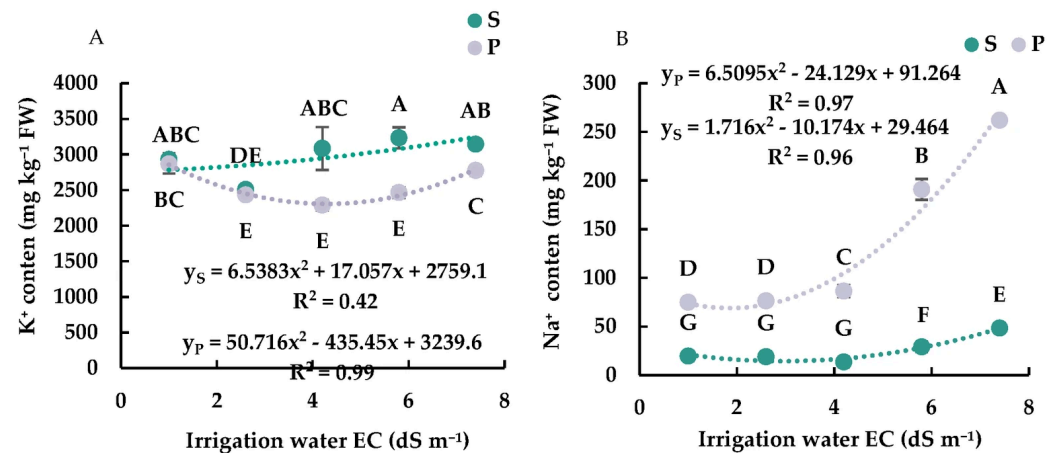


Figure 5. Potassium (K⁺) content (A) and sodium (Na⁺) content (B) in two tomato cultivars under different saline irrigation treatments. Note: The x-axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5).

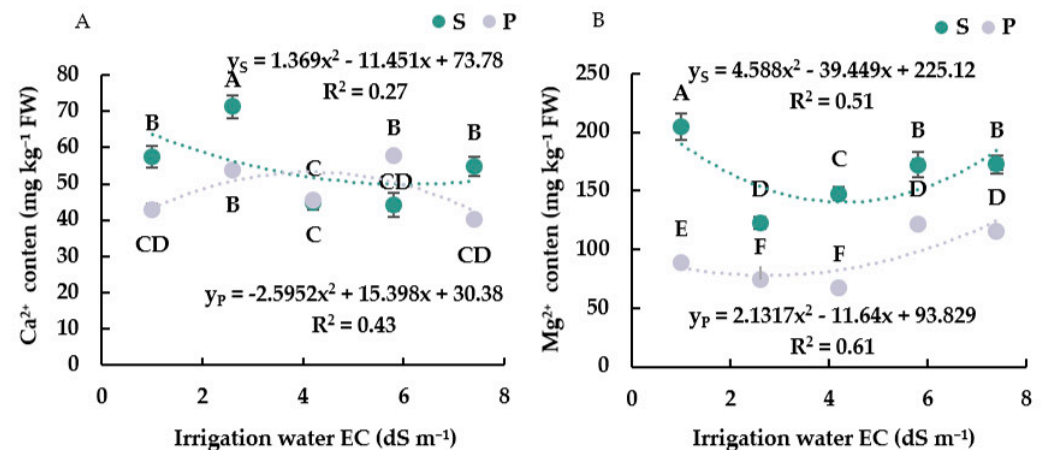


Figure 6. Calcium (Ca²⁺) content (A) and magnesium (Mg²⁺) content (B) in two tomato cultivars under different saline irrigation treatments. Note: The x-axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5).

3.2. Effects of Irrigation Water Salinity on Single-Fruit Weight, Yield per Plant, and Marketable Fruit Yield per Tomato Plant

As shown in Figure 3, regression analysis revealed distinct nonlinear patterns across yield parameters. For single-fruit weight, *Strawberry tomato* exhibited a moderate nonlinear trend ($R^2 = 0.70$), while *Maofen tomato* remained largely unaffected ($R^2 = 0.38$). For yield per plant, *Maofen tomato* showed a stronger nonlinear decline ($R^2 = 0.87$) than *Strawberry tomato* ($R^2 = 0.54$). Despite this, marketable fruit yield in *Maofen tomato* remained relatively stable, whereas *Strawberry tomato* displayed a pronounced threshold-type decline at EC 7.4 dS m⁻¹ ($R^2 = 0.84$ for both cultivars).

With irrigation water salinity increased, compared with S1/P1 treatment, there were no significant differences in single-fruit weight or yield per plant between the S2–S5 treatments (for *Strawberry tomato*) and P2–P5 treatments (for *Maofen tomato*). However, the marketable fruit yield per plant of *Strawberry tomato* decreased significantly by 23.5% under S5 treatment. Under the same EC levels, the single-fruit weight and yield per plant of *Maofen tomato* (P1–P5 treatments) were significantly higher ($p \leq 0.05$) than those of *Strawberry tomato* (S1–S5 treatments) by 147.7%, 135.9%, 162.6%, 160.2%, 140.3% (for single-

fruit weight) and 171.2%, 164.0%, 169.7%, 160.6%, 161.7% (for yield per plant), respectively. Additionally, the average yield per plant of *Maofen tomato* across all treatments was 2.7 times that of *Strawberry tomato*.

This contrast indicates that the yield-component responses to salinity differed fundamentally between the two cultivars: *Maofen tomato* maintained a stable marketable yield despite a reduction in total yield per plant, suggesting that fruit marketability was preserved under high salinity. Meanwhile, *Strawberry tomato* experienced a sharp decline in marketable yield at EC 7.4 dS m⁻¹, coinciding with increased BER incidence, while its total yield per plant remained relatively unchanged.

3.3. Effects of Irrigation Water Salinity on Ion Content Within Tomato Fruits

Regression analysis revealed distinct cultivar-specific anion responses across the salinity gradient (Figure 4). *Strawberry tomato* NO₃⁻ followed a nonlinear trajectory (R² = 0.79), peaking under moderate salinity before declining at high EC, whereas *Maofen tomato* displayed a weaker nonlinear decline (R² = 0.45). Cl⁻ patterns diverged similarly: *Strawberry tomato* exhibited a nonlinear response (R² = 0.74), declining initially at low-to-moderate EC before rising sharply at EC 7.4 dS m⁻¹, while *Maofen tomato* showed a monotonic increase (R² = 0.87).

Relative to their controls, *Strawberry tomato* NO₃⁻ rose by 41.5%, 64.2%, and 88.7% in S2–S4 treatments, then fell by 26.4% following S5 treatment; *Maofen tomato* NO₃⁻ increased by 15.7%, 8.4%, and 37.4% following P2–P4 treatments and decreased by 8.9% after P5 treatment. *Strawberry tomato* Cl⁻ declined significantly only in S4 (−11.3%), whereas *Maofen tomato* Cl⁻ increased progressively across P2–P5 (+66.4% to +89.1%) treatments. Across all EC levels, *Strawberry tomato* NO₃⁻ and Cl⁻ content exceeded those of *Maofen tomato* by 27.8–93.3% and 70.5–226.1%, respectively ($p \leq 0.05$).

The NO₃⁻/Cl⁻ ratio was slightly higher in *Strawberry tomato* under S3/P3 and S4/P4 (1.0–1.1 times), but higher in *Maofen tomato* under P1/S1, P2/S2, and P5/S5 (2.6, 1.1, and 1.7 times, respectively). These contrasting profiles indicate that the two cultivars adopted different strategies for managing anion balance under saline irrigation: *Strawberry tomato* maintained higher absolute ion content with nonlinear adjustments, whereas *Maofen tomato* progressively accumulated Cl⁻ without a corresponding increase in NO₃⁻, resulting in a lower NO₃⁻/Cl⁻ ratio at most EC levels.

As shown in Figure 5, regression analysis revealed distinct cultivar-specific patterns in fruit cation content. For K⁺, *Strawberry tomato* exhibited a moderate increasing trend across the salinity gradient (R² = 0.42), whereas *Maofen tomato* showed a strong nonlinear response, declining initially before rising at higher EC levels (R² = 0.99). For Na⁺, both cultivars displayed strong monotonic increases with EC, with the response being more pronounced in *Maofen tomato* (*Strawberry tomato*: R² = 0.96; *Maofen tomato*: R² = 0.97).

Specifically, compared with the S1 treatment, the K⁺ content in *Strawberry tomato* decreased significantly by 14.3% in S2 treatment, with no significant differences observed in the other treatments. For *Maofen tomato*, compared with P1, the K⁺ content in the P2–P4 treatments decreased significantly by 15.3%, 20.2%, and 14.1%, respectively. Across all treatments, the K⁺ content of *Strawberry tomato* was higher than that of *Maofen tomato*, with significant increases of 34.8%, 31.7%, and 13.2% in the S3–S5 treatments, respectively. For Na⁺, compared with S1, the Na⁺ content in *Strawberry tomato* increased significantly in response to S4 and S5 by 47.9% and 147.2%, respectively. In *Maofen tomato*, Na⁺ content increased progressively with salinity, with significant increases of 15.6%, 155.3%, and 250.3% following the P3–P5 treatments relative to P1. In the inter-cultivar comparison, the fruit Na⁺ content of *Maofen tomato* was significantly higher than that of *Strawberry tomato*.

across all treatments, with increases of 282.1%, 308.6%, 546.5%, 559.7%, and 441.6% for P1–P5 relative to the corresponding S1–S5 treatments ($p \leq 0.05$).

The K^+/Na^+ ratio, a key indicator of ion homeostasis, was 3.9–8.7 times higher in *Strawberry tomato* than in *Maofen tomato* across all treatments. These results indicate that *Maofen tomato* was more sensitive to elevated salinity in terms of fruit K^+ accumulation, particularly under moderate EC levels (4.2–5.8 dS m^{-1}), and accumulated substantially more Na^+ under high salinity. This was consistent with its weaker capacity for selective K^+ uptake and Na^+ exclusion compared with *Strawberry tomato*.

As shown in Figure 6, regression analysis revealed cultivar-specific patterns in fruit Ca^{2+} and Mg^{2+} content. For Ca^{2+} , *Strawberry tomato* exhibited a weak declining trend ($R^2 = 0.27$), whereas *Maofen tomato* displayed a moderate nonlinear response, increasing initially before declining at higher EC levels ($R^2 = 0.43$). For Mg^{2+} , *Strawberry tomato* showed a moderate nonlinear trend ($R^2 = 0.51$), while *Maofen tomato* exhibited a similar nonlinear pattern, declining at low-to-moderate EC before rising at higher EC levels ($R^2 = 0.61$).

Specifically, compared with the S1 treatment, the Ca^{2+} content in *Strawberry tomato* increased significantly in response to the S2 treatment, but decreased significantly by 21.7% and 23.2% in response to the S3 and S4 treatments, respectively. For *Maofen tomato*, compared with P1, the Ca^{2+} content increased significantly by 25.0% and 34.4% in response to the P2 and P4 treatments, with no significant changes observed following the other treatments. With increasing EC, the fruit Mg^{2+} content of *Strawberry tomato* decreased significantly by 40.2% and 27.9% in S2 and S3 relative to S1 treatment, whereas that of *Maofen tomato* decreased significantly by 16.0% and 24.1% in P2 and P3 relative to P1 treatment. In the inter-cultivar comparison, the Mg^{2+} content in fruits of *Strawberry tomato* was significantly higher than that of *Maofen tomato* under all treatments, with increases of 56.7%, 39.2%, 54.4%, 29.3%, and 33.3% following S1–S5 relative to the corresponding P1–P5 treatments ($p \leq 0.05$).

Based on the individual ion content, the Ca^{2+}/Na^+ and Mg^{2+}/Na^+ ratios were calculated to further evaluate cultivar-specific ion selectivity. The fruit Ca^{2+}/Na^+ and Mg^{2+}/Na^+ ratios of *Strawberry tomato* were 5.0–7.4 and 6.7–14.1 times higher than those of *Maofen tomato*, respectively, across all treatments. These results indicate that *Strawberry tomato* maintained substantially more favorable divalent cation balance relative to Na^+ , reflecting a stronger capacity for selective Ca^{2+} and Mg^{2+} uptake and retention under saline conditions.

3.4. Effects of Irrigation Water Salinity on the Nutritional Quality of Tomato Fruits

As shown in Figure 7, regression analysis revealed distinct cultivar-specific nonlinear patterns in fruit quality parameters across the salinity gradient. For soluble solids content, *Strawberry tomato* exhibited a pronounced nonlinear trend ($R^2 = 0.77$), characterized by an increase under moderate salinity before declining at high EC, whereas *Maofen tomato* showed a strong monotonic increase ($R^2 = 0.98$). Specifically, for *Strawberry tomato* fruit, compared with the S1 treatment, the soluble solids content in the S2–S5 treatments increased significantly by 37.5%, 31.3%, 30.7%, and 24.5%, respectively. For *Maofen tomato* fruit, compared with the P1 treatment, the soluble solids content increased significantly by 9.7% and 23.3% in the P4 and P5 treatments, respectively, with no significant changes in the other treatments.

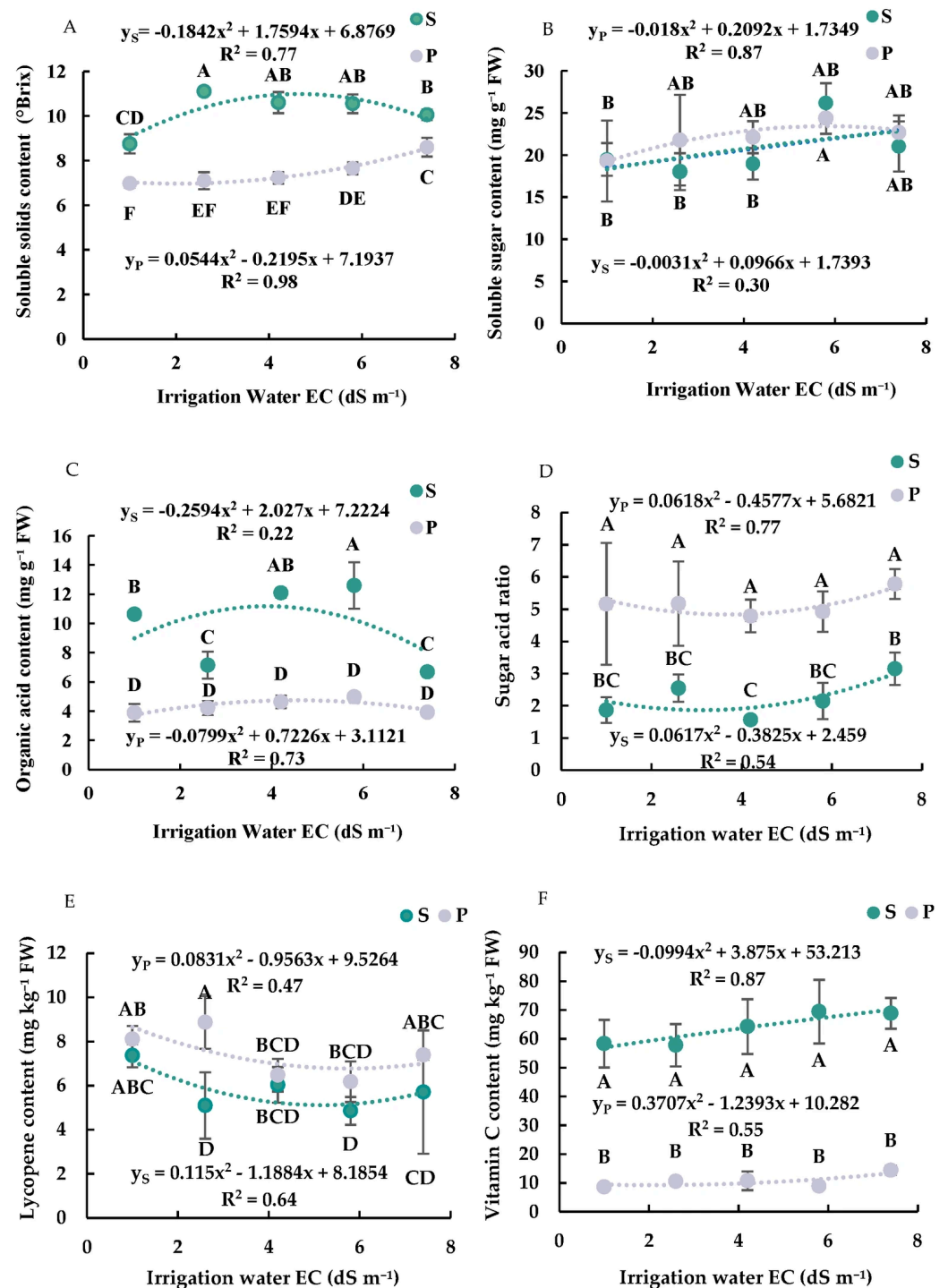


Figure 7. Soluble solids content (A), soluble sugar content (B), organic acid content (C), sugar–acid ratio (D), lycopene content (E), and vitamin C content (F) in tomato fruits of two cultivars under different saline irrigation treatments. Note: The x -axis displays irrigation water EC values of 1.0 (control), 2.6, 4.2, 5.8 and 7.4 dS m⁻¹, corresponding to saline irrigation treatments for *Strawberry tomato* (S1–S5) and *Maofen tomato* (P1–P5). Each bar represents the mean of four biological replicates $\pm$ standard error (SE). Dashed curves represent the quadratic regression fits. Different uppercase letters indicate statistically significant differences among treatments within each cultivar according to two-way ANOVA with cultivar and salinity as factors, followed by Duncan’s multiple range test ($p \leq 0.05$). Regression equations and R^2 values are shown in the figure panels.

For soluble sugar content, *Strawberry tomato* exhibited a weak nonlinear trend ($R^2 = 0.30$), whereas *Maofen tomato* showed a distinct nonlinear response, increasing initially

before declining at higher EC levels ($R^2 = 0.87$). When the EC increased, the soluble sugar content of both *Strawberry tomato* and *Maofen tomato* showed an overall trend of increasing and then decreasing compared with S1/P1 treatment, and reached the maximum values in the S4 and P4 treatments, respectively. With the exception of the S4 treatment of *Strawberry tomato* fruit, which caused the soluble sugar content to increase significantly (by 34.4%) compared with the S1 treatment, there were no significant differences in other treatments.

For organic acid content, *Strawberry tomato* displayed a weak nonlinear trend ($R^2 = 0.22$), while *Maofen tomato* showed a stronger nonlinear response, increasing initially before declining ($R^2 = 0.73$). For *Strawberry tomato* fruit, the organic acid content in the S4 treatment increased significantly by 18.52% compared with the S1 treatment. For *Maofen tomato* fruit, there were no significant changes in organic acid content, sugar–acid ratio, or lycopene content in the P2–P5 treatments compared with the P1 treatment. For sugar–acid ratio, both cultivars exhibited nonlinear trends, declining initially before increasing at higher EC levels (*Strawberry tomato*: $R^2 = 0.54$; *Maofen tomato*: $R^2 = 0.77$). For *Strawberry tomato* fruit, the sugar–acid ratio resulting from the S2, S4, and S5 treatments increased by 36.5%, 15.0%, and 68.8%, respectively, compared with the S1 treatment; however, these increases were not significant. For lycopene content, *Strawberry tomato* showed a moderate nonlinear trend ($R^2 = 0.64$) and *Maofen tomato* showed a weak nonlinear trend ($R^2 = 0.47$), both exhibiting a decline at low-to-moderate EC before recovering at higher levels. Compared with the S1 treatment, the lycopene content of *Strawberry tomato* fruit decreased significantly by 30.8% and 34.1% following the S2 and S4 treatments, respectively, with no significant differences in the other treatments. For vitamin C content, *Strawberry tomato* exhibited a strong nonlinear increase ($R^2 = 0.87$) and *Maofen tomato* exhibited a moderate nonlinear increase ($R^2 = 0.55$) across the salinity gradient. For the VC content of *Strawberry tomato* fruit, the S3–S5 treatments showed increases of 10.2%, 19.1%, and 18.1% compared with the S1 treatment, among which the increase in the S4 treatment was significant ($p \leq 0.05$). For *Maofen tomato* fruit, the VC content in the P2–P5 treatments increased by 22.2%, 24.1%, 2.9%, and 66.7% compared with the P1 treatment, but these increases were not significant.

Under the same EC (S1–S5) treatments, *Strawberry tomato* exhibited significantly higher soluble solids (by 15.8–56.3%), organic acid (69.4–173.5%), and vitamin C content (378.3–681.3%) than *Maofen tomato*. The sugar–acid ratio of *Maofen tomato* in the P1–P5 treatments was significantly higher than that of *Strawberry tomato* fruit, with increases of 226.1%, 77.6%, 75.0%, 70.5%, and 74.4%, respectively. For *Maofen tomato* fruit, there were no significant changes in organic acid content, lycopene content, VC content, or sugar–acid ratio across all treatments compared with the P1 treatment. Collectively, these regression analyses indicate that fruit quality parameters' responses to salinity were predominantly nonlinear and cultivar-dependent. *Strawberry tomato* exhibited stronger nonlinear trends in soluble solids ($R^2 = 0.77$), lycopene ($R^2 = 0.64$), and vitamin C ($R^2 = 0.87$), whereas *Maofen tomato* showed stronger nonlinear responses in soluble sugar ($R^2 = 0.87$), organic acid ($R^2 = 0.73$), and sugar–acid ratio ($R^2 = 0.77$). Moderate stress enhances selected quality traits in a cultivar-specific manner. In general, saline water irrigation increased the contents of soluble solids in tomato fruits; the soluble solid and organic acid content and the sugar–acid ratio in *Strawberry tomato* fruits were more affected by salinity than those in *Maofen tomato* fruits.

3.5. Effects of Irrigation Water Salinity on the Comprehensive Quality Evaluation Index of Tomato Fruits

As shown in Figure 8, the comprehensive quality score (CQS) of tomato fruits was affected by the salinity $\times$ cultivar interaction, indicating that the two cultivars responded differently to increasing EC. Using P1 (for *Maofen tomato*) as the reference, the P2–P5 treat-

ments showed only minor numerical increases of 6.7%, 2.7%, 7.1%, and 12.4%, respectively; the CQS of all S1–S5 saline treatments was significantly higher than that of the control, increasing by 103.9%, 107.0%, 120.0%, 138.5%, and 136.8%, respectively. Under each EC level, the CQS of *Strawberry tomato* exceeded that of the corresponding *Maofen tomato* treatment by 94.0–122.7%, with an average increase of 109%. These results demonstrate that the comprehensive fruit quality of *Strawberry tomato* was significantly superior to that of *Maofen tomato* under saline irrigation.

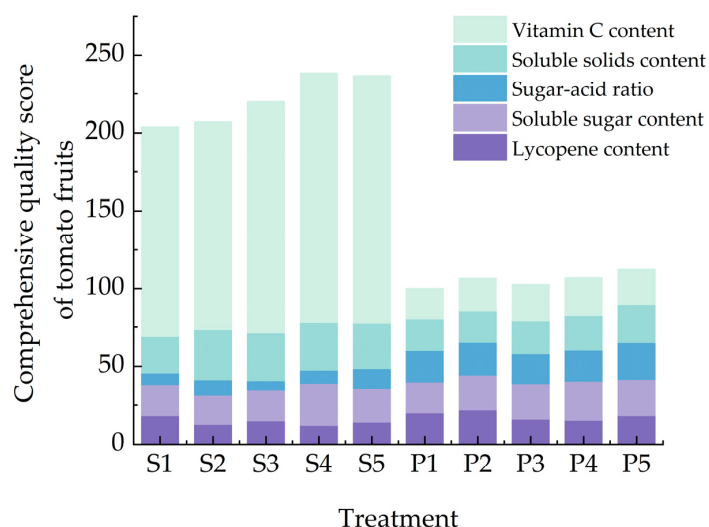


Figure 8. Comprehensive quality score of tomato fruits from two cultivars under different saline water irrigation treatments (based on lycopene, soluble sugar, sugar–acid ratio, soluble solids, and vitamin C content). Note: S1–S5 and P1–P5 represent the saline water irrigation treatments for *Strawberry tomato* and *Maofen tomato*, respectively, with EC values of 1.0, 2.6, 4.2, 5.8, and 7.4 dS m^{−1}.

4. Discussion

4.1. Effects of Irrigation Water Salinity on Tomato Growth Indicators and Yield

Previous studies have indicated that saline water irrigation within an appropriate salinity range can maintain crop yield stability [7,36]. In the present study, no statistically significant differences in growth and yield parameters were detected for either cultivar when comparing each EC treatment with its respective control (S1 for *Strawberry tomato*, P1 for *Maofen tomato*). This absence of yield reduction under moderate salinity likely reflects an adaptive response within a specific developmental window: because saline irrigation was initiated only after the fourth-cluster fruits had reached 60% of their final diameter, the critical stages of vegetative growth and fruit set had already been completed under non-stress conditions. Regression analysis further supported this interpretation, revealing distinct nonlinear patterns in the yield components. *Strawberry tomato* exhibited a pronounced threshold-type decline in marketable yield at EC 7.4 dS m^{−1} ($R^2 = 0.84$), whereas *Maofen tomato* maintained relatively stable marketable yield across the entire salinity gradient ($R^2 = 0.84$), with its stronger nonlinear decline in total yield per plant ($R^2 = 0.87$) being offset by the preservation of fruit marketability. This interpretation is further supported by Li et al. [37], who recommended that in semi-arid regions, freshwater drip irrigation should be used from the seedling to flowering stage, with saline water introduced only from fruit set onward. When comparing the two cultivars, *Maofen tomato* exhibited a clear advantage in single-fruit weight, with increases ranging from 135.9% to 160.2% across all EC levels compared with *Strawberry tomato*, reflecting its inherent genetic characteristics as a large-fruited cultivar.

In this study, the incidence of BER in *Strawberry tomato* increased markedly under EC 7.4 dS m⁻¹, leading to a significant reduction in marketable fruit yield per plant. In contrast, BER incidence in *Maofen tomato* remained negligible across all saline treatments, with no significant differences in marketable fruit yield per plant detected among treatments. The occurrence of BER is synergistically influenced by multiple factors. In addition to environmental stresses such as high temperature, drought, and salinity, the primary underlying mechanism is the inhibition of Ca²⁺ uptake and the disruption of its directional transport to the distal tissues of the fruit, ultimately resulting in a calcium deficiency-related physiological disorder [38]. The nonlinear decline in the Ca²⁺/Na⁺ ratio observed in *Strawberry tomato* at high EC levels (Figure 6) is consistent with the sharp increase in BER incidence, supporting the mechanistic link between disrupted Ca²⁺ homeostasis and BER susceptibility under saline stress. The pronounced difference in BER severity between the two cultivars observed in this study is likely governed primarily by their distinct genetic backgrounds. Taking these findings together, to ensure stable marketable fruit production, the irrigation water EC for *Strawberry tomato* should not exceed 5.8 dS m⁻¹, whereas for *Maofen tomato* it may reach up to 7.4 dS m⁻¹.

4.2. Effects of Irrigation Water Salinity on Ion Content of Tomato Fruits

The mechanism by which salt stress damages plants is complex. It can cause non-specific stress damage to plants by reducing soil water potential, disrupting cellular osmotic balance, and disturbing ion dynamic homeostasis [39]. The results of this experiment showed that under saline water irrigation conditions, excessive accumulation of Na⁺ and Cl⁻ occurred in the fruits of *Maofen tomato* [40]. Due to the significant antagonistic effect between Na⁺ and K⁺ during plant absorption, the excessive intake of Na⁺ further led to a decrease in K⁺ content in the fruits [23]. This ion imbalance not only damages the structural integrity and functional stability of cell membranes, interferes with the normal osmotic regulation process of fruit cells, reduces the plant's ability to selectively absorb essential ions, but also inhibits the efficiency of nitrogen absorption by plants, ultimately causing varying degrees of nutritional imbalance and ion toxicity [29]. However, ion dynamics under salinity are not merely a manifestation of toxicity; they also reflect the plant's adaptive regulation of ion homeostasis. The capacity to maintain favorable K⁺/Na⁺ and Ca²⁺/Na⁺ ratios through selective uptake and vacuolar compartmentalization is a central mechanism of salinity tolerance [27]. To assess cultivar-specific ion selectivity, the ratios of K⁺/Na⁺, Ca²⁺/Na⁺, Mg²⁺/Na⁺, and NO₃⁻/Cl⁻ were calculated. *Strawberry tomato* maintained higher K⁺/Na⁺ and Ca²⁺/Na⁺ ratios than *Maofen tomato* across all EC levels, indicating a stronger capacity for selective K⁺ and Ca²⁺ transport and more efficient Na⁺ exclusion.

As an essential secondary messenger in plants, Ca²⁺ plays an irreplaceable key role in maintaining cell membrane integrity, ensuring the normal functioning of cells, and promoting fruit development [23]. This study found that when EC was in the range of 4.2–7.4 dS m⁻¹, the contents of Ca²⁺ and Mg²⁺ in *Strawberry tomato* fruits were lower than those in the S1 treatment. It is speculated that the reason is that Ca²⁺ is mainly transported to the fruits through the plant xylem, and the decrease in K⁺ content under salt stress will affect the normal opening and closing of leaf stomata [41], resulting in weakened plant transpiration, reduced nutrient transport efficiency, and thus a decrease in the directional transport of Ca²⁺ to the fruits. This transpiration-dependent decline in Ca²⁺ delivery likely contributed to the increased incidence of blossom-end rot and the associated yield loss in *Strawberry tomato* under high salinity. The concurrent reduction in the Mg²⁺/Na⁺ ratio further reflected the progressive deterioration of ion homeostasis under severe stress.

Compared with the S1/P1 treatment, the Na^+ content in fruits of both *Strawberry tomato* and *Maofen tomato* increased significantly under saline irrigation. This finding aligns with the results of Semiz and Suarez [42], who reported that excessive Na^+ accumulation in fruits was one of the primary toxic ions responsible for yield decline in eggplant under saline water irrigation, thereby corroborating that massive Na^+ enrichment is a core factor triggering salt damage in tomato. Meanwhile, as EC increased, the NO_3^- content in fruits of both cultivars under the 2.6–5.8 dS m^{-1} treatments was significantly higher than that in the respective controls ($p \leq 0.05$), whereas K^+ and Mg^{2+} content decreased significantly under the 2.6–4.2 dS m^{-1} treatments. A plausible explanation for the sustained NO_3^- accumulation is that the salinity levels applied, while sufficient to perturb normal metabolic processes, remained below the threshold triggering acute ion toxicity. This sub-toxic condition likely permitted the continued transport and accumulation of NO_3^- in fruits via the transpirational stream [43]. Concurrently, the elevated Na^+ concentration in the root zone inhibited K^+ uptake through competition for shared absorption sites, ultimately leading to the differential changes in ion content described above [18].

Studies have shown that the K^+/Na^+ ratio is a key indicator for evaluating salt tolerance in plants [26]. In the present study, the K^+/Na^+ ratio of *Strawberry tomato* was significantly higher than that of *Maofen tomato*, a characteristic that would typically be considered a positive physiological signal of greater salt tolerance potential. In practice, however, the weak resistance of *Strawberry tomato* to blossom-end rot (BER) meant that the inhibitory effect of BER on fruit development and yield formation under salt stress was more pronounced. Consequently, *Strawberry tomato* did not exhibit a yield advantage commensurate with its superior K^+/Na^+ ratio. Regression analysis of individual ion contents confirmed that the K^+/Na^+ ratio declined nonlinearly with increasing EC in both cultivars, with *Maofen tomato* showing a stronger nonlinear response ($R^2 = 0.99$) than *Strawberry tomato* ($R^2 = 0.42$), reflecting the greater sensitivity of its ion profile to the salinity gradient.

The four ion ratios collectively reveal distinct ion homeostasis strategies between the two cultivars. *Strawberry tomato* maintained 5.0–7.4 times higher $\text{Ca}^{2+}/\text{Na}^+$ and 6.7–14.1 times higher $\text{Mg}^{2+}/\text{Na}^+$ ratios than *Maofen tomato*, along with significantly higher K^+/Na^+ , indicating a systematically stronger capacity for selective cation uptake relative to Na^+ . This ionic advantage underpins the superior fruit quality under moderate salinity. However, the collapse of the $\text{Ca}^{2+}/\text{Na}^+$ ratio at EC 7.4 dS m^{-1} coincided with increased BER and yield loss, demonstrating the physiological limit of even superior ion selectivity. Moreover, the higher K^+/Na^+ ratio did not translate into greater yield stability, underscoring the multi-dimensional nature of salt tolerance. *Maofen tomato* maintained a higher $\text{NO}_3^-/\text{Cl}^-$ ratio at extreme EC levels, reflecting stronger nitrogen–chloride balance under severe stress, consistent with its more stable yield performance. This contrast in ion strategies mechanistically links divalent cation selectivity to quality enhancement and nitrogen–chloride balance to yield stability.

Analysis of the differences in fruit ion composition between the two tomato cultivars revealed that under all EC treatments, the amounts of NO_3^- , Cl^- , K^+ , and Mg^{2+} in the fruits of *Strawberry tomato* were significantly higher than those in *Maofen tomato*. From the perspective of the sensitivity of ion content's response to salinity, the amounts of Cl^- , K^+ , and Na^+ in *Maofen tomato* fruits fluctuated more significantly with changes in salinity, reflecting a weaker capacity for ion homeostasis regulation. This greater fluctuation was quantitatively captured by the regression analyses, in which *Maofen tomato* exhibited stronger nonlinear trends for K^+ ($R^2 = 0.99$), Na^+ ($R^2 = 0.97$), and Cl^- ($R^2 = 0.87$) compared with *Strawberry tomato* ($R^2 = 0.42$, 0.96, and 0.74, respectively), indicating that the ion profile of *Maofen tomato* was more responsive to incremental changes in EC. Meanwhile,

the comprehensive fruit quality evaluation index of *Strawberry tomato* was significantly superior to that of *Maofen tomato*. This contrast suggests that the ability to maintain ion homeostasis—quantified through ion ratios such as K^+/Na^+ and Ca^{2+}/Na^+ —is closely associated with fruit quality under saline irrigation, and that this association is partially independent of yield stability. This research finding provides a clear potential regulatory direction for tomato management with irrigated saline water: on one hand, the balance of ion absorption and distribution in plants can be improved through the supply strategy of key nutrient ions such as Ca^{2+} and Mg^{2+} ; on the other hand, tomato cultivars with strong ion homeostasis maintenance capabilities can be selectively bred. This finding will help tomato maintain relatively stable fruit ion content under saline water irrigation scenarios and ultimately achieve the coordinated goal of stable yield and improved quality.

4.3. Effects of Irrigation Water Salinity on Tomato Fruit Quality

Salt stress disrupts plant physiological processes by inducing osmotic stress, ionic imbalance, and metabolic disorders [44]. Salt-induced osmotic adjustment promotes the accumulation of soluble sugars and organic acids, and these simultaneously serve as key determinants of fruit flavor [45]. Concurrently, mild ionic stress triggers reactive oxygen species (ROS)-mediated signaling cascades [46], leading to the upregulation of enzymes such as sucrose synthase and invertase, thereby enhancing the biosynthesis of reducing sugars such as fructose and glucose [14,47]. Consistent with this, a previous study reported significantly higher soluble sugar content in tomato fruits irrigated with $EC\ 8\ dS\ m^{-1}$ compared with those irrigated with $1\ dS\ m^{-1}$ [11]. Consequently, the quality enhancement observed under saline irrigation does not occur in isolation; it reflects a resource allocation trade-off that, under mild-to-moderate stress, can enhance fruit flavor without a substantial yield reduction. Under severe stress, this adaptive capacity is overwhelmed, resulting in concurrent impairment of both yield and quality. It is worth noting that fruit size may also contribute to the observed differences in fruit quality [48]. Smaller-fruited tomato cultivars generally exhibit superior quality attributes, and the better-quality performance of *Strawberry tomato* may therefore be partly attributable to its medium-sized fruit type.

In this study, compared with S1/P1 treatment, the amounts of soluble solids, soluble sugars, and vitamin C in the fruits of *Strawberry tomato* and *Maofen tomato* showed an overall upward trend under the saline water treatments of $2.6\text{--}7.4\ dS\ m^{-1}$, and the soluble sugar content reached its peak at $5.8\ dS\ m^{-1}$. This conclusion is consistent with the field experiment results of Li et al. [49], which pointed out that irrigation with $EC \leq 4.7\ dS\ m^{-1}$ can effectively improve tomato fruit quality. In addition, Agius et al. [50] irrigated cherry tomatoes (a tomato cultivar) in planting bags with saline water containing $17\text{--}34\ mmol/L$ NaCl, and found that fruit quality improved with the increase in NaCl concentration, accompanied by a significant increase in soluble solids content. This is consistent with the trend observed in this study, where the soluble solids content of *Strawberry tomato* under the $2.6\text{--}7.4\ dS\ m^{-1}$ treatments was significantly higher than that of the control.

Although saline water irrigation disrupts ionic balance in tomato plants, it simultaneously promotes the accumulation of soluble sugars in fruits through two interconnected mechanisms: enhanced sucrose metabolic flux and increased starch synthesis. It can be seen that under the saline water irrigation conditions set in this study, the fruit quality of both tomato cultivars was improved to varying degrees, with a more significant quality improvement effect observed in *Strawberry tomato*. Further observation results showed that as the EC increased, the Na^+ content and soluble solids content in the fruits of *Strawberry tomato* and *Maofen tomato* all exhibited an overall upward trend compared with the control treatment, among which the increase in soluble solids content reached a statistically significant level ($p \leq 0.05$). This result is consistent with the conclusion of the greenhouse drip irrigation

tomato experiment conducted by Oliveira et al. [18], which found that when tomato plants transport a large amount of Na^+ to the above-ground parts, the amounts of vitamin C, total phenolic compounds, and total soluble solids in the fruits all increase significantly.

Based on the premise that cultivation practices and environmental conditions remain consistent, significant differences in fruit weight and quality were observed among different tomato cultivars. This phenomenon is mainly determined by the genetic differences between cultivars [51]. Specifically, these genetic differences are reflected in the variations in gene expression that regulate key processes of fruit development, including cell division and expansion, fruit shape formation, ion absorption and accumulation, as well as the transport and distribution of photosynthates to fruits. Notably, significant salinity $\times$ cultivar interactions were detected for soluble solids content, organic acid content, sugar–acid ratio, and vitamin C content in this study, indicating that the response patterns of these key quality parameters to elevated salinity levels were cultivar-dependent. Therefore, the selection of cultivar genotypes is one of the key factors for ensuring yield and optimizing quality in saline water irrigation cultivation [52]. While verification in broader germplasm is needed, these findings highlight the practical value of incorporating ion homeostasis parameters into screening strategies when developing cultivar-specific saline water management protocols.

The regression analyses revealed that fruit quality parameters' responses to salinity were predominantly nonlinear and cultivar-dependent. *Strawberry tomato* exhibited stronger nonlinearity in soluble solids, lycopene, and vitamin C, whereas *Maofen tomato* showed more pronounced trends in soluble sugar and organic acid. These cultivar-specific nonlinear patterns, together with the yield and ion responses observed in this study, indicate that these cultivar-specific EC thresholds merit cautious interpretation, as their economic viability, applicability across diverse cultivation systems and water qualities, and transferability to other genotypes await further validation. The proposed strategy should therefore be regarded as a physiologically grounded framework rather than a universal prescription, with on-farm trials needed for broader adoption.

5. Conclusions

- (1) Significant cultivar differences were observed in fruit ion accumulation under saline irrigation. *Maofen tomato* accumulated substantially more Na^+ , with a K^+/Na^+ ratio that was only 1/3.9–1/8.7 of that of *Strawberry tomato*, while *Strawberry tomato* maintained higher NO_3^- , Cl^- , K^+ , and Mg^{2+} content. The ion profile of *Maofen tomato* was more sensitive to increasing salinity.
- (2) Fruit quality response to salinity was closely associated with the variation in ion content and exhibited clear cultivar specificity. *Strawberry tomato* showed greater responsiveness to salinity, with soluble solids content increasing by 24.5–37.5% under EC 2.6–7.4 dS m^{-1} , whereas *Maofen tomato* exhibited only a marginal quality improvement under high salinity and remained stable overall.
- (3) Under high salinity (EC 7.4 dS m^{-1}), the higher incidence of blossom-end rot (BER) and the reduction in marketable fruit yield in *Strawberry tomato* appeared to be related to decreased fruit Ca^{2+} content. A 23.5% loss in marketable yield coincided with reduced Ca^{2+} accumulation and increased BER incidence, whereas *Maofen tomato* maintained relatively stable fruit Ca^{2+} content without significant marketable fruit yield change.
- (4) *Strawberry tomato* fruit quality is better than *Maofen tomato*. For practical application, a comprehensive quality score (CQS) was constructed to quantify overall fruit quality. *Strawberry tomato* had a much higher CQS increase (109% on average) than *Maofen tomato* across salinity treatments. Regression analysis confirmed that the

responses of key yield, ion, and quality parameters to the salinity gradient were distinctly nonlinear.

Based on these findings, the two cultivars exhibited distinctly nonlinear responses to saline irrigation, consistent with the concept of an “optimal salinity window”. In terms of physiological mechanisms—such as ion selectivity and quality responsiveness—*Strawberry tomato* excelled compared to *Maofen tomato*, whereas *Maofen tomato* demonstrated greater yield stability under high salinity. The optimal irrigation thresholds were accordingly determined as $EC \leq 5.8 \text{ dS m}^{-1}$ for quality-oriented *Strawberry tomato* and $EC \leq 7.4 \text{ dS m}^{-1}$ for yield-oriented *Maofen tomato*. Consequently, a production goal-oriented differentiated irrigation strategy was proposed to simultaneously achieve yield stability and quality enhancement.

Overall, this study refines the application of saline irrigation technology by extending it from single-cultivar adaptation to multi-goal adaptation, thereby broadening its applicability in areas with salinity problems. The physiological, biochemical, and molecular mechanisms underlying the differential salt tolerance between the two cultivars have yet to be further elucidated. Future work should integrate in-depth mechanistic exploration with multi-environment field verification to facilitate the large-scale application of this technology.

Author Contributions: D.F. and W.X. conceived and designed the research. N.Y. and D.F. conducted the experiments and data surveys. N.Y., S.N., J.C., and J.L. analyzed the data and wrote the manuscript. J.W., T.Q., R.D., G.T., W.X. and D.F. revised the paper. All authors have read and agreed to the published version of the manuscript.

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