Effects of Salinity on Color Changes, Sugar and Acid Concentration in Tomato Fruit

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Summary

Tomato (*Lycopersicon esculentum,* Mill) is vegetable which is relatively resistant to salt concentration in growing substrate. However, research has shown that salinity stress causes changes in the quality of the fruit, which indirectly affects the yield. So the aim of this research was to determine the change in color of ripening fruits, the amount of sugar and acid in the fruit as indicators of the quality of the fruit. Tests were conducted in a greenhouse on tomato cv. Buran F1, where were two varieties of seedlings, grafted and non grafted, grown in the control substrate (EC = 1.7 dS/m) and substrate with EC = 6.8 dS/m. The quality of fruit is observed by a difference in the maturing of the first fruit of the first and second branches of tomatoes, and through the concentration of sugar and acid in the fruit, depending on the position of the plants. The obtained results show that salinity induces higher sugar content and total acidity in grafted and non-grafted tomato fruits. Also salinity leads to faster ripening of grafted and non-grafted tomato.

Key words

tomato, salinity, grafted, nongrafted

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Introduction

Tomato (*Lycopersicon esculentum*, Mill.) is one of the most important vegetable in the world. Also, it is the second most commonly consumed vegetable in the Europe. Fresh tomato and tomato products are good sources of vitamins, carotenoids, and phenolic compounds, which can be beneficial for the prevention of oxidative stress and degenerative disorders. Tomato fruit quality for fresh consumption is determined by appearance (colour, size, shape, freedom from physiological disorders and decay), firmness, texture, dry matter, and organoleptic (flavor) and nutraceutic (health benefit) properties. The organoleptic quality of tomato is mainly attributed to its aroma volatiles, sugar and acid content, while its mineral, vitamin, carotenoid and flavonoid content define the nutraceutical quality. Sugar, acids and their interactions are important to sweetness, sourness and flavor (Stevens et al., 1977). About 50% of tomato fruit dry matter are sugars (glucose 22%, fructose 25% and sucrose 1%) and 13% organic acids (citric 9% and malic 4%; Davies and Hobson, 1981).

Greenhouse horticulture has been developed to protect crops from unfavorable environmental conditions. The result of the management of microclimate conditions throughout the year, according to the biological requirements of cultivated plants, is a significant increase in yield per plant (Kastori et al, 2013). In greenhouse cultivation, due to intensive supplemental feeding and lack of natural leaching of land often leads to the occurrence of a salt stress, especially at high temperatures and high water consumption by transpiration of plants (Tais and Zeiger, 2010). Irrigation combined with poor drainage is a major source of salinization of agricultural land (Zhu, 2007; Kotuby-Amacher et al 2000; Munns et al, 2002).

The high concentration of Na + in the soil solution may modify the ratio of Na^+ / Ca^{2+} or Na^+ / K^+ (Grattana and Grieveb, 1999). Increase of cations and their salts, in particular NaCl, leads to an increase in the osmotic potential that can precisely cut off or reduce the ingress of water to the root (Bohnert, 2007).

Intensive fertilization and irrigation with well water (which has a higher EC-electric conductivity) in addition to the salt stress represents the ecological loads. A plant damaged by high salinity may suffer reduced shoot and root growth, yield loses and eventual death. These changes in plant growth are the result of salt's detrimental effects on plant physiology, which include ion toxicity, osmotic stress, nutrient deficiency and oxidative stress (Xiong and Zhy, 2002). Plant's behavioral response to salinity is complex, and different mechanisms are adopted by plants when they encounter salinity.

One of the ways to overcome the problem of soil salinization is a complete replacement of soil substrate to a depth of penetration of the root system. Since this measure is very rare and extremely expensive, grafting tomatoes is becoming more essential agro-technical measure.

Therefore, the aim of this study was to assess the quality of 'Buran F1' hybrid tomato cultivated in two variants (grafted on Maxifort and nongrafted seedlings at two levels of salinity (EC = 1.7 dS/m i EC= 6.8 dS/m).

Materials and methods

Sampling of tomato

Research was conducted in the greenhouse on tomato cv. Buran F1. Variants on which were monitored and tested fruits of cv. Buran F1 were grafted seedlings on Maxifort and non-grafted seedlings at two levels of salinity EC = 1.7 dS/m and EC= 6.8 dS/m. The fruits were carefully picked in full physiological ripeness from the first and second bearing branch. The changes in fruit skin color and the time of ripening were monitored until harvest.

After sampling the fruit was mashed in shortest possible time and placed in a freezer at a temperature of -4°C.

Colorimetric analysis

Changes in the color of epidermis were observed at intervals of four days, with the device Chroma meter CR -400 / 410 from the moment of the first change of color to full maturity, taken into consideration on how to examine always the same point on the fruit. Color cards of changes in ripening were obtained by entering the colorimetric values of a *, b * and L * in Lab tool of Corel Draw x8. The values of a *, b * and L * were converted into the nearest value of the standard colors.

Refractometric analysis

Sugars were measured on defrosted samples with Digital refractometer PR-32 alpha. Before measuring refractometer was calibrated to 0 using distilled water. Each sample of mashed tomatoes was taken with a plastic pipette and transferred to the device.

Total Titratable Acidity (TTA)

Homogenized sample of tissue of the fruit mass of 37.5 g was diluted with 120 ml of distilled water.

For extraction of the acid sample was heated in a water bath at temperature of 80°C for 30 minutes. Taken out sample was left to cool, in a dark place for 20 to 30 minutes. Then, distilled water to a total volume of 250 ml was added to the sample. The filtering was performed using a vacuum pump.

The pH meter was calibrated with pH 7 buffer solution and the pH of the fourth calibration point was confirmed before the start of titration

A solution of 0.1 M NaOH was added dropwise. After each addition filtrate was stirred with a magnetic stirrer and was read until the pH value was 8.1. The values of the spent 0.1 M NaOH in ml was introduced into the chemical formula for the calculation of the citric acid in the fruit of tomatoes. For one fruit titration was repeated three times to exclude inaccuracy in the measurement.

Results and discussion

The ratio of acids and sugars determines the taste of tomato fruit. High sugar concentrations together with relatively high acids are required for best flavor; low sugars and high acids produce a tart tomato, high sugars and low acids a bland taste and both low sugars and acids results in a tasteless fruit (Grierson and Kader, 1986). For the south eastern and central part of Europe it is typical to eat tomato hybrids that have a lower sugar content and taste (Mišković, 2008).

Salinity stress improves the fruit quality of tomato by increasing the level of total soluble solids, including sugars, organic acids, and amino acids in fruits (Adams, 1991; Ullah, 1994; Petersen, 1998; Gao et al., 1998; Krauss et al., 2006). Grafting was found to improve the salt tolerance of tomato (Santa-Cruz et al. 2002; Estan et al., 2005). Grafting can raise the salt tolerance of tomato by limiting transport of sodium and chloride to the shoot (Santa-Cruz et al., 2002; Estan et al., 2005).

In relation to salt tolerance, many studies have been carried out to determine the response of grafted plants to salinity (Fernández-García et al., 2002; Santa-Cruz et al., 2002; Estaan et al., 2005; Colla et al., 2005, 2006; Goreta et al., 2008; Martinez-Rodriguez et al., 2008; He et al., 2009; Huang et al., 2009a,b; Edelstein et al., 2011; Abd El-Wanis et al., 2012). For instance, grafting reduced the concentrations of Na^+ and Cl^- in the xylem (Fernández-García et al., 2002), as well as accumulation in leaves of tomato plants (Santa-Cruz et al., 2002). However, the effect induced by the rootstock may vary with the degree of stress and duration of salt treatment (Estan et al., 2005). Salama et al. (2016) working on response of cucumber grafted onto three different wild rootstocks noticed that all vegetative characters under salt stress significantly increased up to EC= 4.2 dS/m

Total Titratable Acidity (TTA)

In tomato fruit are various acids: acetic, oxalic, tartaric, lactic, malic and citric. These acids affect the taste of the fruit and depending on their part in the dry matter of the fruit we have more or less acidic fruit tomato.

Tomato fruits grown under salt stress show higher organic acid content and higher titratable acidity than fruits grown with fresh water (Mitchell et al., 1991). Increased acidity of salt-stressed vegetable crops has been reported for tomato (Feigin et al., 1987; Martinez and Cerdá, 1989), cucumber (Martinez and Cerdá, 1989), eggplant (Savvas and Lenz, 1996), and melon (Feigin et al., 1987), and it has been associated with an increase in the level of organic acids. Camposet al. (2006) in their experiment also noticed that titratable acidity increased linearly with increasing water salinity.

In our experiment the effects of salinity treatments and grafting on total soluble solids (TSS) are summarized in Fig. 1. General Linear Model of the studied characteristics in Buran F1 hybrid tomatoes indicated significant influence of grafting and salinity interaction ($F=4.964$, $p=0.035$) on TTA. Further analysis with Bonferroni adjustment for multiple comparisons indicated statistically highly significantly ($p<0.01$) higher TTA in non-grafted plants on 6.8 [dS m-1] in comparison to all other groups. Other studied factors and interactions did not have statistically significant influence (Tab. 1)

Total sugar content

Sugar concentrations of tomato fruit can generally be increased by salt stress to plant root zones before harvest (Adams and Ho, 1992; Ehret and Ho, 1986; Saito et al., 2006). Our results show that General Linear Model indicated statistically highly significant difference in the influence of the tested salinity levels on sugar content ($F=10.778$, $p=0.003$). Namely, tomatoes grown on EC=6.8 [dS m-1] salinity had significantly higher sugar content (1.62±0.49) in comparison to control plants grown on 1.7 [dS m-1]. Other studied factors and interactions did not have statistically significant influence (Tab. 2)

Table 1. Average titratable acidity content in grafted and non-grafted tomato fruit in two different salt level concentration on first two branches

	EC=1.7 dS/m		EC=6.8 dS/m	
	$\bar{x}$	Sx	$\bar{x}$	Sx
Non-grafted Buran F1				
Branch 1	0.259	±0.013	0.385	±0.104
Branch 2	0.223	±0.092	0.469	±0.229
Grafted Buran F1				
Branch 1	0.263	±0.052	0.283	±0.029
Branch 2	0.268	±0.023	0.293	±0.044

Table 2. Average sugar content in grafted and non-grafted tomato fruit in two different salt level concentrations on first two branches

	EC=1.7 dS/m		EC=6.8 dS/m	
	$\bar{x}$	Sx	$\bar{x}$	Sx
Non-grafted Buran F1				
Branch 1	4.775	±0.964	6.675	±1.917
Branch 2	4.775	±0.465	7.15	±2.938
Grafted Buran F1				
Branch 1	5.4	±0.606	6.125	±0.618
Branch 2	5.075	±0.562	6.55	±1.021

As shown in Tab. 2, salinity stress strikingly enhanced soluble sugar accumulation in grafted and non-grafted tomato fruit.

In spite of more sucrolytic activity in salt-stressed than in non-salt-stressed fruits higher sucrose content has been measured in salt-stressed fruits (Balibrea et al., 1996). It is possible that although sucrose is partially hydrolyzed by cell wall acid invertase (Iki et al., 1978) it may enter the cell and sugar accumulation in tomato fruit is driven by subsequent intracellular metabolism (Damon et al., 1988). The increase in sucrose content could then be caused by inactivation of cell wall invertase due to pH changes in apoplast (Pressey, 1994) or to Na^+ accumulation in the cell wall. This may help to explain the enhanced activities in salt-treated fruits of neutral invertase and sucrose synthase that would become the regulatory sucrose cleavage enzymes in salinised fruits (Balibrea et al., 1996).

Increases in sugar and total soluble solids in tomato fruits subjected to salt or water stress are due to decreased water uptake (Bolarin et al., 2001; Chretien et al., 2000; Ehret and Ho, 1986; Li et al., 2001). Because of the tradeoff between increased sugar concentration and fruit size, however, final yields per plant are markedly reduced. Saito et al. (2006) and Sakamoto et al. (1999) have also reported that addition of sodium chloride (NaCl) to nutrient solutions increases tomato fruit sugar concentrations, but tends to decrease fruit yield.

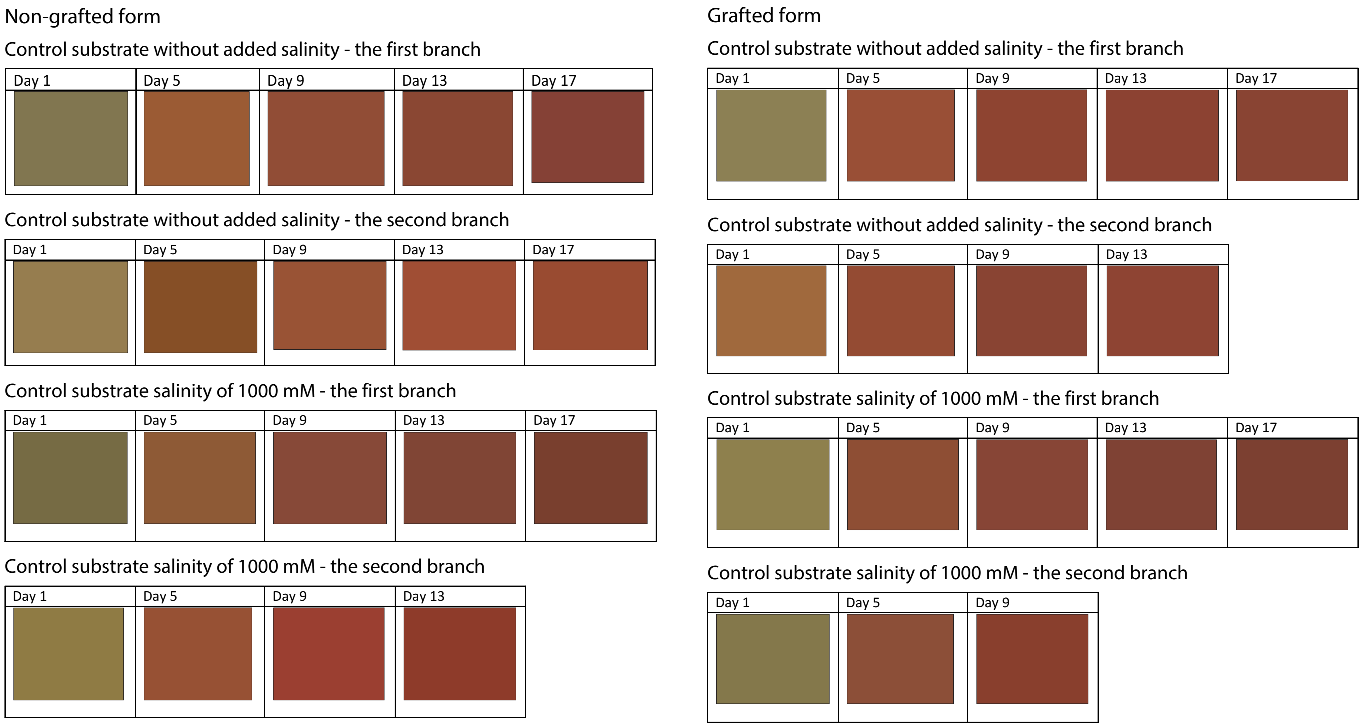

Figure 1. The effects of salinity treatments and grafting on total soluble solids (TSS)

Very high ECs (12 dS/m) reduced the fruit content in sugars and acids (Adams, 1990) and thus, fruit flavour. Flores et al. (2003) found that supplying 60 mM of NaCl significantly increased the concentrations of fructose and glucose in tomato fruit.

Growers often use the °Brix value to indicate sugar contents in tomato fruit. However, °Brix is not solely a reflection of sugars: it also reflects other soluble solids in the fruit, including organic acids. Therefore, using °Brix as a representation of the total sugar content can be misleading (Manolopoulou et al., 2015).

The color change after days of ripening

NaCl treatment applied to the whole plants shortened the time between full anthesis and the initiation of the ripening process by 4 to 15%. Fruits that developed on the saline-treated plants tasted better than did fruits of the control plants. This was true for vine-ripened fruits as well as for fruits harvested at 100% of development and allowed to ripen for 9 d at 20°C. A preference test showed this difference in taste to be highly significant (Mizrahi, 1982). This study confirmed our results. Increased salinity at the immature green stage improved fruit quality more than increased salinity at the decoloring stage but decreased fruit yield more (Sakamoto et al., 1999). Also Martine Dorai et al. (2001) showed that the exact rate of yield decline varies with interactions between cultivars, environmental factors, composition of the nutrient solution, and crop management. According to different studies and growth conditions, salinities higher than 2.3–5.1 mS·cm−1 result in an undesirable yield reduction, while ECs of 3.5–9.0 mS·cm−1 improve tomato fruit quality Influence of electric conductivity management on greenhouse tomato yield and fruit quality.

Non-grafted form

In our study, by using colorimetry we found that increasing levels of salinity lead to rapid ripening of the fruit on the second branch on grafted and non-grafted Buran F1 hybrids. In the face of a global market economy, obtaining high yields of tomato fruit of very high quality and flavor is essential for ensuring consumer satisfaction and for the success of the greenhouse industry. Relationships between greenhouse environment, salinity and mineral nutrition of the tomato plant are extremely complex.

Cultivars do not have the same response to salinity; consequently no general recommendation could be made for all types of tomato.

Conclusion

In our research, increased salinity led to an increase of total sugars in the fruit of grafted and non-grafted tomatoes. As for the total acid, grafting of tomatoes reduced the stress due to increased salt concentrations, so for these plants there was no accumulation of acid in the EC = 6.8 dS / m.

Also, higher levels of salinity at the grafted varieties and non-grafted Buran F1 hybrids leads to faster ripening of fruits, which is very important from an economic point of view.

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