

## **SALINITY EFFECTS ON GROWTH, PHYSIOLOGY, AND YIELD IN LOWLAND TOMATO GROWN IN SOILLESS CULTURE**

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### **ABSTRACT**

Salinity is one of the environmental stresses which give detrimental effects to crop growth, physiological changes and lowering yield production. Crops grown under soilless culture system also have no exception on salinity problem. In fact, salinity occurs very quickly in small root volumes like in soilless culture due to the accumulation of salts. Thus, this study was carried out to study the influence of salt stress on physiological changes and quality attributes of lowland tomato grown hydroponically in Malaysia. Two cultivars of lowland tomato (Pearl and MT1) were treated with sodium chloride (NaCl) at 70 and 140 mM. A significant interaction between cultivar Pearl and MT1 with salinity level were shown on stomatal conductance, relative water content and electrolyte leakage. Photosynthetic rate of MT1 was higher by 18% than those in Pearl. However, no significant interaction was observed on total chlorophyll content. Overall, NaCl level at both 70 and 140 mM had significantly reduced the physiological parameters in both Pearl and MT1. Likewise, no significant interaction between cultivar and salinity was shown on yield, but Pearl with a higher yield production was observed to be more salinity-tolerant than MT1. In addition, total soluble solids were positively affected by salinity level, as the content significantly increased with increasing salinity. A blossom end rot was recorded the highest at salinity level of 140 mM with 30% of incidence. In conclusion, different cultivars of tomato showed different responses and degrees of tolerance towards salinity.

**Keywords:** salinity, lowland tomato, hydroponic, photosynthetic rate, yield, blossom-end rot

### **INTRODUCTION**

Tomato can be categorized as one of the main vegetables produced in Malaysia with an average production of 67.6 metric tonne per hectare, second after sweet pepper with 68.3 metric tonne per hectare in 2013 (Department Of Agriculture 2013). Pahang, Kelantan and Sabah are the three states that have the largest acreage to produce highland tomato in Malaysia with 2500, 198 and 110 hectare, respectively. The tomato variety of MT1 from the Malaysian Agricultural Research and Development Institution (MARDI) and F1 hybrid Pearl are both commercial cultivars that are cultivated in hydroponic system. To date, tomato cultivation in Malaysia encounters no serious problem during cultivation until they are harvested as the hydroponic system under rain shelter had been built for more systematic nutrient management. The system has increased the yield from 5 to 10 times higher compared to direct cultivation in soil (Harun 1989).

Environmental stresses such as salinity, drought and temperature stress are not likely to be avoided although a closed environment system (CES) has been practiced in most of the vegetable cultivation. They do not only affect the physiological processes of greenhouse fresh vegetables, but also influence the quality of vegetables. Salinity or salt stress is a very threatening problem to crop production and agricultural sustainability as it significantly reduced once productive land to unproductive (Shiyab 2011). Growth retardation (Maggio et al. 2004), leaf senescence (Lutts et al. 1995), loss of yield (Kaya et al. 2002) and fruit physiological disorder such as blossom-end rot (Tuna et al. 2007) are some of the common responses by plants previously reported due to salt stress. The presence of Na<sup>+</sup> and Cl<sup>-</sup> at high concentrations is responsible for this detrimental effect that eventually becomes toxic to plant, and leads

to nutritional imbalance as they restrict the uptake of other ions such as  $K^+$  and  $Ca^{2+}$  (Caines and Shennan 1999). The salinity occurred because of the large application of fertilizers in hydroponic and fertigation technique, which leads to more salt accumulation in the media as leaching process cannot take place. Gradually, the media become salinized and influence the growth as well as reduce the yield of crops which are the salt-sensitive type (Wong and Jaafar 1993).

Physiological changes of plants during stress are very important information in order to understand how plants regulate the mechanism to survive under salinity stress. Photosynthetic rate, stomatal limitation and carbon dioxide availability are the primary processes which are affected by salinity (Chaves 1991; Munns et al. 2006, Flexas et al. 2007). Retardation of growth of tomato was significantly correlated with physiological changes (Munns 2002) especially photosynthetic activity as the plants suffer from ionic stress due to excessive salt absorption as a long term effect. As a moderately tolerant plant to salt stress, tomato also suffered from the loss of yield by about 30% with electrical conductivity (EC) of  $7.8 \text{ dS m}^{-1}$ . Despite that, fruit quality showed the opposite response as salinity actually improved fruit quality such as total soluble solids and titratable acidity (Magan et al. 2008). As environmental stress is a serious issue especially salinity, it is important to conduct this study, especially when very little information is available for lowland tomato cultivars in Malaysia. Thus, this study was conducted to investigate the response of lowland tomato cultivars to different levels of salinity in the hydroponic system.

## MATERIALS AND METHODS

### Experimental site

This experiment was conducted at Glasshouse Centre, Field 2, Universiti Putra Malaysia (UPM), Serdang, Selangor, Malaysia, at latitude of  $3.008^\circ\text{N}$  and longitude of  $101.705^\circ\text{E}$ , from January 2013 until April 2013. The temperature was 30 to  $32^\circ\text{C}$  during daytime and night temperature between 22 to  $23^\circ\text{C}$ , with relative humidity at 70 to 80%.

### Plant materials and medium preparation

Seeds of two tomato cultivars (*Lycopersicon esculentum* Mill.) were used in this study, namely F1 Hybrid Pearl Tomato and MT1 purchased from local company (Sin Seng Huat Seeds Sdn. Bhd.) and MARDI, respectively. Seeds were sown in the seedling trays filled with 100% peat and watered twice daily under 70% of shading. The uniform seedlings were transplanted after two weeks into 40 cm long x 40 cm wide UV white polybags containing 100% coconut coir dust (CCD). The CCD was flushed with water 24 hours prior to transplanting. The composition of macronutrient in the CCD was nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) at 0.39, 0.06, 1.76, 0.13 and 0.11 %, respectively. The

### NaCl treatments

The basic nutrient solution used was Cooper formulation (Cooper 1979), where the composition of nutrient solution ( $\text{mg L}^{-1}$ ) consisted of 200 N, 60 P, 300 K, 170 Ca, 50 Mg, 12 Fe, 2 Mn, 1.5 B, 0.1 Zn, 0.1 Cu, and 0.2 Mo. Nutrient solution was diluted in 250 L tank, and the pH was adjusted to 5.6 with 0.1 mM KOH. Salinity was imposed by adding 70 and 140 mM NaCl to the nutrient tanks. A control experiment without addition of NaCl was also prepared. In early vegetative growth, all plants were applied with basic nutrient solution via drip irrigation with electrical conductivity (EC)  $1.0 \text{ mS cm}^{-1}$  for a week. When the first flower truss was fully bloomed, a nutrient solution was raised to  $EC 2.5 \text{ mS cm}^{-1}$ . The EC for all the treatments were shown in Table 2.

Table 2. Electrical conductivity (EC) of each treatment throughout the experiment

NaCl (mM)	EC (mS cm <sup>-1</sup> )
0	2.5
70	10.2
140	16.0

### Plant maintenance

Tomato plants were grown with single stem, and trellising was done after 2 weeks of transplanting using raffia rope for plant support. All lateral shoots were removed once a week to maintain a single stem. The irrigation system was set up at 0800 hr and 1700 hr daily for 10 min using a timer. A calibration was done before hand to determine the volume of nutrient solution to be irrigated in a polybag per day. Since the system was able to irrigate 400 mL (40 mL min<sup>-1</sup>) of nutrient solution for 10 min, approximately 800 mL of nutrient solution was made for each polybag per day. Flushing the media with water was done every week to prevent salt accumulation on top of the media.

### Photosynthetic rate and stomatal conductance

Photosynthetic rate and stomatal conductance of the plants were measured by using a portable photosynthesis system (LI-6400, LICOR, U.S.A.) at 2-week intervals after treatment was applied. The measurement was done between 0900 hr to 1100 hr. The youngest, fully expanded leaves at the third truss from the shoot tip was measured with 6 replication readings under optimal cuvette conditions (900 µmol m<sup>-2</sup> s<sup>-1</sup>, PPFD, CO<sub>2</sub> level of 400 µmol m<sup>-2</sup> s<sup>-1</sup>, 30°C cuvette temperature, 60% RH, and air flow rate at 500 cm<sup>3</sup> min<sup>-1</sup>).

### Total chlorophyll content

Total chlorophyll content was measured according to Coombs et al. (1987). Four leaf discs of 1 cm<sup>2</sup> size fresh leaf taken from third truss were placed in aluminum covered bottle containing 20 mL of 80% (v/v) acetone. The samples were kept in the dark (3 to 7 days) until all chlorophyll was extracted. Chlorophyll content was then determined using scanning spectrophotometer (Shimadzu Model UV3101 PC, Japan) at wavelength of 664 nm and 647 nm. The chlorophyll *a* and *b* content in milligrams (mg cm<sup>-2</sup>), and total chlorophyll content was estimated using the formula of Arnon (1949) as shown below:

$$\begin{aligned} \text{Chlorophyll } a \text{ (mg cm}^{-2}\text{)} &= 13.19 (A_{664}) - 2.57 (A_{647}) \\ \text{Chlorophyll } b \text{ (mg cm}^{-2}\text{)} &= 22.10 (A_{647}) - 5.26 (A_{664}) \\ \text{Total chlorophyll content (mg cm}^{-2}\text{)} &= \frac{3.5 \times (\text{chlorophyll } a + \text{chlorophyll } b)}{4} \end{aligned}$$

### Electrolyte leakage

An electrolyte leakage was determined by using a method described by Lutts et al. (1996). Fresh leaves were used and cut using a cork borer to produce 9 leaf discs (9 cm<sup>2</sup>) for each treatment. Then, the leaf discs were washed with deionised water three times and placed in a closed vial containing 10 mL of deionised water. The samples were incubated at 25°C and placed on a rotary shaker for 24 hours. After that, samples were measured to get the initial EC reading (*L<sub>i</sub>*). Afterwards, the samples were autoclaved at

120°C, and the final EC reading was measured ( $L_0$ ) at 25°C. Electrolyte leakage of the samples was obtained by using the equation below:

$$\text{Electrolyte leakage (\%)} = (L_t / L_0) \times 100$$

#### **Relative water content**

A relative water content (RWC) was assessed according to Weatherly's (1950) method. Fresh leaves were used and cut using a cork borer to produce 10 leaf discs (10 cm<sup>2</sup>). The leaf discs were then weighed to get the fresh weight (FW). After that, they were floated in distilled water overnight. Their turgid weight (TW) was determined afterwards. The leaf discs were dried in the oven at 65°C for 24 hours or until their weight remained constant. Their dry weight (DW) was then determined. Values of FW, DW and TW were used to calculate RWC as given below:

$$\text{RWC} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100\%$$

#### **Fruit yield and quality**

At the end of the experiment, total soluble solids (TSS) and titratable acidity (TA) of fruits were measured. Total soluble solids were measured using a refractometer (Atago Pocket Refractometer PAL-1, Japan). A drop of juice was applied on the refractometer, and the readings were directly taken and expressed as % Brix at room temperature (21±2°C).

A titratable acidity was analysed by extracting 10 g fruit fresh weight in 50 mL distilled water. After mixing thoroughly, the extract was filtered. A five mL of filtrate was taken and 2 drops of 1% phenolphthalein were added into the filtrate as the indicator. The mixture was then titrated with 0.1 N NaOH until pH 8.1 was obtained or the colour of mixture had changed slightly pinkish. The titration volume was recorded and titratable acidity of fruit was expressed as % citric acid using the equation below (Ranganna 1986):

$$\% \text{ citric acid} = \frac{\text{Titre} \times \text{Normality of Alkali} \times \text{Volume Made Up} \times \text{Equivalent Weight of Acid} \times 100}{\text{Volume of Sample Taken For Estimation} \times \text{Weight of Sample Taken} \times 1000}$$

A blossom-end rot (BER) incidence was also recorded. The fruit number and weight were determined after harvesting at ripening stage.

#### **Experimental design and statistical analysis**

A two-factorial experiment consisted of different levels of NaCl and tomato cultivars (Pearl and MT1) were arranged in a Completely Randomized Design (CRD). Each treatment was replicated four times with six plants per replication. A total of plants used in this experiment were 144 plants. The three levels of NaCl were 0 mM (control), 70 mM and 140 mM.

The data were analyzed using SAS® 9 (SAS Institute, 1990, Version 9). The data obtained were subjected to two ways of analysis of variance (ANOVA) to assess the significance of treatment means. The differences between treatment means were compared by using Duncan's Multiple Range Test (DMRT) at  $p \leq 0.05$  level. A Pearson correlation was used to test the linear strength between variables.

## RESULTS AND DISCUSSION

### Growth parameters and yield

There was a significant interaction ( $p < 0.05$ ) between NaCl level and tomato cultivars observed in plant height and total leaf area (Table 3). Increasing salinity significantly restricted both plant height (Figure 1) and total leaf area (Figure 2) in both Pearl and MT1 cultivars. The saline-treated tomatoes were shorter and had small leaf area with 50% reduction compared to control (0 mM NaCl). Salinity stress resulted in a clear stunting of plants. The results obtained in this study was compatible with the previous study by Chookhampaeng et al. (2008) on tomato, Chartzoulakis and Klapaki (2000) on pepper, Bakht et al. (2011) on maize, and Miranda et al. (2014) on gooseberry, where plant height was inhibited after being exposed to salinity. According to Foolad (2004), salt stress and nutrient imbalance caused plants to face problems such as hyperosmotic stress and ion disequilibrium, whereby the cellular functions of plants were disturbed and caused reduced growth even at low concentrations of salt. When plants were under salt stress, they cannot tolerate the presence of large amount of salts in the cytoplasm, forcing them to restrict the excess salts in the vacuole or compartmentalize the ions into different tissues in order to facilitate their metabolic functions (Parida and Das, 2005). In addition, Taffouo et al. (2010) showed that high  $\text{Cl}^-$  and  $\text{Na}^+$  in the media resulted in physiological and biochemical changes that inhibit plant growth and development because of water deficit. It was well known that water potential and osmotic potential of plants became negative when salinity level increased (Hossain and Nonami 2012). Reduction of turgor in expanding tissues due to lower water potential in root growth medium had resulted in the reduction of shoot and root, hence affected the plant height. Besides, the disturbance in photosynthesis also has become one of the factors that contributed to inhibition of plant height under saline condition. Alam et al. (2004) explained that reduction on photosynthesis may limit the supply of carbohydrate to the plant organs which are needed for growth. However, Munns et al. (1995), on the other hand, found that salts taken up by plants did not affect the plant growth directly from turgor, photosynthesis or the activity of one or another enzyme. Instead, the loss of leaves due to the build-up of salts in old leaves affected the supply of assimilates or hormones to the growing organs, thereby affecting plant growth. Previous study on tomato by Shiam et al. (2015) showed 16 lines of tomato responded differently on salinity, showing 30 to 56% of reduction in total leaf area at salinity between 6 and 12  $\text{dS m}^{-1}$ . It was due to inhibition in the length of the leaf at elongating zone which had caused growth intensity and distal portions to decrease. Besides, toxicities of  $\text{Na}^+$  and  $\text{Cl}^-$  in the plants also contributed to the reduction in total leaf area as it modified the metabolic activities of the cell wall and its elasticity (Yasar et al. 2006).

The fruit fresh weight, fruit number, and total yield per plant of both tomato cultivars showed no significant interaction ( $p > 0.05$ ) with NaCl treatment (Table 3). Fruit fresh weights for both of cultivars were reduced approximately by 46% and 70% with 70 and 140 mM NaCl, respectively, as compared to control treatment (0 mM NaCl). Fruit number per plant was significantly reduced with increasing salinity levels. A similar trend was observed in total yield per plant which showed no significant effect by the salinity treatments. Nevertheless, total yield was still reduced by 62% and 85% with 70 and 140 mM NaCl, respectively, compared to control. In comparison, Pearls cultivar exhibited significantly higher fruit fresh weight, fruit number and total yield compared to those in MT1. Moreover, the study also showed that yield of both cultivars was affected by salinity, reducing their productions by 84% at the highest concentration of salinity. Even at the medium level of NaCl (70 mM), Pearl and MT1 had lost 62% of their yield, indicating a moderate salinity-tolerant of the cultivar studied. A loss of yield is commonly correlated with fruit fresh weight rather than fruit number (Amjad et al. 2014). This is because water uptake from root to the fruits is suppressed by high ion accumulation, and subsequently affected fruit enlargement during cell expansion in which water acts as motive force for cellular expansion (Amjad et al. 2014). According to Johnson et al. (1992), an increase of osmotic potential in the root medium may be a factor for reduction in phloem turgor, which eventually affects the fruit expansion rate. However, it

contradicted with the results obtained in this study as both fruit fresh weight and fruit number per plant significantly gave negative influence to total yield of tomato under the saline condition (Table 6).

Table 3. Effects of salinity on plant growth and yield of tomato cultivar Pearl and MT1 at 12 WAT

Treatment	Plant height (cm)	Total leaf area (cm <sup>2</sup> )	Fruit fresh weight (g fruit <sup>-1</sup> )	Fruit number	Total yield (g plant <sup>-1</sup> )
<b>Cultivar (C)</b>					
<b>Pearl</b>	131.83 a	960.05 a	75.02 a	21.83 a	1840.6 a
<b>MT1</b>	120.66 b	711.46 b	59.72 b	20.08 b	1386.6 b
<b>Salinity (S)</b>					
<b>0 mM</b>	156.12 a	1162.10 a	109.86 a	28.75 a	3172.4 a
<b>70 mM</b>	122.50 b	675.70 b	59.44 b	20.00 b	1192.8 b
<b>140 mM</b>	100.12 c	669.40 b	32.81 c	14.13 c	475.5 c
<b>Interaction C × S</b>	**	*	ns	ns	ns

Mean separation within columns and factors followed by the different letters are significant by DMRT at  $p < 0.05$ .

\* $p < 0.05$ ; \*\* $p < 0.01$ ; ns=not significant

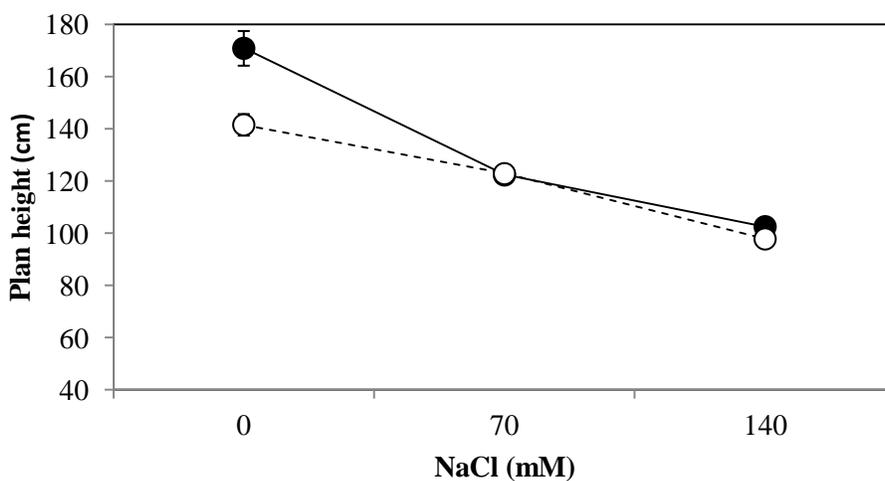


Figure 1. Plant height of Pearl and MT1 as influenced by different levels of NaCl at 12 WAT (Pearl-closed circle, MT1-opened circle). Each point represents the mean values ( $n=4$ )  $\pm$  SE ( $p < 0.05$ ). Some SE marks reside within symbols.

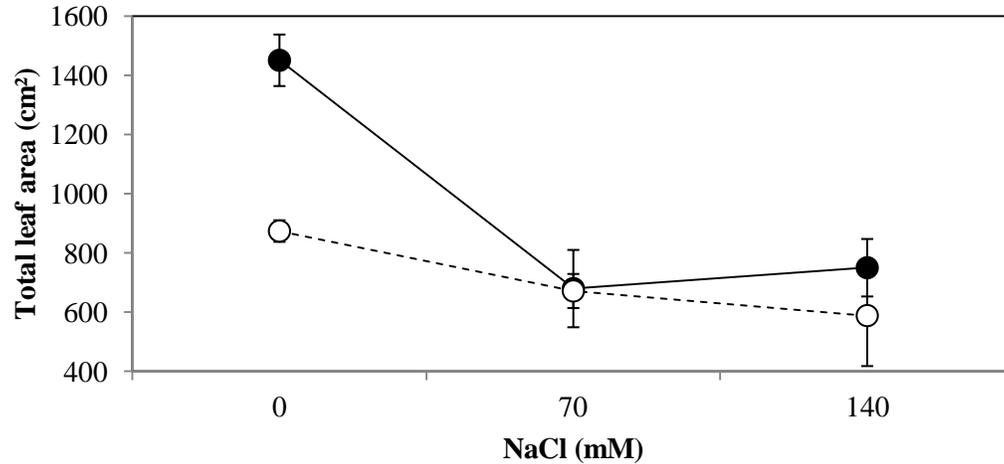


Figure 2. Total leaf area of Pearl and MT1 as influenced by different levels of NaCl at 12 WAT. Pearl-closed circle, MT1-opened circle). Each point represents the mean values ( $n=4$ )  $\pm$  SE ( $p<0.05$ ). Some SE marks reside within symbols.

### Physiological parameters

A statistical analysis showed no significant interaction ( $p>0.05$ ) between cultivars and NaCl levels on photosynthetic rate and chlorophyll content at 12 WAT (Table 4). However, salinity caused a significant reduction in photosynthetic rate with 27 and 54% of reduction with 70 and 140 mM NaCl, respectively. Salinity also slightly reduced the chlorophyll content in both cultivars with not more than 13% of reduction as compared to control. In contrast, there was a significant ( $p<0.05$ ) interaction between cultivar and NaCl levels on stomatal conductance, relative water content and electrolyte leakage (Table 4). This indicated that the presence of salinity significantly affected these parameters by reducing stomatal conductance (Figure 3A) and relative water content (Figure 3B) as NaCl level increased in both cultivars. However, electrolyte leakage was significantly increased with increasing NaCl (Figure 3C).

In this study, photosynthetic rate and chlorophyll content were reduced under saline condition. The presence of high  $\text{Na}^+$  in the plants especially in the chloroplasts affects photosynthetic electron transport activities in photosynthesis (Sudhir and Murthy 2004). Generally, there are a few reasons of how photosynthetic rate is decreased under saline condition such as decrease in  $\text{CO}_2$  diffusion into the chloroplasts due to the limitation of stomata and mesophyll, as well as regulations in the photosynthesis metabolism (Chaves et al. 2009). It was assumed that the decreasing stomatal conductance had lowered photosynthetic rate and chlorophyll content in this study. Stomatal conductance which plays a role in the rate of passage of  $\text{CO}_2$  entering the stomata of the leaf was decreased under saline condition. The closure of stomata in the response of decline in leaf turgor consequently impaired the supply of  $\text{CO}_2$  to ribulose-1,5-biphosphate carboxylase (RuBisCO) which is the main enzyme for carbon fixation in photosynthesis (Chaves et al. 2009).

Photosynthetic rates of both tomato cultivars under NaCl treatment were altered possibly due to the regulation of relative water content. Under the saline condition, leaf water potential and osmotic potential in the plants become negative, and turgor pressure positively increases as the salt level increases (Parida and Das 2005). In this study, the decline in relative water content indicated the loss of turgor through inadequate osmotic adjustment which leads to a reduction in leaf area (Curtis and Lauchli 1987). Reduction in membrane permeability for both tomato cultivars in this study can be seen from their

electrolyte leakage result. Both cultivars had a significant increase in electrolyte leakage compared to control. This means that leaf membrane of tomato had a greater permeability to  $\text{Na}^+$  under the saline condition, thus leads to high accumulation of  $\text{Na}^+$  in the leaf instead of  $\text{K}^+$ . According to Lutts et al. (1996), the cellular membrane dysfunction caused by salt stress can be proven by the increase in permeability for ions and electrolytes which can be readily measured by the efflux of electrolytes.

Table 4. Effects of salinity on physiological parameters of tomato cultivar Pearl and MT1 at 12 WAT

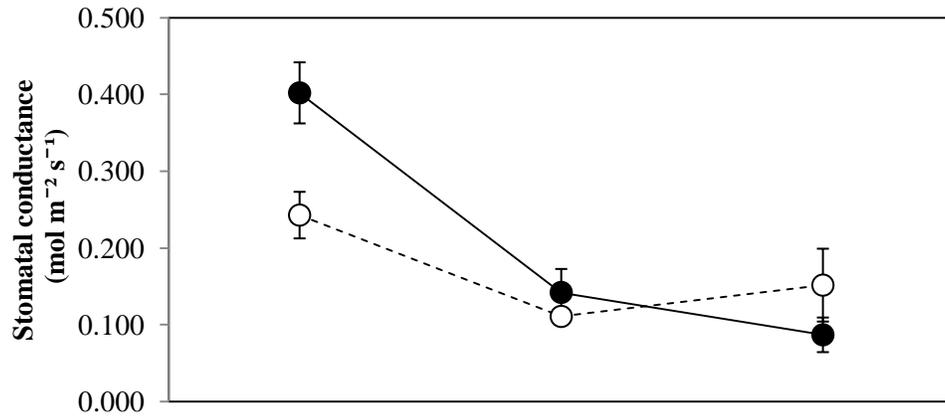
<b>Treatment</b>	<b>Pn</b> ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ )	<b>gs</b> ( $\text{mol m}^{-2} \text{s}^{-1}$ )	<b>Chl</b> ( $\text{mg cm}^{-2}$ )	<b>RWC</b> (%)	<b>EL</b> (%)
<b>Cultivar (C)</b>					
<b>Pearl</b>	10.49b	0.21a	6.73a	80.91a	38.65a
<b>MT1</b>	12.80a	0.17a	6.25 a	79.46a	43.59a
<b>Salinity (S)</b>					
<b>0 mM</b>	15.97a	0.32a	6.99a	89.01a	20.95c
<b>70 mM</b>	11.61b	0.13b	6.36a	76.11b	35.99b
<b>140 mM</b>	7.34c	0.12b	6.10a	75.44b	66.43a
<b>Interaction</b>					
<b>C × S</b>	ns	*	ns	*	*

Mean separation within columns and factors followed by the different letters are significant by DMRT at  $p < 0.05$ .

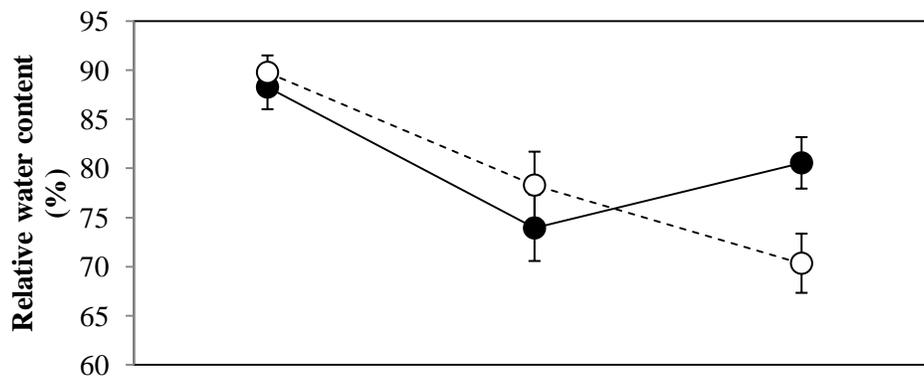
\* $p < 0.05$ ; ns=not significant

Pn=photosynthetic rate; gs=stomatal conductance; Chl=total chlorophyll content; RWC=relative water content; EL=electrolyte leakage.

A



B



C

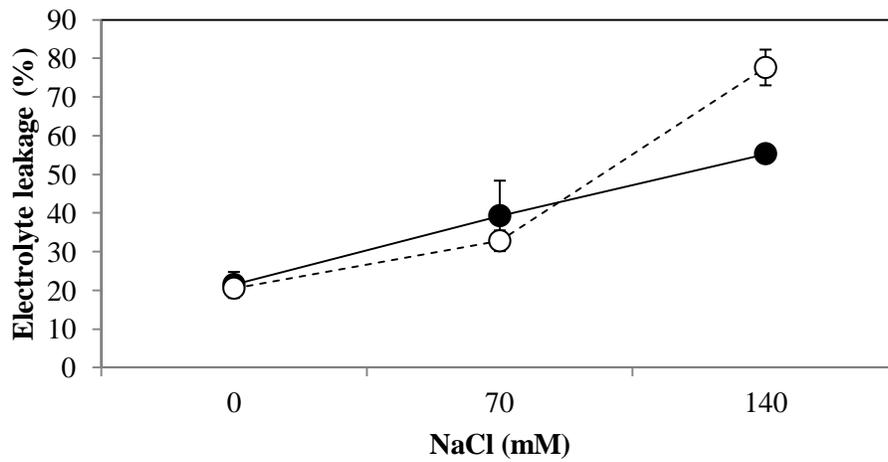


Figure 3. Stomatal conductance (A), relative water content (B) and electrolyte leakage (C) as influenced by different levels of NaCl at 12 WAT (Pearl-closed circle, MT1-opened circle). Each point represents the mean values ( $n=4$ )  $\pm$  SE ( $p<0.05$ ). Some SE marks reside within symbols.

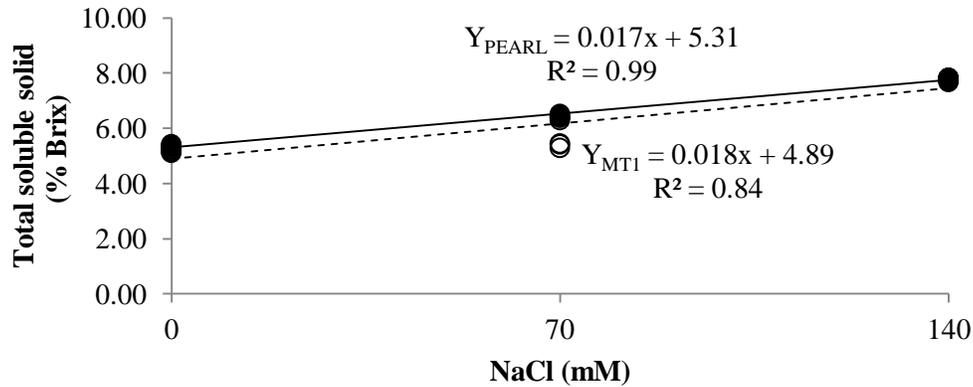


Figure 4. Effect of NaCl on total soluble solid of Pearl and MT1 cultivar (Pearl-closed circle, MT1-opened circle).

### Fruit quality

There was a significant interaction ( $p < 0.05$ ) between NaCl level and tomato cultivars observed in total soluble solids (Table 5). Increasing salinity significantly enhanced total soluble solids of both cultivars with not more than 32% of enhancement compared to control (Figure 4). A significant interaction ( $p < 0.05$ ) between NaCl level and tomato cultivars observed in titratable acidity and blossom-end rot incidence (Table 5). Both TA and BER were significantly increased with increasing salinity levels. Approximately 30% of increment was recorded in TA content from 0 to 140 mM NaCl treatment. Apart from that, blossom-end rot at the bottom-end of the fruit was visible in all treatments. The highest BER incident was recorded for plants treated with 140 mM NaCl, and it was decreased with decreasing salinity levels. However, no significant ( $p > 0.05$ ) effect was shown between tomato cultivars on TA and BER incidence.

Contrary to yield, total soluble solid increased with increasing salinity. NaCl improved the quality and sweetness of tomato, but at the same time, reduced the number and weight of the fruits. A significant correlation between yield component and a quality component of these tomatoes is shown in Table 6. Alterations in translocation of assimilates may be the cause of this response in the fruits under salt stress. According to Campos et al. (2006), soluble solids of tomato increased under saline condition due to a reduction in water import to the fruit. As a consequence, solutes (i.e. ions and organic molecules) were actively accumulated and soluble solids were concentrated in the fruit pulp. In this study, citric acid level increased when treated with NaCl compared to control. Saito et al. (2008) suggested that the involvement of tricarboxylic acid (TCA) cycle (malate-oxaloacetate-PEP-pyruvate-citrate) in organic acid metabolism was stimulated by salt stress.

Table 5. Effects of salinity on total soluble solids titratable acidity and blossom end rot incidence (%) of tomato cultivar Pearl and MT1

Treatment	Total soluble solids (% Brix)	Titratable acidity (% citric acid)	Blossom-end rot incidence (%)
<b>Cultivar (C)</b>			
<b>Pearl</b>	6.54 a	0.27 a	18.68 a
<b>MT1</b>	6.18 b	0.27 a	21.42 a
<b>Salinity (S)</b>			
<b>0 mM</b>	5.27 c	0.23 c	6.50 c
<b>70 mM</b>	6.02 b	0.26 b	21.88 b
<b>140 mM</b>	7.78 a	0.30 a	31.78 a
<b>Interaction C × S</b>	**	ns	ns

Mean separation within columns and factors followed by the different letters are significant by DMRT at  $p < 0.05$ .

\*\* $p < 0.01$ ; ns=not significant

Blossom-end rot is well-known as a physiological disorder due to calcium deficiency in the tomato fruits and leads to blackish rotten tissue in the adjacent pericarp (Saure 2001). In this study, blossom-end rot occurrence increased for both cultivars as salinity level increased. The incidence did not only occur to the matured fruit but also at the early stage of maturity (Figure 5). BER incidence was also recorded in control plants with the appearance of lesion below the surface of the fruit whilst plants treated with 140 mM had blackish rot. Mostly, fruit at the second and third truss of the plants had this symptom with not more than 20% of occurrence in each truss.

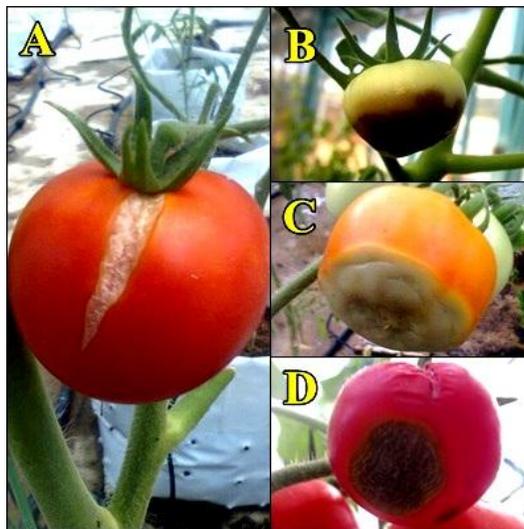


Figure 5. Calcium disorders under saline condition in tomato fruits such as cracking (A), blackish blossom-end rot in immature fruit (B), brownish lesion in half ripe fruit (C), and blackish blossom-end rot in fully ripe fruit (D).

Table 6. Pearson correlation between fruit yield and quality components of tomato cultivar Pearl and MT1 under saline condition

<b>Cultivar</b>		<b>FFW</b>	<b>FN</b>	<b>FY</b>	<b>TA</b>	<b>TSS</b>	<b>BER</b>
<b>Pearl</b>	FFW	1.00	0.951*	0.993*	-0.821*	-0.913*	-0.795*
	FN		1.00	0.959*	-0.800*	-0.959*	-0.781*
	FY			1.00	-0.802*	-0.901*	-0.814*
	TA				1.00	0.810*	0.695*
	TSS					1.00	0.792*
	BER						1.00
<b>MT1</b>	FFW	1.00	0.954*	0.986*	-0.665*	-0.861*	-0.951*
	FN		1.00	0.968*	-0.661*	-0.852*	-0.892*
	FY			1.00	-0.614*	-0.808*	-0.916*
	TA				1.00	0.718*	0.674*
	TSS					1.00	0.864*
	BER						1.00

Coefficients of variation larger than 0.5 are significant at  $p < 0.05$

FFW=fruit fresh weight; FN=fruit number; FY=fruit yield; TA=titratable acidity; TSS=total soluble solids; BER=blossom-end rot

### CONCLUSION

The study showed that plant height, total leaf area, photosynthesis rate, stomatal conductance, total chlorophyll content, relative water content and yield of both cultivars were reduced under salinity stress. On the other hand, total soluble solids, titratable acidity and BER incidence increased with increasing salinity levels. In comparison, Pearl was more tolerant to the salinity than MT1 in terms of growth and yield in both medium and high level of NaCl.

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### REFERENCES

- Alam MZ, Stuchbury TR, Naylor EL and Rashid MA**, 2004. Effect of salinity on growth of some modern rice cultivar. *J Agron* **3(1)**, 1-10.
- Amjad M, Akhtar J, Anwar-Ul-Haq M, Imran S and Jacobsen S**, 2014. Soil and foliar application of potassium enhances fruit yield and quality of tomato under salinity. *Turkish J Biol* **38**, 208-218.
- Arnon DI**, 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol* **24**, 1-15.
- Bakht J, Shafi M, Jamal Y and Sher, H**, 2011. Response of maize (*Zea mays* L.) to seed priming with NaCl and salinity stress. *Span J Agric Res* **9**, 252-261.
- Caines AM and Shennan C**, 1999. Interactive effects of  $Ca^{2+}$  and NaCl salinity on the growth of two tomato genotypes differing in  $Ca^{2+}$  use efficiency. *Plant Physiol Biochem* **37**, 569-576.

- Campos CAB, Fernandes PD, Gheyi HJ, Blanco FF, Gonçalves CB and Campos SAF**, 2006. Yield and fruit quality of industrial tomato under saline irrigation. *Sci Agric (Piracicaba, Braz)* **63** (2), 146-152.
- Chartzoulakis K and Klapaki G**, 2000. Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages. *Sci Hort* **86**, 247-260.
- Chaves MM**, 1991. Effects of water deficits on carbon assimilation. *J Exp Bot* **42**, 1-16.
- Chaves MM, Flexas J and Pinheiro C**, 2009. Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. *Ann Bot* **103**, 551-560.
- Chookhampaeng S, Pattanagul, W and Theerakulpisut P**. 2008. Effects of salinity on growth, activity of antioxidant enzymes and sucrose content in tomato (*Lycopersicon esculentum* Mill.) at reproductive stage. *ScienceAsia* **34**, 069-075.
- Coombs J, Hind G, Leegood RC, Tieszen LL and Vonshak A**, 1987. Analytical Techniques. In: *Techniques In Bioproductivity And Photosynthesis*. Coombs J, Hall DO, Long SP, Scurlock JMO. Pergamon Press, Oxford, UK, 219-220.
- Cooper AJ**, 1979. The ABC of NFT. Grower Books, London.
- Curtis P and Lauchli A**, 1987. The effect of moderate salt stress on leaf anatomy in *Hibiscus cannabinus* (kenaf) and its relation to leaf area. *Am J Bot* **74**(4), 538-542.
- Department of Agriculture**, 2013. Vegetables and cash crops statistics. Putrajaya Malaysia.
- Flexas J, Diaz-Espejo A, Galmes J, Kaldenhoff R, Medrano H and Ribas-Carbo M**, 2007. Rapid variations of mesophyll conductance in response to changes in CO<sub>2</sub> concentration around leaves. *Plant Cell Environ* **30**, 1284-1298.
- Foolad MR**, 2004. Recent advances in genetics of salt tolerance in tomato. *Plant Cell Tissue Organ Cult* **76**, 101-119.
- Harun RMR**, 1989. Potential productivity of hydroponically-grown tomatoes Genting Highlands, Malaysia. *Pertanika* **12**(3), 293-298.
- Hossain MM and Nonami H**, 2012. Effect of salt stress on physiological response of tomato fruit grown in hydroponic culture system. *Hort Sci* **39**, 26-32.
- Johnson DW, Smith SE and Dobrenz AK**, 1992. Genetics and phenotypic relationships in response to NaCl at different developmental stages in alfalfa. *Theor Appl Genet* **83**, 833-838.
- Kaya C, Kirnak H, Higgs D and Saltali K**, 2002. Supplementary calcium enhances plant growth and fruit yield in strawberry cultivars grown at high (NaCl) salinity. *Sci Hort* **9**, 65-74.
- Lutts S, Kinet JM and Bouharmont J**, 1995. Changes in plant response to NaCl during development of rice (*Oryza sativa* L.) varieties differing in salinity resistance. *J Exp Bot* **46**, 1843-1852.
- Lutts S, Kinet JM and Bouharmont J**. 1996. NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. *Ann Bot* **78**: 389-398.
- Magán JJ, Gallardo M, Thompson RB and Lorenzo P**, 2008. Effects of salinity on fruit yield and quality of tomato grown in soilless culture in greenhouses in Mediterranean climatic conditions. *Agric Water Manag* **95**, 1041-1055.
- Maggio A, Pascale SD, Angelino G, Ruggiero C and Barbieri G**, 2004. Physiological response of tomato to saline irrigation in long-term salinized soils. *Eur J Agron* **21**, 149-159.
- Miranda D, Fischer G, Mewis I, Rohn S and Ulrichs C**, 2014. Salinity effects on proline accumulation and total antioxidant activity in leaves of the cape gooseberry (*Physalis peruviana* L.). *J Appl Bot Food Qual* **87**, 67-73.
- Munns R**, 2002. Comparative physiology of salt and water stress. *Plant Cell Environ* **25**, 239-250.
- Munns R, James RA and Lauchli A**, 2006. Approaches to increasing the salt tolerance of wheat and other cereals. *J Exp Bot* **57**, 1025-1043.
- Munns R, Schachtman DP and Condon AG**, 1995. The significance of a two-phase growth response to salinity in wheat and barley. *Aust. J Plant Physiol* **22**, 561-569.
- Parida AK and Das AB**, 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicol Environ Saf* **60**, 324-349.

- Ranganna S**, 1986. Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill Education, New Delhi.
- Saito T, Matsukura C, Ban Y, Shoji K, Sugiyama M, Fukuda N and Nishimura S**, 2008. Salinity stress affects assimilate metabolism at the gene-expression level during fruit development and improves fruit quality in tomato (*Solanum lycopersicum* L.). *J Jpn Soc Hortic Sci* **77**, 61-68.
- Saure MC**, 2001. Blossom-end rot of tomato (*Lycopersicon esculentum* Mill.) - A calcium- or a stress-related disorder? *Sci Hort* **90**, 193-208.
- Shiam IH, Nahiyah ASM, Momena K, Mehraj H and Jamal Uddin AFM**, 2015. Effect of NaCl salt on vegetative growth and yield of sixteen tomato lines. *J Biosci Agric Res* **3**, 15-27.
- Shiyab S**, 2011. Effects of NaCl application to hydroponic nutrient solution on macro and micro elements and protein content of hot pepper (*Capsicum annuum* L.). *J Food Agric Environ* **9(2)**, 350-356.
- Sudhir P and Murthy SDS**, 2004. Effects of salt stress on basic processes of photosynthesis. *Photosynthetica* **42 (4)**, 481-486.
- Taffouo VD, Nouck AH, Dibong SD and Amougou A**, 2010. Effects of salinity stress on seedlings growth, mineral nutrients and total chlorophyll of some tomato (*Lycopersicon esculentum* L.) cultivars. *Afr J Biotechnol* **9 (33)**, 5366-5372.
- Tuna AL, Kaya C, Ashraf M, Altunlu H and Yokas I**, 2007. The effects of calcium sulphate on growth, membrane stability and nutrient uptake of tomato plants grown under salt stress. *Environ Exp Bot* **59**, 173-178.
- Weatherly PE**, 1950. Studies in the water relations of cotton 1. The field measurement of water deficits in leaves. *New Phytol* **49**, 81-97.
- Wong NC and Jaafar AM**, 1993. Soil chemical characteristics of vegetable plots at Cameron Highlands. MARDI. Report no. 170, 9 pp.
- Yasar F, Ulzal O, Tufenkci S and Yildiz K**, 2006. Ion accumulation in different organs of greenbean genotypes grown under salt stress. *Plant Soil Environ* **52**, 476-480.