The effects of Root Zone Temperature and Electrical Conductivity on the Lycopene, *β*-carotene, Chlorophyll Concentration and Quality of Tomato Fruit grown in Hydroponic Culture**.**

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Abstract

The effect of different levels of root zone temperature (RZT) and electrical conductivity (EC) of nutrient solution on lycopene, *β*-carotene, chlorophyll concentration and tomato quality (TSS, TA and TSS/TA ratio) of tomato plants grown under greenhouse conditions were determined. Tomato plants were irrigated with various EC (0, 1.5, 3 and 6 ds.m^{-1}) via pumps connected to 4 sets of water tanks and RZT (20, 25 and 30 ^{o}C) regulated via electrical heater in each experimental unit. All the plants were supplied with a mixture of nutrient solution containing all essential elements. Lycopene, *β*-carotene and chlorophyll concentration of fruits measured at yellow and red ripening stages, but TSS, TA and TSS/TA measured at the end of fruit harvest time. The results showed that TSS and TA contents of red ripe tomato fruits grown in high EC treatment were significantly greater than those grown in low EC treatment. Furthermore, RZT 30^{o}C had a significant effect on TSS content in comparison with RZT 25 ^{o}C, while for TA trait, a significantly greater effect was observed by RZT 25 ^{o}C than that of RZT 30^{o}C. High EC treatment enhanced lycopene concentrations of fruits at red and yellow ripening stages compared to low EC treatment. Based on the results, EC treatment showed no significant effect on *β*-carotene concentration at the yellow stage, while it started to increase in high EC of 6 ds.m^{-1} at the red stage. Besides, our results showed that RZT did not significantly affect lycopene and *β*-carotene concentrations at the two ripening stages. Chlorophyll *a* concentration in fruit decreased in high EC treatment compared with low EC (control) at both red and yellow stages. RZT had a significant impact on chlorophyll *a* at yellow but not red stage. The highest amount of chlorophyll *a* was seen in RZT 20 ^{o}C compared with RZT 30 ^{o}C with the lowest amount. Regarding chlorophyll *b*, no significant effect was observed by EC treatments at both yellow and red stages, Moreover, RZT had a significant effect on chlorophyll *b* content at yellow but not red stage, so that a significant decrease was observed in high RZT.

Keywords: Lycopene, *β*-Carotene, fruits, EC, RZT, TSS, *Solanum Lycopersicum* L.

Introduction

Tomato *(Solanum Lycopersicum* L.) can be adapted for cultivation in various environments ranging from tropical to nearly alpine regions, its production area is now expanding worldwide. On the other hand, in the traditional cultivation area, which is concentrated about the Mediterranean Sea and in the southern and western parts of the United States (USA) because of the warm and drought climate that is favorable for tomato cultivation, yield loss from salt injury has arisen as a serious problem in 19.5 % of the irrigated land area and in the irrigation water (Foolad, 2004). More specifically, tomato fruits productions are very good sources of the carotenoid lycopene, which is bioavailable and has been reported to accumulate in different organs in both laboratory animals and humans (Schmitz et al., 1993, Khachik et al., 2002). Lycopene, alongside with its metabolites, continues attracting much attention among scientists due to its capacity to scavenge radicals and the different biological functions it seems to be involved in (Mein et al., 2008). In addition, lycopene is major responsible for the color of red tomatoes and is widely used as a colorant. The color of food is a very important factor in determining its acceptability; hence, the objective measurement of this attribute in different tomatoes and tomato products has been the topic of numerous studies (Arias et al., 2000, Melendez-Martinez et al., 2010). Different environmental factors, including light, temperature, CO_2, water supply, and pathogens determine plant growth and development (Sakamoto and Suzuki, 2015a, Rivas-San Vicente and Plasencia, 2011). These factors often trigger plant's abiotic and biotic stress responses, including minor metabolites production, which plays a key role in stress resistance (Zhao et al., 2005, Akula and Ravishankar, 2011). Although greater levels of secondary metabolite production may induce environmental stress tolerance when salt stress has unfavorable effects on both plant growth and fruit magnification in tomatoes. On the other hand, it has been reported that moderate salt stress improves fruit quality by impacting the levels of soluble solids, such as total sugar and acids, as well as the pH value, these are key factors in quality valuation of fruit sold in markets, and salinity generally improves fruit quality by increasing the content of these substances. This phenomenon has been related to a "concentration effect" that results from the suppression of fruit enlargement in plants exposed to salinity. However, during the past decade, increasing evidence has indicated that alterations in assimilatory metabolism and the translocation of assimilates into the fruit are likely to be involved in the increase in soluble solids and other components (Saito and Matsukura, 2015). Salinity stress improves the fruit quality of tomatoes via increasing the level of total soluble solids, including sugars, organic acids, and amino acids in fruits (Gao et al., 1998). An increase in soluble solids enhances not only the market value of fresh fruit but also it's processing efficiency because it increases flavor and lowers water content (Stark et al., 1991) and (Yin et al., 2009). In African snake tomato, raising the root-zone heating increased the contents of phenols, ascorbic acid, and chlorophylls in the leaves (Adebooye et al., 2010). In contrast, decreasing the root-zone temperature of cucumber seedlings promoted soluble sugar production (Yan et al., 2013). Temperature stress application in root zone caused a shift in the production of some secondary metabolites in the greenhouse (Chadirin et al., 2011). The solution temperature affects the oxygen content and, in lettuce when the temperature is height, it can cause the root death and accelerates the bonding process. In this issue, it is recommended that the temperature does not exceed 20 ^{o}C (Valadares Filho et al., 2006). High EC and zone root temperature which require a flushing rate of 30% or more of the nutrient solution (Stanghellini et al., 1998). Usually, nutrient solutions used for growing tomato plants in soilless systems have a salinity level ranging from 25 mM (closed irrigation system) to 40 –75 mM (open irrigation system) total ion concentration (equivalent to an EC of 1.6 –5.0 $mS.cm^{-1}$ (Van Ieperen, 1996).

Root zone temperature and EC influence growth and quality of tomato plants under field and greenhouse conditions. Therefore, it is the purpose of the present study to investigate the effect of optimum level of EC in nutrient solution and RZT on lycopene, β-carotene, TSS, TA, TSS/TA ratio, and chlorophyll of tomato grown hydroponically under greenhouse conditions.

2- Materials and Methods

2-1 Culture of seeds and translation of seedlings

The experiment was conducted at a greenhouse in Department of Horticulture, Ferdowsi University of Mashhad. Tomato seeds (*cv*. Memory) were first sown in 2×2×2 cm sponge cubes, then covered with a thin layer of vermiculite on first January 2016 and germinated under. The nutrient solution was depended on half strength culture solution. 30 days after sowing, the seedlings were transferred to the soilless system. For conducting transactions on plants, a special system was used, in which a plastic container with the height and length of 30 and 50 cm, respectively, was prepared. Root zone temperature in the experiment was set by putting a very transparent plastic cylinder with the height and diameter of 25 and 20 cm inside the container, then the cylinder filled with water, and heater electrical aquarium was placed in water for setting root zone temperature, and finally the plastic cylinder was closed by special cover to prevent or reduce evaporation process. Thereafter, plastic container was filled with perlite and coco peat at the ratio of 50:50. Temperature transferred from water in cylinder plastic to growth medium of heat exchange 48 hours after warming water. Root zone temperature in the growth medium was measured by using a digital thermometer. It was found that temperatures in the agricultural medium were similar to the hot water in the plastic cylinder. Root zone temperature was set at three levels of 20, 25 and 30 ^{o}C, and the distance between plants was 25 cm.

2-2 Measurement

The air temperature inside the greenhouse was set using warm water located within the plant growth zone in the greenhouse. Data related to solar radiation and humidity outside the greenhouse were obtained from weather institutions of Mashhad. Within the greenhouse, there were four blocks, each includes 12 experiments. Electrical conductivity and root zone temperature treatments were randomly distributed within each block. Average day and night temperatures inside the greenhouse during the experiment were 23.0 ± 4 and 20 ± 4.5 ^{o}C, respectively. Fig 1 shows the average monthly rate for temperature, humidity and solar radiation of outside the greenhouse. The EC, pH, and volume of the inflow nutrient solution were recorded daily using a handheld EC and pH meter. (EC meter tester EC-963 LED digital hydroponics and digital pen type PH meter PH-009). The EC, pH, and volume of the influx nutrient solution were recorded weekly. The pH of the solutions was adjusted to 5.5 – 6. During the experiment, care was taken to monitor and control the greenhouse in terms of pests and diseases.

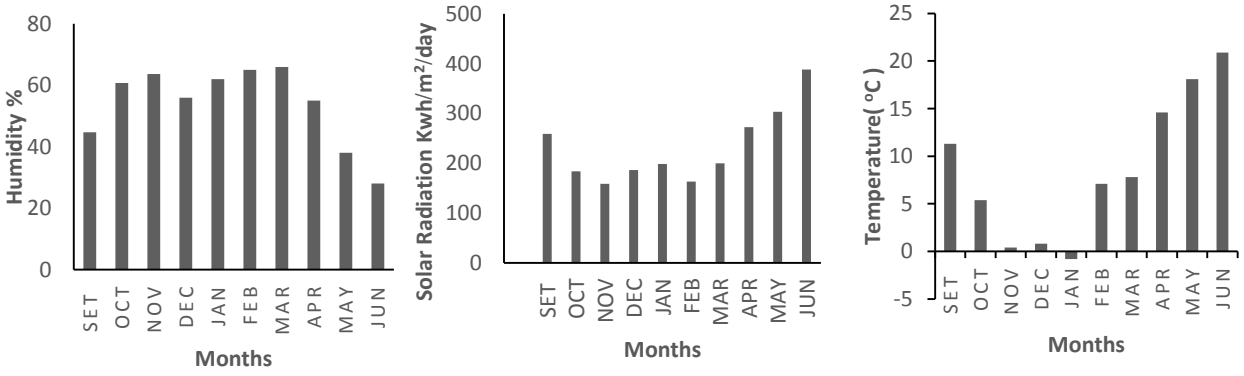


Fig.1. Monthly rates for temperature, humidity and solar radiation of outside.

2-2-1 Nutrient solution

Nutrient solution composition for tomatoes grown in stirred solution culture for 24 weeks was based on full strength modified Hoagland's nutrient solution with H_2KO_4P =130, KNO_3 500, Ca $(NO_3)_2$ 1180, Mn So_4 490 mg L^{-1}, Iron Chelate 25 cc and micronutrients stock 4 cc. EC was applied at four levels (0 (distilled water only), 1.5, 3 and 6 $ds.m^{-1}$) after setting pH at 5.5 - 6 by acid or base.

2-2-2 The total soluble solid (TSS). The total soluble solids content was measured using a portable refractometer.

2-2-3 Determination of titratable acidity (TA): Titratable acidity was determined by using titration with 0,1 mg sodium hydroxide solution (NaOH), using phenolphthalein as the indicator, according to the AOAC official method (Association, 1998).

2-2-4 Determination of lycopene, *β*- carotene, chlorophyll *a* and *b* in tomato fruits: Extraction was performed with acetone-hexane (4:6) and determined according to the method described by (Nagata and Yamashita, 1992) and (Silva et al., 2013). Tomato samples were first harvested at two different ripening stages (yellow and red) and then one gram of each sample mixed with 10-20-ml Acetone-Hexane (4:6) in the tube and homogenized. Finally, absorbance was read using a spectrophotometer at A_{663}, A_{645}, A_{505}, A_{453}, and the content of mentioned parameters was determined by using the following equations:

1- *β*- carotene = 0.216 A_{663}-1.22 A_{645}-0.304 A_{505} +0.452 A_{453}
2- Lycopene mg/100 ml = -0.0458 A_{663} + 0.204 A_{645} + 0.372 A_{505} – 0.0806 A_{453}
3- Chlorophyll *b* mg/100 ml = -0.328 A_{663} +1.77A_{645}
4- Chlorophyll *a* mg/100 ml = 0.999 A_{663} – 0.0989 A_{645}

(A_{663}, A_{645}, A_{505}, and A_{453} are absorbance at 663 nm,645 nm, 505 nm and 453 nm, respectively)

Statistical Analysis and Experimental Design

The data obtained for each parameter was analyzed using statistical JMP 8 software, and the related graphs were drawn by using Microsoft® Excel. One-way analysis of variance (ANOVA) was used for determining the difference between treatments and means comparison was performed using the least significant difference (LSD) at the probability level of 5%. The experiment was performed as split-plot design in a Completely Randomized Design (RCD) with four replications and two factors. The first factor was three Root Zone Temperatures (RZT) (20, 25 as control (Haghighi et al., 2015) and 30°C) and the second factor was four levels of Electrical Conductivity (EC) in nutrition solution (0 using (Distilled water only),1.5, 3 and 6 $ds.m^{-1}$).

3- Results and Discussion

3-1 Total soluble solids concentration in juice

Table (2) shows that juice TSS was affected by electrical conductivity and root zone temperature treatments. High EC treatment increased TSS of fruits so that TSS under high EC treatment was 3.74 ^{0}Brix compared to TSS 3.14 ^{0}Brix in control treatment. TSS content at EC 6 $ds.m^{-1}$ was significantly higher than that of control treatment. A similar effect of high EC on TSS was reported by (Sakamoto et al., 1999, Wu and Kubota, 2008) and (Cornish, 1992). These results that increasing the salinity after the beginning of fruit development increased the concentration of soluble solids TSS in tomato plants, the amendment in quality. Similar to the result (Sakamoto et al., 1999). Furthermore, based on (Table 3), root zone temperature had a significant effect on TSS, where TSS 3.66 ^{0}Brix was obtained in RZT 30 °C compared to TSS 3.17 ^{0}Brix in RZT 25 °C ,similar results were observed by (Husain et al., 2015) who found quality of tomato had no significant

at root zone temperature 25°C. Data in (Fig 2) showed that interaction between root zone temperature and electrical conductivity caused significant differences in TSS contents. Treatment of the interaction between EC 1.5 ds.m^{-1} and root zone temperature 20 °C showed the highest TSS content (4.15 ^{0}Brix) in comparison with the combination of 0 ds.m^{-1} and root zone temperature 25 °C.

Table 1. Analysis variance of different EC and root zone temperature application on tomato

S.O.V	df	TSS	TA	TSS/TA	Lycopene at red stage	Lycopene at yellow stage	*β*-carotene at the red stage	*β*-carotene at yellow stage	Chl *a* at the red stage	Chl *a* at yellow stage	Chl *b* at red stage	Chl *b* at yellow stage
EC	3	0.72*	31.71*	0.257*	0.198*	0.009*	0.00112*	0.0084 ns	0.00021 ns	0.00001 ns	0.00019 ns	0.0000 ns
RZT	2	1.00*	8.73*	0.210*	0.005 ns	0.000 ns	0.0000 ns	0.0161 ns	0.00000 ns	0.00009 ns	0.00000 ns	0.0008 *
EC×RZT	6	1.43*	17.28*	0.252*	0.012*	0.001*	0.00012*	0.0185*	0.00008 ns	0.00016 ns	0.00006 ns	0.0005 *
Error	36	0.09	3.45	0.043	0.020	0.002	0.00009	0.0177	0.00022	0.00040	0.00022	0.0003

ns not significant *significant at 5%

3-2 Titratable acidity (TA) and TSS/TA

The increase in EC level from 0 to 6 ds.m^{-1} increased the average of titratable acidity from 4.48 to 8.37 m.e/100 mL, respectively. As seen in (Table 2), titratable acidity at 6 ds.m^{-1} was significantly (*P* 0.05) higher than at 0 ds.m^{-1} and 1.5 ds.m^{-1} treatments. Based on the results, root zone temperature resulted in a significant increase in titratable acidity. On average, titratable acidity in root zone temperature 25 °C was 7.46 m.e/100 mL, whereas the rate in root zone temperature 30 °C was 5.48 m.e/100 mL. Data in (Fig 3) showed that titratable acidity was affected significantly by the interaction between different EC and root zone temperature levels. The highest amount of titratable acidity was obtained in combination of EC 1.5 ds.m^{-1} and root zone temperature 25 °C with 10.30 m.e/100 mL, while the lowest rate of 3.83 m.e/100 mL was obtained in the treatment containing 0 ds.m^{-1} and root zone temperature 30 °C. Regarding the ratio of TSS to titratable acidity, there were significant differences among different treatments of EC and root zone temperature. The results showed that TSS to titratable acidity ratio increased in root zone temperature 20 and 30 °C compared with root zone temperature 25 °C. Moreover, TSS/ TA ratio decreased in higher levels of EC especially 6 ds.m^{-1}. Results also showed that interaction effects of EC and root zone temperature on TSS to titratable acidity ratio were significant (Fig 4). The results of the present experiment confirm that a substantial increase in TSS can be obtained under salt stress, so that increase in EC from 0 to 6 ds.m^{-1} resulted in a significant increase in TSS. The response to salinity showed that different salt levels appeared to be equally effective in rising of TSS, suggesting that it is the osmotic effect on plant water relations that underlies the response, rather than specific ionic effect. It has been shown that tomato reacted to salt stress by accumulating organic solutes in leaves in order to osmotically balance the increased concentration of inorganic ions in the growing medium (Rush and Epstein, 1976). Titratable acidity also increased in high levels of EC. This increase has a beneficial effect on flavour, which depends on both TSS and the ratio of TSS to titratable acidity (Hobson and Bedford, 1989). Root zone temperature causes an imbalance in plant metabolism and disruption to cellular homeostasis, resulting in deleterious damage to plant cells (Suzuki et al., 2005). Heat stress to the roots also causes a significant change in plant physiological processes such as water uptake and leaf conductance (Kowalski et al., 2008). In this study, root zone temperature treatments induced TSS, TA and TSS/TA ratio. It has been shown that root zone temperatures of 25 and 30°C led to the gradual deterioration of tomato plants grown hydroponically.

Table 2. The main effect of different EC on (TSS, TA and TSS/TA ratio) of tomato plants

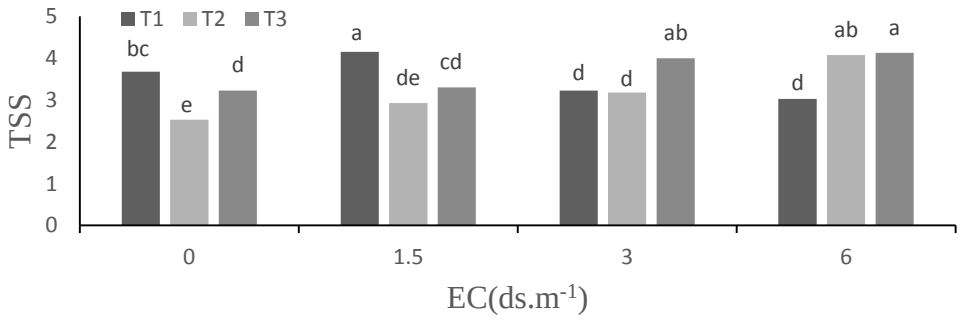
EC ($ds.m^{-1}$)	TSS (^{0} Brix)	TA (m.e/100 mL)	TSS/ TA
Control (Distilled water)	3.14 c	4.48 c	0.726 a
1.5	3.45 b	6.78 b	0.629 ab
3	3.46 b	7.15 ab	0.493 bc
6	3.74 a	8.37 a	0.467 c

Within a column means followed by the same letter are not significantly different at P < 5% according to least significant different test.

Table 3. The main effect of different root zone temperature on (TSS, TA and TSS/TA ratio) of tomato plants.

RZT (^{o}C)	TSS (^{0} Brix)	TA (m.e/100 mL)	TSS/ TA
20	3.51 a	6.64 ab	0.65 a
25	3.17 b	7.46 a	0.45 b
30	3.66 a	5.48 b	0.64 a

Within a column means followed by the same letter are not significantly different at P < 5% according to least significant different test. Low temperature (20°C), optimum temperature (25°C) and high-temperature stress (30°C).



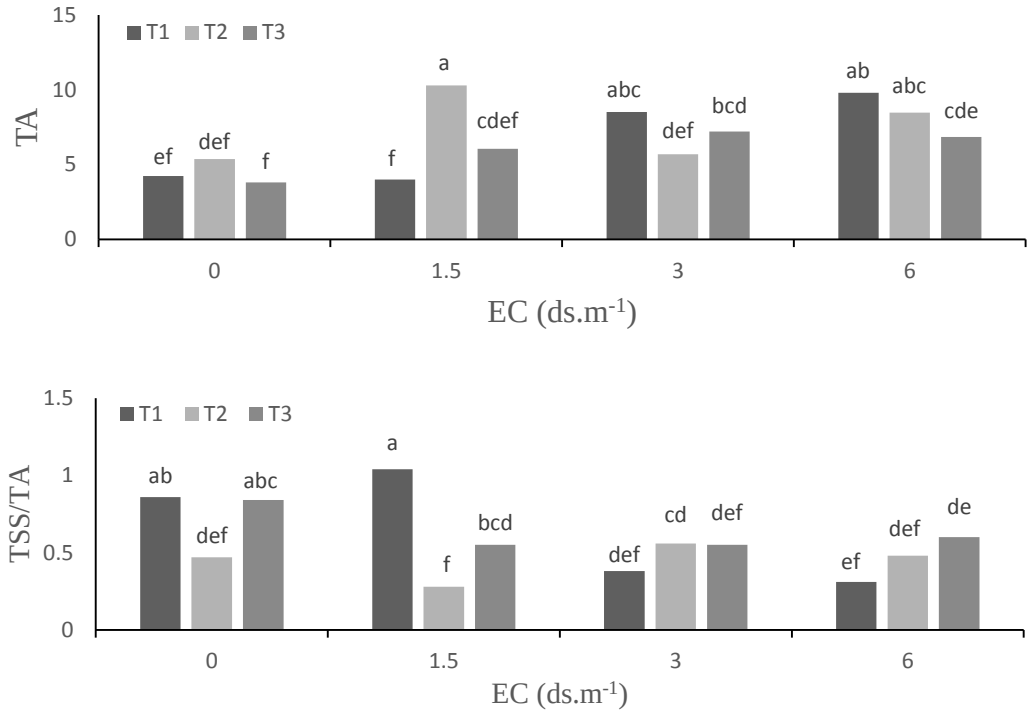


Fig 2,3 and 4 respectively. The interaction effect of root zone temperature and different levels of electrical conductivity on **(TSS, TA and TSS/TA ratio).** Low temperature (T1 = 20°C), optimum temperature (T2 = 25°C), and high temperature stress (T3 = 30°C).

3-3 Lycopene and *β* - carotene concentration

As (Table 4) shows lycopene concentration at the yellow stage was significantly affected by different levels of EC, so that EC 6 ds.m^{-1} increased the lycopene concentration of fruit in comparison with control (0 ds.m^{-1}). Results in (Table 4) showed that EC treatment did not have a significant impact on *β* – carotene concentration of tomato fruits at the yellow stage. However, its content was higher than lycopene concentration at this stage. Moreover, based on the results in (Table 5), the lycopene concentration recorded in high EC treatment at the red stage was 0.644 mg/100 ml, increase compared to low EC treatment with lycopene content of 0.347 mg/100 ml. *β*- carotene was significantly influenced at the red stage (Table 5). Results also that interaction effects of EC and root zone temperature on *β*- carotene was significantly at stage yellow affected at (EC 3 ds.m^{-1} with RZT 30 ºC) when compared with (EC 0 (Control) with (RZT) 20 ºC), (Fig 5). Moreover, as the results in a (Fig 6 and 7) showed, lycopene concentrations in fruit at red and yellow stages were affected by (EC 6 ds.m^{-1} with RZT 30 ºC), which showed the highest values in comparison with (EC 0 (Control) with (RZT) 20 ºC) which had the lowest values. Similarly, lycopene concentration in tomatoes was reportedly increased by applying high EC in nutrient solution (Pascale et al., 2001). In addition, the darker red color was found in tomatoes grown at 60 mM NaCl than that of control (0 mM NaCl) (Fanasca et al., 2007). It was also found that lycopene concentration of tomato fruits grown under 8 ds.m^{-1} increased by 25% compared to those grown under 2.5 ds.m^{-1}, lycopene concentration of the fruit showed a faster increase in high EC treatment than in low EC treatment. It is reported that the enhancement of pigments affected by stress-induced upregulation of the genes encoding can be due to the increase in the enzymes interested in the key steps of lycopene biosynthesis (Krauss et al., 2006). In the present study, rising salinity levels (0,1.5,3 and 6 ds.m^{-1}) increased lycopene and ß-carotene contents in tomato, which is in agreement with the results reported by (Krauss et al., 2006). Based on the results (Tale 5), *β*- carotene concentration of the fruit increased in high EC level of 6 ds.m^{-1} when compared with low EC level of 0 ds.m^{-1} (Control). Our results showed that root zone temperature did not have a significant effect on lycopene and *β*-carotene concentrations at the two ripening stages of tomato fruits. In agreement with the

present experiment (Sakamoto and Suzuki, 2015b) showed that content of *β*-carotene was not affected by root zone temperature. Regarding of the interaction effect of EC and RZT, the results in (Fig 6 and 7) showed that interaction between electrical conductivity and root zone temperature caused an increase in lycopene concentration at red and yellow stages, the greatest concentration of lycopene at red and yellow stages were observed in (Electrical conductivity 6 $ds.m^{-1}$ and root zone temperature 30°C), while the lowest amount was seen in (Electrical conductivity 0 $ds.m^{-1}$ with root zone temperature 20°C). The results also showed that combination of electrical conductivity level of 6 $ds.m^{-1}$ and root zone temperature 30°C, increased concentration *β*-carotene at red stage, while the combination of electrical conductivity of (0 $ds.m^{-1}$ with root zone temperature 20°C) had the lowest concentration *β*- carotene (Fig 5 and 8). As seen in (Fig 5), the highest *β*-carotene concentration at the yellow stage was observed in (root zone temperature 30°C with electrical conductivity 3 $ds.m^{-1}$.

Table 4. The main effect of different EC on (Lycopene, *β*- Carotene, Chlorophyll *a* and Chlorophyll *b*) of tomato at the yellow stage.

EC ($ds.m^{-1}$)	Lycopene (mg/100ml)	*β*- Carotene (mg/100ml)	Chlorophyll *a* (mg/100ml)	Chlorophyll *b* (mg/100ml)
Control**(**Distilled water)	0.0302 b	0.0655 a	0.0215 a	0.0260 a
1.5	0.0865 a	0.0909 a	0.0201 a	0.0244 a
3	0.0819 a	0.1301 a	0.0194 a	0.0211 a
6	0.0909 a	0.0948 a	0.0193 b	0.0217 a

Within a column means followed by the same letter are not significantly different at $P < 5\%$ according to least significant different test.

Table 5. The main effect of different EC on (Lycopene, *β*- Carotene, Chlorophyll *a* and Chlorophyll *b*) of tomato at stage red.

EC ($ds.m^{-1}$)	Lycopene (mg/100ml)	*β*-Carotene (mg/100ml)	Chlorophyll *a* (mg/100ml)	Chlorophyll *b* (mg/100ml)
Control**(**Distilled water)	0.347 b	0.0217 c	0.0125 a	0.0135 a
1.5	0.562 a	0.0355 b	0.0106 a	0.0106 a
3	0.577 a	0.0393 ab	0.0067 a	0.0078 a
6	0.644 a	0.0443 a	0.0030 b	0.0040 a

Within a column means followed by the same letter are not significantly different at $P < 5\%$ according to least significant different test.

Table 6. The main effect of different temperature of root zone on (Lycopene, *β*- Carotene, Chlorophyll *a* and Chlorophyll *b*) of tomato at stage red.

RZT (°C)	Lycopene (mg/100ml)	*β*- Carotene (mg/100ml)	Chlorophyll *a* (mg/100ml)	Chlorophyll *b* (mg/100ml)
20	0.510 a	0.0326 a	0.0090 a	0.0089 a
25	0.542 a	0.0350 a	0.0075 a	0.0093 a
30	0.545 a	0.0380 a	0.0082 a	0.0088 a

Within a column means followed by the same letter are not significantly different at $P < 5\%$ according to least significant different test. Low temperature (20°C), optimum temperature (25°C) and high-temperature stress (30°C).

Table 7. The main effect of different temperature of root zone on (Lycopene, *β*- Carotene, Chlorophyll *a* and Chlorophyll *b*) of tomato at the yellow stage.

RZT (°C)	Lycopene (mg/100ml)	*β*- Carotene (mg/100ml)	Chlorophyll *a* (mg/100ml)	Chlorophyll *b* (mg/100ml)
20	0.0666 a	0.0719 a	0.0264 a	0.0298 a
25	0.0738 a	0.0826 a	0.0206 a	0.0244 ab
30	0.0766 a	0.1315 a	0.0132 b	0.0157 b

Within a column means followed by the same letter are not significantly different at $P < 5\%$ according to least significant different test. Low temperature (20°C), optimum temperature (25°C) and high-temperature stress (30°C).

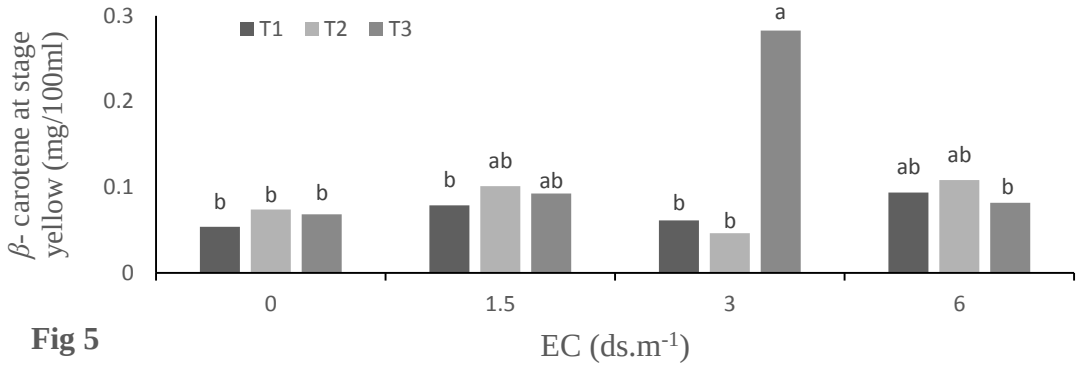


Fig 5

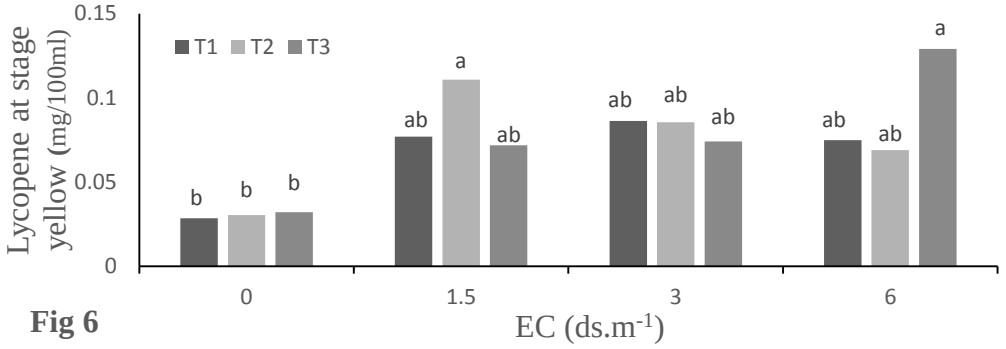


Fig 6

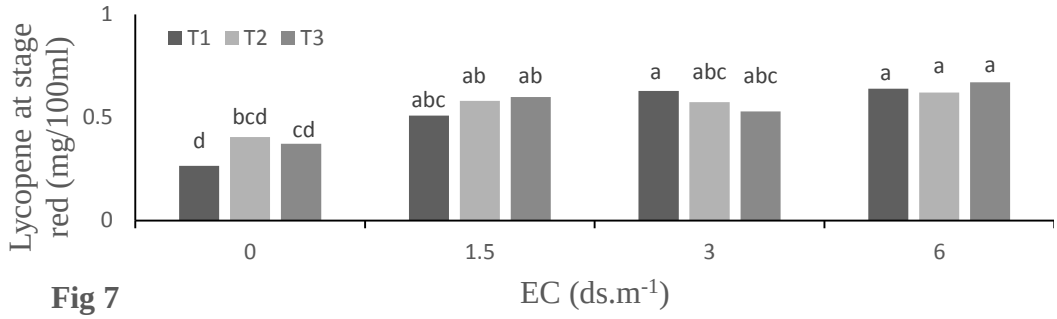


Fig 7

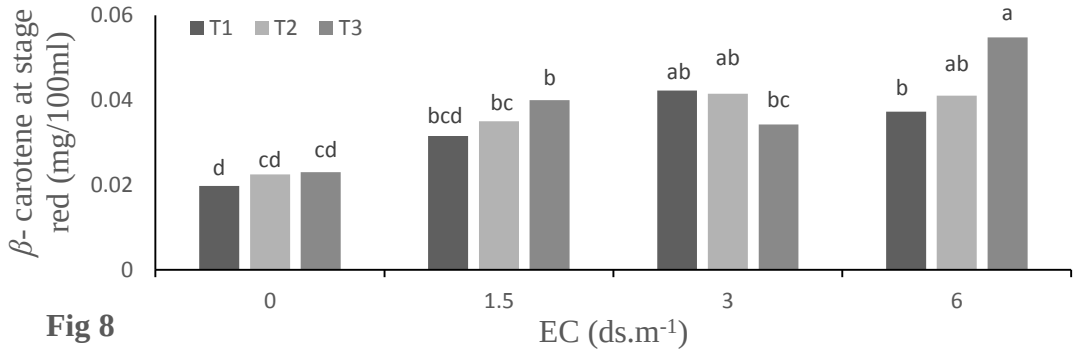


Fig 8

Fig.5,6,7 and 8 respectively. The interaction effect of root zone temperature and different levels of electrical conductivity on ***β*- carotene and lycopene at the yellow and red stage.** Low temperature (T1 = 20°C), optimum temperature (T2 = 25°C), and high temperature stress (T3 = 30°C).

3-4 Chlorophyll *a* and *b* concentrations

Results in (Tables 4 and 5) showed that chlorophyll *a* in fruit at the red stage was significantly affected by EC treatments. The concentration of chlorophyll *a* in fruit started to decrease as EC levels increased, where chlorophyll *a* content at red and yellow stages reduced from 0.0030 and 0.0193 mg/100 ml in high EC level to 0.0125 and 0.0215 mg/100 ml in control (EC 0), respectively. Similar results were observed by (Sakamoto et al., 1999) who found salinity increased the concentration of chlorophyll *a* and chlorophyll *b* in the fruit, several studies have reported similar results (Ehret and Ho, 1986) the efficiency of the salt stress depends on the fruit development stage at which it is applied salt stress at a previously stage of fruit development would have more obvious effects on fruit development. But chlorophyll *b* contents in fruit at yellow and red stages, as shown in (Table 4 and 5), were not significantly influenced by EC treatments. Chlorophyll was shown to degrade during the transformation of fully differentiated chloroplasts into chromoplasts by electron micrographic analysis (Thelander et al., 1986). There were no significant effects of EC on fruit chlorophyll content in all developmental stages. Chlorophyll concentration of the fruit showed reduction along with the increase in EC

level (Tables 4 and 5). In addition, (Table 7) showed that root zone temperature affected significantly chlorophyll *a* at the yellow stage; however, the level of effect at the yellow stage was more pronounced in root zone temperature 20°C with the highest content of 0.0264 mg/100 ml compared with root zone temperature 30°C with the lowest concentration of 0.0132 mg/100 ml. Regarding the effect of root zone temperature on chlorophyll *b* concentration, significant differences were observed between the different levels of root zone temperature at yellow but not the red stage. The highest chlorophyll *b* concentration was due to root zone temperature 20 °C led to with 0.0298 mg/100 mL, while the lowest content was obtained in high root zone temperature 30 °C with 0.0157mg/100 ml. It has been reported that in soilless, root zone temperature can be controlled by warming culture media (substrates) and thus providing the heat energy requirements for optimum plant growth and development, thus chlorophyll content in fruits affected significantly by root zone temperature. The result shows in chlorophyll *a* concentration at red and yellow stage showed not affected by the interaction between root zone temperature and electrical conductivity of the nutrient solution. On the contrary, chlorophyll *a* and *b* concentrations at the red stage were not significantly affected, but chlorophyll *b* concentration at yellow stage showed higher values under (EC 0 $ds.m^{-1}$ with RZT 20 °C) in comparison with (EC 0 with RZT 30 °C).

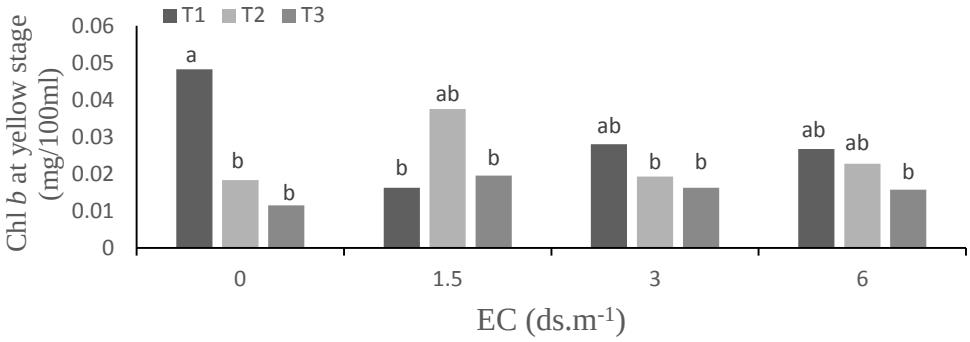


Fig 9. The interaction effect of root zone temperature and different levels of electrical conductivity on **Chl *b* at yellow**. Low temperature (T1 = 20°C), optimum temperature (T2 = 25°C), and high temperature stress (T3 = 30°C).

Conclusions

In the present study, we showed that optimum and high root zone temperature had increased TSS and TA, while root zone temperature not significant on lycopene, *β*-carotene, Chl *a* and Chl *b* at the red stage but Chl *a* and Chl *b* decreased under low root zone temperature at the yellow stage. High EC improved TSS, TA, lycopene at two stages and *β*-carotene only at the yellow stage, while Chl *a* and TSS/TA ratio decreased under the effect of electrical conductivity.

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