Journal of Agricultural Sciences
(Tarim Bilimleri Dergisi)

J Agr Sci-Tarim Bili
e-ISSN: 2148-9297

jas.ankara.edu.tr

JAS

Effects of Different Types of Irrigation Water Quality and Silicon Doses on Fruit Yield, Chlorophyll and Carotenoid Contents of Tomato (*Lycopersicon esculentum L.*) under Soilless Culture Technique

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ARTICLE INFO
Research Article
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Received: 13 Apr 2021 / Revised: 2 Sept 2021 / Accepted: 6 Sept 2021 / Online: 19 Sept 2023

Cite this article

YILMAZ Y, KORKMAZ A (2023). Effects of Different Types of Irrigation Water Quality and Silicon Doses on Fruit Yield, Chlorophyll and Carotenoid Contents of Tomato (Lycopersicon esculentum L.) under Soilless Culture Technique. *Journal of Agricultural Sciences (Tarim Bilimleri Dergisi),* 29(3):868-880. DOI: 10.15832/ankutbd.915237

ABSTRACT

This study was conducted to determine the effects of different irrigation water quality and silicon doses on leaf soil plant analysis development meter readings, chlorophyll content and carotenoid contents of tomato plants. Tybiff Aq tomato seedlings were grown in 3-liter pots filled with 1100 g of 1:1 peat-perlite mixture for 70 days. Four different types of irrigation water quality were prepared with the use of sea and tap water. Irrigation waters included i) Full seawater, ii) ½ seawater + ½ tap water, iii) ¼ seawater + ¾ tap water, iv) full tap water (control). Each irrigation water was supplemented with silica gel (SiO_2.x H_2O) at 0, 0.5, 1 and 2 mM Si doses. Nutrient solutions were supplied to meet macro and micronutrient requirements of tomato plants. Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly increased with increasing tap water ratios of the irrigation water. Significant increases were observed in chlorophyll-a, chlorophyll-b and total chlorophyll contents with increasing silicon doses. Such increases achieved with silicon treatments were more remarkable for chlorophyll-a and total chlorophyll contents. Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly decreased with increasing leaf sodium, chlorine and magnesium contents, but significantly increased with increasing leaf active iron and potassium contents. Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents increased with increasing leaf calcium contents, but such increases were not significant. Leaf carotenoid contents significantly increased with increasing tap water ratios of the irrigation water. Effects of silicon doses on leaf carotenoid contents varied with the type of irrigation water. The 0.5 mM silicon supplementation into tap water significantly increased carotenoid contents.

Keywords: Tomato, Seawater, Tap water, Silicon, Chlorophyll, Carotenoid

1. Introduction

Since 1966 the use of seawater for agriculture was often studied. Despite intensive research and projects, only few organisms have been found, which can be grown with seawater: some mangrove trees and shrimps. Even today there is still no considerable use of seawater irrigation. Some halophytic vascular plants, however, can fulfil their whole lifecycle with seawater. But they also grow better on half seawater concentration. In many thousands of other projects (with many cash crops) the use of only 10-20% seawater concentration has been tried. But even this concentration is often too high and spoils the soils in their structure, especially if not an efficient leaching is applied. A sustainable agriculture based on irrigation with seawater on a large scale seems to be still a utopic illusion (Breckle 2009).

Alternative water sources for irrigation can represent a valid help for the preservation of the already overexploited freshwater. In particular, seawater is considered a realistic option in agriculture, either desalinized or blended with freshwater (Yermiyahu et al. 2007). Even if in recent years numerous large-scale seawater desalination plants have been built, such a technique is anyhow very energivourous and thus presents environmental concerns (Elimelech & Phillip 2011). Besides, desalination cost has decreased because of technical improvements in a world of increasing fossil fuel prices (Karagiannis & Soldatos 2008). Nevertheless, in developing countries, often characterized by water shortage, desalination has been generally excluded because of the economic conditions (Wade

2001). A different option is to use seawater as a complementary irrigation source at concentrations not harmful for the cultivated crops. Seawater is the most abundant source of water of the planet and its specific composition represents a well balanced ionic environment for plants (Boyko 1966). In fact, despite its very high chloride content (about 75% NaCl and 10% of $MgCl_2$), seawater is rich in all nutritive elements needed by plants,

Soilless systems offer an important alternative to soil cultivation in case of soil and/or water issues, as for example, among the most important, water shortage and salinization (Olympios 1999). The three main soilless systems are liquid hydroponics, solid media culture and aeroponics. Hydroponics is further categorized in open or closed systems, depending on the collection and reuse (i.e. in closed systems) of the nutrient solution until its depletion. Solid media culture systems can in the same way be open or closed and several substrates are used for plants anchorage (i.e. perlite, vermiculite, coconut coir), as long as characterized by water and air holding capacity and by an easy drainage. Aeroponics, in the end, enables the maximum utilization of space by growing plants with roots suspended in air sprayed every 2-3 minutes, plants getting nutrients and water from the solution film that adheres on roots (Hussain et al. 2014). This diversity of techniques makes soilless culture adaptable to very dissimilar situations, with the common potential application in providing food in areas characterized by soil and water availability issues (Sheikh 2006).

Net photosynthesis is an indicator of biomass production and resultant growth. Thus, environmental stress factors influencing plant growth and development also influence photosynthesis. Therefore, the changes in plant photosynthetic activity under stress conditions somehow reveal information about general health of the plants. Such changes in photosynthetic activity are considered to be a sensor of stress in plants, algae and cyanobacteria (Biswal et al. 2011). Stress factors, including soil salinity, play a great role in photosynthetic pigment quantity, light absorbance of these pigments and resultant primary photochemical reactions, structural organization of thylakoid membranes and units, electron transport and rate of CO_2 fixation reactions (Mittal et al. 2012). For more than a century, researchers have been working on effects of salts around the roots. Salinity has osmotic effects on plants and toxic effects on plant nutrition (Levitt 1980). Tomato plants are moderately sensitive to salinity (Maas & Hoffman 1977). Besides, Alian et al. (2000) indicated significant differences in salt tolerance of tomato cultivars. In soilless culture, salinity of the root zone could be modified through changing nutrient solution composition or alteration of irrigation frequency and it was reported that tomato could tolerate salt concentrations of root zone of between 2.5-2.9 dS m^{-1} without any losses in yields (Sonneveld & Van der Burg 1991). The salt levels of growing environment vary based on sensitivity of the cultivars and environmental conditions (Li et al. 2001). Irrigation water to be used in soilless culture should have an EC value of less than 0.5 dS m^{-1}, sodium concentration of less than 35 ppm, chlorine concentration of less than 50 ppm, bicarbonate concentration of less than 250 ppm and boron concentration of less than 0.5 ppm. Irrigation water pH values should be between 5.0 and 7.0 (Gül 2012). Negative impacts of excessive salt levels on plant growth and development could be summarized as 1) Reduction in plant water uptake (water stress), 2) Inhibition of uptake of some nutrients, 3) Specific ion effect (salt stress) (Marschner 1995).

Zhu & Gong (2014) reported that silicon treatments increased water uptake of roots, reduced water loss of leaves, provided nutrient balance and improved photosynthesis rates. It was also reported that silicon treatments increased antioxidant enzyme activity, non-antioxidant enzyme contents, thus prevented plants from oxidizing effect of salt, provided contributions to osmatic regulation, thus increased activity of photosynthetic enzymes. Researchers also indicated that silicon treatments reduced sodium accumulation in roots and shoots.

Coşkun et al. (2016) indicated that although silicon is not an essential element for plants, it provides various contributions to plant growth and development under stress conditions like salinity and drought. Silicon provides suberization, lignification and silicification in cell wall, and then reduce transpiration of water and salt-induced oxidative damage. Recent studies have revealed that Si addition under salinity stress can increase water content in plants through increasing root water absorption (Zhu et al. 2015; Wang et al. 2015). In tomato, Li et al. (2015) found that Si promoted root growth and root hydraulic conductance, thereby increasing root water uptake and further improving leaf water content.

Cell wall is the outer most layer of the plant cells and composed of polysaccarite and polymer secretions of the cells. Cell wall is a supporting cover with a primary functions to regulate cell volume and designate cell shape. Under salt stress conditions, Na^+ is accumulated at high concentrations in apoplast. The accumulated Na^+ distords ionic bondings of sturcutural members like pectine in cell wall or negatively incluences apoplastic enzymes, thus prenvents cell wall from performing basic functions (Rengel 1992).

Another harmfull effect of salt stress in on cell membrane. Cell membrane is a semi-permiable memberane composed of double phopholite layers and proteins embedded into this layer. Salt stress triggers the change in lypid composition of cell membrane and results in cell membrane damage. The changes in lypid composition are resulted from the changes in activity of enzymes participating into lypid synthesis, degredations (disintegration, destraction) or hydrolysis of phospholypids (Huang 2006).

Besides reductions in water potential, NaCl also impairs ion balance of the cell, thus negatively incluence plant growth and development. High NaCl uptakes increase cell Na^+ and Cl^- levels and reduce Ca^{+2}, K^+ and Mg^{+2} concentrations (Parida & Das 2005). The Na^+ intrusion into cell destructs membrane potential and facilitate passive intrusion of Cl^- into the cell through ion cannels (Niu et al. 1995; Tuteja 2007).

This study was conducted to determine the effects of different irrigation water quality and silicon doses on leaf soil plant analysis development (SPAD) meter readings, chlorophyll content and carotenoid contents of tomato plants.

2. Material and Methods

The experiment was carried *out* in a greenhouse environment. Plastic pots of 3 liters were filled with 1100 g substrate (1:1 peat:perlite mixture) materials. The particle diameter of the perlite used in the experiment varies between 0-6 mm. Its pH is 7.0 and its volume weight is 80-90 kg/m^3, whereas peat is uniformly brown, strongly to almost completely decomposed (H7-H9), and moderately acidic (pH 5.5).

Tybiff Aq tomato seedlings were planted into the pots as to have one seedling per pot. Four different types of irrigation water qualities were applied. Irrigation water quality included: i) Full seawater, ii) ½ seawater + ½ tap water, iii) ¼ seawater + ¾ tap water, iv) Full tap water (control).

Irrigation waters were supplemented with silica gel (SiO_2 xH_2O) (0, 0.5, 1 and 2 mM Si). Experiments were conducted in randomized plots 4×4 factorial design with 3 replications. From planting to harvest (70 days), following nutrient solutions were applied to tomato plants as recommended by Alpaslan et al. (1998):

1.25 mM KH_2PO_4; 15 µM Fe (FeEDDHA); 4.25 mM Ca $(NO_3)_2 \cdot 4H_2O$; 10 µM Mn ($MnCl_2$); 1.25 mM NH_4NO_3; 5 µM Zn ($ZnSO_4 \cdot 7H_2O$); 4.0 mM KNO_3; 30 µM B (H_3BO_3); 2.0 mM $MgSO_4.7H_2O$; 0.75 µM Cu ($CuSO_4 \cdot 5H_2O$); 1.75 mM K_2SO_4;

0.5 µM Mo [$(NH_4)_6Mo_7O_{24}4H_2O$]

Soilless growing mediums included a mixture of peat and perlite (1:1) in pots and were brought to the field capacity with 4 different irrigation applications according to the experimental subjects. Tomato seedlings were planted in the solid growing media brought to the field capacity. Growing medium have a high water-holding capacity (135%) to supply water to seedlings.

From planting to the first fruit set, 150 mL nutrient solution and 300 mL irrigation water was applied in each day; from the first fruit set to the harvest, 300 mL nutrient solution and 600 mL irrigation water was applied in each day. Following the application of irrigation water and nutrient solution, experimental pots were freely drained through the holes provided at the bottom of each pot.

2.1. Leaf analysis

Leaf potassium, calcium, magnesium, sodium and chlorine contents of tomato plants were determined in accordance with Kacar & İnal (2008). Fresh leaf samples were used to determine chlorophyll-a, chlorophyll-b and carotenoid contents in accordance with Arnon (1946). and Withan et al. (1971).

SPAD meter readings were taken from mid-point of the leaves with the use of portable SPAD meter device (Konica Minolta SPAD-502 Plus). Active iron contents were determined in dry leaf samples with the use of an AAS device (Oserkowsky 1933).

2.2. Irrigation water analysis

The pH, EC, SAR values, carbonate, bicarbonate, chlorine, calcium, magnesium, sodium contents (Sağlam 2008); sulphate (Kacar 1994); boron (Bayraklı 1987) contents of different irrigation waters were determined. SAR values were calculated with the use of the following equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

where; Na^+, me L^{-1}, Ca^{+2}+Mg^{+2}, me L^{-1}

Irrigation water analysis results are provided in Table 1.

Table 1- Chemical properties of irrigation waters prepared from sea and tap water

Irrigation water parameter	*Full seawater*	*½ seawater + ½ tap water*	*¼ seawater + ¾ tap water*	*Full tap water*
pH	8.05	8.20	8.0	7.70
$EC_{25\,°C}$, dS m^{-1}	62.40	37.20	18.70	0.70
$CO_3^{=}$, me L^{-1}	0.46	0.25	0.03	0.00
HCO_3^{-}, me L^{-1}	6.13	5.12	4.69	3.56
Cl^{-}, me L^{-1}	316.40	168.10	89.20	8.70
$SO_4^{=}$, me L^{-1}	6.40	7.30	4.80	0.80
Ca^{++}, me L^{-1}	10.90	7.25	5.40	3.40
Mg^{++}, me L^{-1}	62.14	36.59	20.10	2.32
Na^{+}, me L^{-1}	220.70	89.80	43.05	0.75
B, mg L^{-1}	1.42	1.07	0.91	0.71
SAR	36.54	19.20	12.10	0.44

2.3. Statistical analysis

Experimental data were subjected to variance analysis (ANOVA) in accordance with randomized plots 4×4 factorial experimental design with the use of SPSS 17.1 software. Significant means were compared with the use of Duncan's test at $p<0.05$ level. Correlation analysis was conducted to identify the relationships of some leaf nutrients with chlorophyll and carotenoid contents.

3. Results and Discussion

3.1. Evaluation of the agricultural suitability of irrigation waters

Entire parameters of full seawater, ½ seawater + ½ tap water and ¼ seawater + ¾ tap water were not suitable for irrigations to be conducted in soilless culture and field farming. On the other hand, entire parameters of tap water were ideal for irrigations (Sağlam 2008).

3.2. Effects of different irrigation waters and silicon doses on tomato fruit yield

Effects of different irrigation waters and silicon doses on tomato fruit yield are given in Table 2.

Table 2- Effects of different irrigation waters and silicon doses on tomato fruit yield

Parameters	*Irrigation waters*	*Si doses, mM*				*Average*
		0.0	*0.5*	*1.0*	*2.0*	
Fresh fruit yield, g $plant^{-1}$	Seawater	289.67	362.68	254.10	225.87	283.08D
	½ seawater + ½ tap water	618.15	660.35	674.30	692.43	661.31C
	¼ seawater + ¾ tap water	1181.43	1203.33	1078.87	1042.47	1126.53B
	Tap water	2051.40	2226.05	1971.77	2115.17	2091.10A
	Average	1035.16	1113.11	994.76	1018.98	

As can be inferred from Table 2, effects of irrigation waters on fruit yield were found to be significant at $p<0.01$ level, but the effects on silicon doses were not found to be significant.

Fruit yields significantly decreased with increasing seawater ratio of the irrigation water. While tap water treatments had an average fruit yield of 2091.05 g $plant^{-1}$, fruit yield per plant decreased to 1126.11 g $plant^{-1}$ with ¼ seawater-containing irrigation water, to 661.30 g $plant^{-1}$ with ½ seawater-containing irrigation water and to 283.08 g $plant^{-1}$ with full seawater. The correlations between seawater ratio of the irrigation water and yield loss revealed that 20% yield loss was seen at 6.5% seawater ratio, 40% yield loss was seen at 25.2% seawater ratio, 50% yield loss was seen at 43.45% seawater ratio, 80% yield loss was seen at 80.49% seawater ratio and 86.51% yield loss was seen at 100% seawater ratio (full seawater). Kahlaoui et al. (2011) indicated that tomato fruit yields were badly influenced when 70% of plant water need was met with saline irrigation waters.

3.3. Effects of irrigation water quality and silicon doses on fruit yield, chlorophyll and carotenoid contents of tomato plant

Effects of irrigation water treatments and silicon doses on leaf SPAD meter readings, chlorophyll-a, chlorophyll-b and total chlorophyll contents of tomato plants and variance analysis results for these effects are respectively provided in Table 3 and Table 4.

Table 3- Effects of irrigation water treatments and silicon doses on leaf SPAD meter readings, chlorophyll-a, chlorophyll-b and total chlorophyll contents of tomato plants

Parameters	*Irrigation water*	*Si doses, mM*				*Average*
		0.0	*0.5*	*1.0*	*2.0*	
SPAD meter reading	Seawater	48.81d-h	38.24h	44.13f-h	45.35e	**44.13C**
	½ seawater + ½ tap water	73.57ab	77.83a	63.17b-d	70.74a	**71.20A**
	¼ seawater + ¾ tap water	82.73a	53.18d-g	71.70ab	70.20a	**69.45A**
	Tap water	55.90c-f	59.53b-e	40.13gh	61.97b	**54.38B**
	Average	**65.25A**	**57.19BC**	**54.78C**	**61.94AB**	
Chlorophyll-a, mg g^{-1} FW	Seawater	0.98	0.46	0.84	1.09	**0.84B**
	½ seawater + ½ tap water	0.89	0.79	0.88	0.85	**0.85B**
	¼ seawater + ¾ tap water	1.16	1.17	1.29	1.48	**1.28A**
	Tap water	1.14	1.30	1.56	1.54	**1.39A**
	Average	**1.04BC**	**0.93C**	**1.14AB**	**1.24A**	
Chlorophyll-b, mg g^{-1} FW	Seawater	0.41	0.20	0.34	0.43	**0.35C**
	½ seawater + ½ tap water	0.35	0.32	0.39	0.36	**0.36C**
	¼ seawater + ¾ tap water	0.49	0.46	0.51	0.58	**0.51B**
	Tap water	0.51	0.55	0.70	0.62	**0.59A**
	Average	**0.44AB**	**0.38B**	**0.49A**	**0.50A**	
Total chlorophyll, mg g^{-1} FW	Seawater	1.39	0.66	1.19	1.52	**1.19B**
	½ seawater + ½ tap water	1.23	1.12	1.27	1.22	**1.21B**
	¼ seawater + ¾ tap water	1.66	1.63	1.81	2.06	**1.79A**
	Tap water	1.65	1.85	2.26	2.17	**1.98A**
	Average	**1.48BC**	**1.31C**	**1.63AB**	**1.74A**	

FW: fresh weight

Table 4- Variance analysis results for the effects of irrigation water treatments and silicon doses on leaf SPAD meter readings, chlorophyll-a, chlorophyll-b and total chlorophyll contents of tomato plants

Parameters	*Variation*							
	Irrigation water		*Silicon dose*		*Irrigation water x silicon dose*		*Error*	
	DF	*MS*	*DF*	*MS*	*DF*	*MS*	*DF*	*MS*
SPAD meter readings	3	1991.889**	3	265.063**	9	214.802**	32	61.105
Chlorophyll-a, mg g^{-1} FW	3	0.97**	3	0.22**	9	0.07	32	0.04
Chlorophyll-b, mg g^{-1} FW	3	0.177**	3	0.033*	9	0.010	32	0.008
Total chlorophyll, mg g^{-1} FW	3	1.97**	3	0.41**	9	0.13	32	0.08

*significant at p<0.05 level, **significant at p<0.01 level, FW: fresh weight

As can be inferred from Table 4, effects of irrigation waters, silicon doses and irrigation water × silicon dose interactions on leaf SPAD meter readings were found to be significant at $p<0.01$ level. Effects of irrigation waters on chlorophyll-a, chlorophyll-b and total chlorophyll contents were found to be significant at $p<0.01$ level and effects of silicon doses on the same parameters were respectively found to be significant at $p<0.01$, $p<0.05$ and $p<0.01$ levels. Effects of irrigation water × silicon dose interactions on leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents were not found to be significant.

As compared to tap water, seawater supplementations into irrigation water significantly increased SPAD meter readings. Leaf SPAD meter reading was 44.13 in full seawater irrigations, 71.33 in ½ seawater + ½ tap water irrigations, 69.47 in ¼ seawater + ¾ tap water irrigations and 53.64 in full tap water irrigations. Effects of silicon treatments on SPAD meter readings varied with the type of irrigation water (Figure 1).

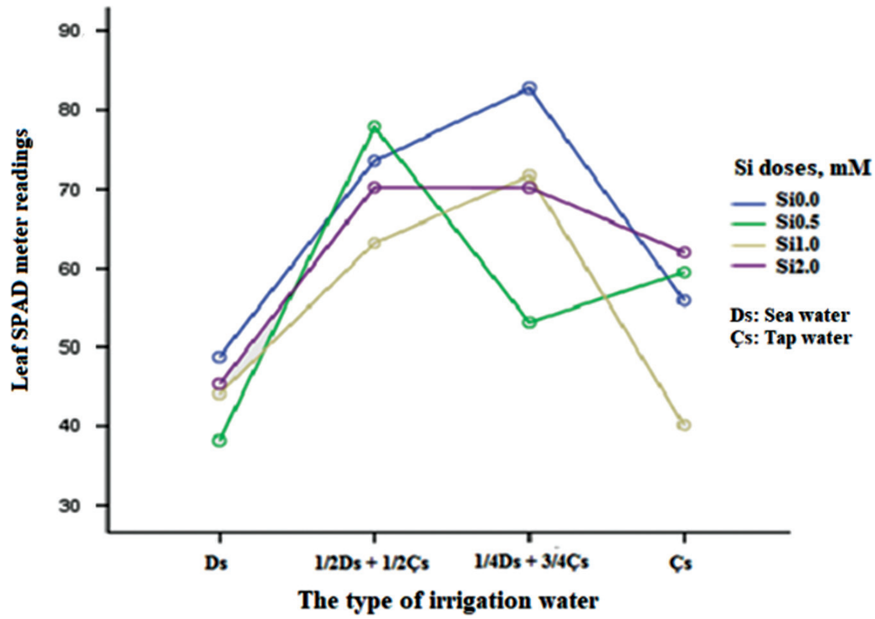

Figure 1- Effects of irrigation water × silicon dose interactions of leaf SPAD meter readings

Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents increased significantly with increasing tap water ratios of the irrigation water. While chlorophyll-a, chlorophyll-b and total chlorophyll contents were respectively measured as 0.84, 0.35 and 1.19 mg g^{-1} fresh weight (FW) in full seawater irrigations, the values were respectively measured as 0.85, 0.36 and 1.21 mg g^{-1} FW in ½ seawater + ½ tap water irrigations, as 1.27, 0.51 and 1.79 mg g^{-1} FW in ¼ seawater + ¾ tap water irrigations and as 1.39, 0.59 and 1.98 mg g^{-1} FW in full tap water irrigations (Table 3).

Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents increased significantly with increasing silicon doses. Such increases achieved with silicon treatments were more remarkable for chlorophyll-a and total chlorophyll contents (Table 3). On the other hand, effects of silicon doses on chlorophyll-a, chlorophyll-b and total chlorophyll contents were similar in different irrigation waters.

Photosynthetic pigment quantity of the plants generally decreases under salt stress. Agastian et al. (2000) indicated that salt treatments result in chlorosis in old leaves at early stage and in case of prolonged stress durations, these leaves were subjected to abscission. However, Wang & Nil (2000) reported increased chlorophyll content of Amaranthus plants subjected to salt stress. In previous studies, as compared to the control plants, decreased total chlorophyll and protochlorophyllide contents were reported in *Greviela arenaria*, total chlorophyll and chlorophyll-a contents in tomato, chlorophyll-a and chlorophyll-b contents in *Bruguiera parviflora* and total chlorophyll content in paddy (Kennedy & Fillippis 1999; Khavarinejad & Mostofi 1998; Alamgir & Ali 1999). Chutipaijit et al. (2011) asserted that the changes encountered in chlorophyll contents of plants under salt stress could be used as a sensitive indicator for cellular metabolisms. Maxwell & Johnson (2000) indicated changes in photosynthetic pigment biosynthesis as an apparent effect of salt stress on plants.

Tavakkoli et al. (2016) investigated the effects of alkalinity stress generated through the use of alkaline irrigation waters and growing media on development and physiological traits of gerbera. Researchers indicated that under irrigation water-induced alkalinity stress conditions, with increasing sodium carbonate levels from 0 to 40 mM, significant decreases were seen in plant growth and development, glutamine synthetase activity, leaf relative water content, chlorophyll-a, chlorophyll-b and total chlorophyll contents and carotenoid contents. Alkalinity stress-induced decreases in vegetative development, leaf relative water content, glutamine synthetase enzyme activity and photosynthetic pigment quantity were lower in coconut fiber media than the other growth media. Researchers pointed out that alkalinity stress resulted from high sodium carbonate of irrigation water could be eliminated with the use of proper substrate materials.

Dannon & Wydra (2004) reported that silicon supplementation into nutrient solution of tomato plants grown in hydroponic culture reduced the incidence of *Ralstonia solanacearum*-induced bacterial wilt disease. It was reported that silicon treatments reduced the harmful effects of NaCl salinity on growth and development of tomato plants (Stamatakis et al. 2003). Stimulating effects of silicon treatments on growth and development of tomato plants subjected to NaCl salt reduced sodium and chlorine uptakes (Stamatakis et al. 2003), improved water status of the plant (Romero-Aranda et al. 2006) and increased superoxide dismutase and catalase enzyme activities. Thusly, it was indicated that superoxide dismutase and catalase enzyme activities prevented plant tissues from oxidative damage of the salt (Al-Aghabary et al. 2004). Silicon was also reported to increase net photosynthesis rate of tomato plants exposed to NaCl. Such an effect of silicon was attributed to increased leaf chlorophyll contents and phytochemical efficiency of Photosystem II (Romero-Aranda et al. 2006).

3.4. Effects of irrigation treatments and silicon doses on leaf carotenoid contents of tomato plants

Effects of different irrigation waters and silicon doses on leaf carotenoid contents of tomato plants and variance analysis results for these effects are respectively provided in Table 5 and Table 6.

Table 5- Effects of different irrigation waters and silicon doses on leaf carotenoid contents of tomato plants

Parameter	*Irrigation water*	*Si doses, mM*				*Average*
		0.0	*0.5*	*1.0*	*2.0*	
Carotenoid, mg g^{-1} Fresh weight	Seawater	0.159cd	0.095d	0.146cd	0.185b-d	0.146C
	½ seawater + ½ tap water	0.147cd	0.157cd	0.146cd	0.146cd	0.149C
	¼ seawater + ¾ tap water	0.206bc	0.194b-d	0.208bc	0.243bc	0.213B
	Tap water	0.201bc	0.394a	0.241bc	0.262b	0.274A
	Average	0.178	0.209	0.185	0.209	

Table 6- Variance analysis results for the effects of different irrigation waters and silicon doses on leaf carotenoid contents of tomato plants

Parameter	*Variation*							
	Irrigation water		*Silicon doses*		*Irrigation water x silicon doses*		*Error*	
	DF	*MS*	*DF*	*MS*	*DF*	*MS*	*DF*	*MS*
Carotenoid, mg g^{-1} Fresh weight	3	0.044**	3	0.003	9	0.008**	32	0.003

*Significant at p<0.05 **Significant at p<0.01

Effects of irrigation water and irrigation water × silicon doses interactions on leaf carotenoid contents were found to be significant at p<0.01 level, but the effects of silicon doses were not found to be significant (Table 6).

Leaf carotenoid contents significantly increased with increasing tap water ratios of the irrigation water. Leaf carotenoid content was identified as 0.146 mg g^{-1} FW in full seawater irrigations, as 0.149 mg g^{-1} FW in ½ seawater + ½ tap water irrigations, as 0.213 mg g^{-1} FW in ¼ seawater + ¾ tap water irrigations and as 0.274 mg g^{-1} FW in full tap water irrigations (Table 5).

Effects of silicon doses on leaf carotenoid contents varied with the type of irrigation water. The 0.5 mM silicon supplementation into tap water significantly increased carotenoid contents. The greatest carotenoid content (0.394 mg g^{-1} FW) was obtained from 0.5 mM dose of full tap water irrigations. Effects of silicon supplementations on carotenoid contents were not found to be significant in the other irrigation waters (Figure 2).

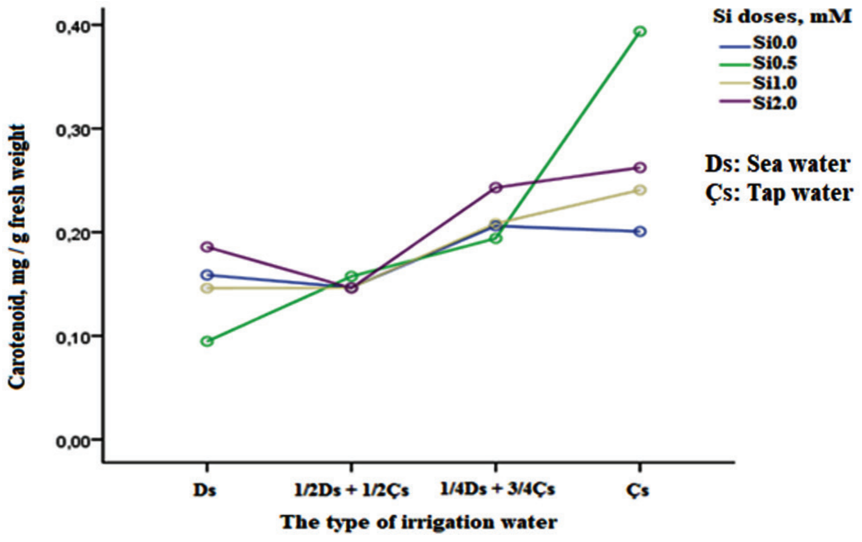

Figure 2- Effects of irrigation water and silicon doses on leaf carotenoid contents of tomato plants

It was reported that salt stress reduced quantity of photosynthetic pigments (chlorophyll and carotenoid) in light harvesting complexes (LHC) of photosynthesis systems (Parida & Das, 2005).

3.5. Correlation coefficients of the relation between leaf SPAD values, chlorophyll-a, chlorophyll-b, total chlorophyll, carotenoid contents and leaf nutrients

The correlation coefficients of the relations between leaf SPAD values, chlorophyll and carotenoid contents in the leaf and some element contents in the leaf are given in the Table 7.

Table 7- The correlation coefficients of the relations between chlorophyll and carotenoid contents in the leaf and some element contents in the leaf

Chlorophyll and carotenoid content in the leaf	*Correlation coefficients (r)*					
	Some element contents in the leaf					
	Na	*Cl*	*Ca*	*Mg*	*K*	*Active Fe*
Chlorophyll-a	-0.681**	-0.734**	0.477	-0.574*	0.602*	0.761**
Chlorophyll-b	-0.701**	-0.761**	0.469	-0.597*	0.641**	0.814
Total chlorophyll	-0.690**	-0.744**	0.476	-0.584*	0.620*	0.778
SPAD values	-0.489	-0,285				
Carotenoid	-0.595*			-0.498		0.541*

*significant at p<0.05, **significant at p<0.01

Correlations of SPAD meter readings with leaf sodium and chlorine contents were also not found to be significant (r=-0.489 and r=-0.285).

Leaf active iron contents had significant positive correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=0.761**, r=0.814** and 0.778**, respectively). In other words, chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly increased with increasing active iron contents of the leaves. On the other hand, leaf sodium contents had significant negative correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=-0.681**, r=-0.701** and r=-0.690**). In other words, chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly decreased with increasing leaf sodium contents.

Leaf magnesium contents had significant negative correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=-0.574*, r=-0.597* and r=-0.584*, respectively) indicating significantly decreasing chlorophyll-a, chlorophyll-b and total chlorophyll contents with increasing leaf magnesium contents.

Leaf chlorine contents had significant negative correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=-0.734**, r=-0.761** and r=-0.744**) also indicating significantly decreasing chlorophyll-a, chlorophyll-b and total chlorophyll contents with increasing leaf chlorine contents.

Leaf potassium contents had significant positive correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=0.602*, r=0.641** and r=0.620*, respectively). In other words, chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly increased with increasing leaf potassium contents. On the other hand, leaf calcium contents had insignificant positive correlations with chlorophyll-a, chlorophyll-b and total chlorophyll contents (r=0.477, r=0.469 and r=0.476, respectively). In other words, chlorophyll-a, chlorophyll-b and total chlorophyll contents increased with increasing leaf calcium contents. Salt stress significantly affects morphology, physiology and fruit weight of tomato. Salinity also adversely affects the shoot dry weight, leaf area, leaf chlorophyll content and also fruit weight/plant mostly at 8 dS m^{-1}. Exogenous application of Ca^{2+} significantly mitigates the adverse effects of salinity on plant biomass production or morphology, physiology and fruit production. The plant height, leaf number/plant, branch number/plant, dry weight of shoot/plant, leaf chlorophyll content, fruit weight/plant were increased with the application of calcium in saline condition compared to without calcium (Parvin & Haque 2015).

There was a significant positive correlations between leaf active iron content and carotenoid content (r=0.541*), in other words, carotenoid contents significantly increased with increasing leaf active iron content. Correlations coefficients for correlations of leaf carotenoid contents with leaf sodium and magnesium contents were respectively identified as r=-0.595* and r=-0.498.

4. Conclusion

Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly increased with increasing tap water ratios of the irrigation water. Significant increases were observed in chlorophyll-a, chlorophyll-b and total chlorophyll contents with increasing silicon doses. Such increases achieved with silicon treatments were more remarkable for chlorophyll-a and total chlorophyll contents.

Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents significantly decreased with increasing leaf sodium, chlorine and magnesium contents, but significantly increased with increasing leaf active iron and potassium contents. Leaf chlorophyll-a, chlorophyll-b and total chlorophyll contents increased with increasing leaf calcium contents, but such increases were not significant.

Leaf carotenoid contents significantly increased with increasing tap water ratios of the irrigation water. Effects of silicon doses on leaf carotenoid contents varied with the type of irrigation water. The 0.5 mM silicon supplementation into tap water significantly increased carotenoid contents.

There were significant positive correlations between leaf active iron content and carotenoid content (r=0.541*), thus, carotenoid contents significantly increased with increasing leaf active iron contents. Correlations coefficients for the correlations of leaf carotenoid contents with leaf sodium and magnesium contents were respectively identified as r=-0.595* and r=-0.498.

If seawater with high salt content is to be used for agricultural purposes, it must be diluted with tap water or it is necessary to reduce the stress effect of salinity on plant production by adding silicon to seawater.

Acknowledgments

We would like to thanks Research Assistant Dr. Güney Akınoğlu for helping on our work.

Data availability: Data are available on request due to privacy or other restrictions.

Authorship Contributions: Concept: A.K., Design: A.K., Data Collection or Processing: Y.Y., Analysis or Interpretation: Y.Y., A.K., Literature Search: Y.Y., A.K., Writing: A.K.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

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