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Application of Deep Sea Water for Multi-Trusses Cultivation of Tomato Using A Nutrient Film Technique

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Deep sea water (DSW) that was applied to 3 trusses of cultivated tomato for 2 weeks affected fruits properties. However, advantageous effects on the soluble solids content, acidity, and dry matter content of the fruit tend to decline from 1st truss to the successive trusses. Thus it is necessary to study the effect of DSW application when it is applied for longer than 2 weeks in cultivated multi-trusses. In this study, DSW treatment was applied for different durations to obtain effect on fruits development and fruit properties of the 1st to 3rd truss in a 3 truss tomato cultivation system using a nutrient film technique. The results of the study show that DSW treatment has strong effect on fruit enlargement during the stage of rapid fruit growth, which lasts until the fruit almost reaches the final size. Treated plants produced tomatoes with better organoleptic with higher soluble solids content and higher acidity, higher dry matter content, a thicker and more resistant cuticle and also gave higher yields (weight and no of fruits) than in single truss tomato cultivation.

Key words: tomato (*Lycopersicon esculentum*), deep sea water, fruit development, fruit properties, multi-trusses cultivation, nutrient film technique

INTRODUCTION

Deep sea water (DSW) generally refers to sea water from a depth of more than 200 m. With low temperature as its characteristic, when cold, DSW was pumped through fields of spinach in underground pipes, the spinach grew very well. The abundant nutrients of DSW which contains mineral such as Na^+, Mg^{2+}, K^+, and Ca^{2+} are also favorable for agriculture (Nakasone & Akeda 1999). When a nutrient solution is supplemented with DSW, it increases electrical conductivity (EC) of the nutrient solution. Deep sea water that supplemented into nutrient solution increases the electrical conductivity thus creates saline conditions at the root zone. Previous experiments showed DSW treatment that was applied during fruit growth could produce tomatoes with high fruit quality (Chadirin *et al.* 2007). DSW treatment could increase quality parameters such as soluble solids content, acidity, and dry matter. However there was a deleterious effect on the saline condition in the root zone. Fresh weight per fruit has been shown decreases with DSW treatment and thus results in yields reduction (Chadirin *et al.* 2007).

Deep sea water treatment that was applied only during rapid growth stage of fruit produced bigger tomato with high soluble solids compared to that applied over fruit growth period until harvest time. This method could apply for single-truss cultivation because fruits have high uniformity. Fruits are pollinated at the same time and grow in the same growth rate (Okano *et al.* 2002). But, grower only obtains fewer yields here than that of the multi-trusses cultivation.

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When salinity that started at rapid growth stage method was applied for multi trusses cultivation, DSW treatment affected fruit properties to different extents because fruits are not all in the same growth stage. Previous experiments have shown that DSW that was applied for 2 weeks during 3 trusses cultivation, affected fruit properties but the effects tend to decline from 1st truss to the successive trusses (Chadirin *et al.* 2007). In this study, DSW treatment was applied at different duration to produce high quality of fruit tomatoes from 1st to 3rd truss in 3 trusses tomato cultivation of nutrient film technique (NFT) system. The objective of this study was to obtain the effect of treatment duration on fruit development and properties of tomato in multi-trusess cultivation.

MATERIALS AND METHODS

Tomatoes (*Lycopersicon esculentum* cv. House Momotaro) were grown on NFT system during autumn in greenhouse at Biomechanical Systems Laboratory of Kochi University, Japan. The nutrient film technique system contained 4 beds and each bed was 10 m long and slope 1%. Each bed contained 47 plants and nutrient solution was circulated from 100 l solution tank with a flow rate of 3 l min^{-1} using a pump. The volume of nutrient solution in the tank was maintained at the same level using an automatic valve, which was connected to nutrient supply tank. Control nutrient solution of 1.5 dS m^{-1} concentration was made from Otsuka Solution and DSW was supplemented into the control nutrient solution to reach 15.0 dS m^{-1}.

The solution supplemented with DSW with an EC level 15.0 dS m^{-1} was applied to 3 beds for 2, 3, and 4 weeks, respectively. Meanwhile, the other one was circulated with control nutrient solution without DSW. The fruit conditions when the treatment was started were 18 days after pollination (1st truss), 11 days after pollination (2nd truss). Fruits at 3rd truss were pollinated 4 days after DSW was applied. After DSW treatment was released, nutrient solution was maintained at 1.5 dS m^{-1}, which is the same with the control bed. Tomatoes were maintained on 5 fruits per truss and 3 trusses per plant. Physical properties and chemical properties of full ripe tomato were measured.

Environmental factors such temperatures and solar radiation were measured and recorded by using wireless LAN system. Temperatures are temperature of nutrient solution at the inlet, the outlet bed and inside tank, air temperature inside, and outside of greenhouse. These data were taken and measured every minute using data loggers. Electrical conductivity of nutrient solution was measured using EC meter (CM-21P) and pH of nutrient solution was measured with pH meter (HM-21P).

Fruit Enlargement. Ten fruits were selected randomly from each truss and each bed and diameter of fruit measured by a caliper every 3 days during fruit growth period until fruits harvest time at ripe condition. Fruit volume (V) was estimated by the following equation (Okano *et al.* 2002):

$$V = \frac{4}{3}\pi\left[\frac{a}{2}\right]\left[\frac{b}{2}\right]^2 \times 10^{-3}$$

a: major axis of the fruit (mm), b: minor axis of fruit (mm), V: Volume of fruit (cm^3).

Analysis of Fruit Properties. Full ripe tomatoes were harvested from each bed and 10 fruits were selected randomly from each bed and each truss for measurement of fruit properties. Tomatoes were weighed and the size of fruit was measured by a caliper. Density and volume of tomatoes were evaluated according to Chadirin *et al.* 2007. The volume of fruits were evaluated using the equation:

$$V = \frac{(W_a - W_l)}{(\rho_l - \rho_a)g} \times 10^3$$

The density of tomatoes can be calculated by:

$$\rho = \frac{M}{V} = \frac{W_a + V\rho_a g}{W_a - W}(\rho_l - \rho_a) \times 10^{-3}$$

$$\rho = \frac{W_a}{W_a - W}(\rho_l - \rho_a) + \rho_a$$

W_a: weight of fruit in air (N), W_l: weight of fruit in liquid (N), M: mass of fruit (kg), g: gravitation (m s^{-2}), V: volume of fruit (l), r: density of tomato (kg m^{-3}), r_a: density of air (kg m^{-3}), r_l: density of liquid (kg m^{-3}).

After volume of fruits was evaluated, puncture strength of its peel was measured using rheometer. For measurement of puncture strength, tomato skin from 3 positions of fruit, stem end, middle and blossom end, was cut using a speed cork borer size 11 (diameter 19 mm) and fixed in an annular ring clamp with 20 mm of diameter. The load was applied perpendicular to the peel specimen using 3 mm cylindrical probe with a needle end at the speed of 2 mm min^{-1} until it passed through the skin disc. The strength was calculated by dividing the maximum force with the cross-sectional area of the probe.

Measuring soluble solids content and acidity and dry matter was conducted by dividing a tomato into 4 pieces by slicing vertically and horizontally. Two pieces were juiced using a hand mixer and then filtered using filter paper. This puree was used to determine soluble solids content and acidity. Soluble solids content of tomato was measured in term % of Brix by using digital refractometer (model PR-101). Acidity (% w/v) was measured by an acid meter (FT-1) supplied with a standard reagent. The other two pieces of the tomato sample were dried by using oven at 70 °C temperature until the weight was constant and weighed to determine dry matter.

Measuring mineral content of tomato was conducted by dividing a tomato into 4 pieces by slicing vertically and horizontally. Two of the them were homogenized using a hand miller for 2 minutes. A 5 mg sample of homogenate was put in 50 ml tube and added 45 ml distilled water. The sample was then shaken using shaker set at 228 rpm for 60 minutes before being and then was centrifuged using centrifuge, at 3,000 rpm for 20 minutes. Thirty ml of the supernatant was transferred duplicate into tube for ion analysis.

RESULTS

Environmental Conditions. Figure 1 shows the . Electrical conductivity of nutrient solution (a), total solar radiation (b), and water uptake of tomato plant (c) by time course during cultivation. Electrical conductivity increased after the DSW treatment was started. During DSW treatment, EC of the treated bed increased from the initial level with time which was faster at the fine days than in the cloudy or rainy days because of high evapotranspirations. Nutrient solution was changed with the new solution (15.0 dS m^{-1}) when it's value was about 25 dS m^{-1}.

During DSW treatment, water uptake from the control plants was higher than that of the treated plants. An increase in total solar radiation always increased the water uptake, whereas an increase in the EC level of nutrient solution decreased water uptake. Figure 1b shows solar radiation while Figure 1c shows water uptake from both of the control and the treated plant. At a low radiation level water uptake of treated plants was 57% of control plants (control plant 0.28 l d^{-1} per plant, treated plant 0.16 l d^{-1} per plant). At a high level water uptake of treated plants was about 38% of control (control plant 1.32 l d^{-1} per plant vs treated plant 0.51 l d^{-1} per plant). The higher the radiation, the higher the negative effect of EC on the water uptake rate.

Fruit Enlargement. Figure 2 shows changes of fruits volume. Fruits of 1st and 2nd truss were in rapid growth stage when treatment was started meanwhile 3rd truss was pollinated 3 days after treatment was started. Among 3 trusses, fruits in the early stage (about 10 days after pollination), grow normally even in the saline nutrient. Three days after the treatment, fruits enlargement was slightly different between the control and the treated beds. The differences became clearlier 1 week after treatment. One week after the treatment was released, enlargement of the treated fruits slightly increased until the

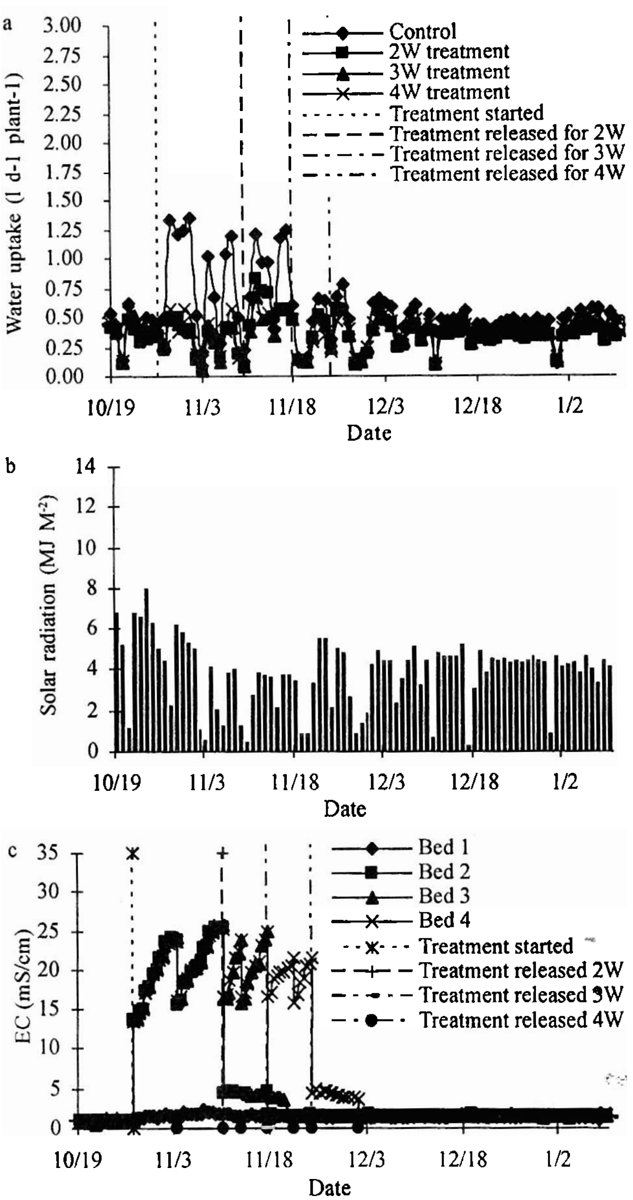

Figure 1. Electrical conductivity of nutrient solution (a), total solar radiation (b), and water uptake of tomato plant (c) by time course during cultivation.

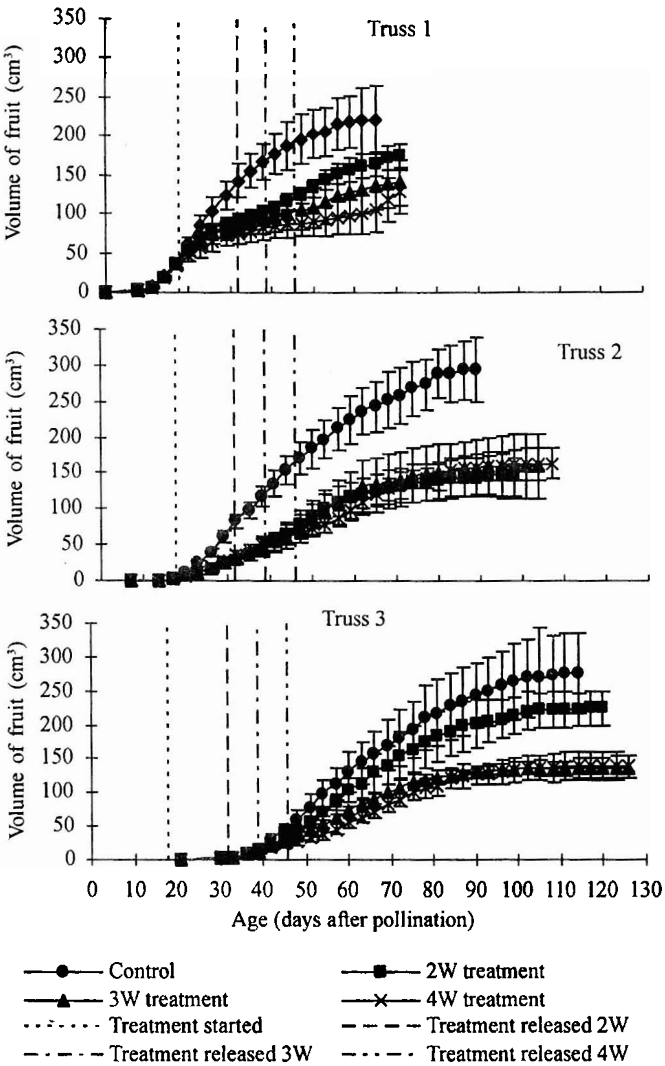

Figure 2. Changes in volume of fruit on 1st, 2nd, and 3rd truss plants grown in each duration of DSW treatment.

final size. Fruits from the treated bed developed slowly than that of the control bed. The treated tomatoes need longer time than control tomatoes to reach maturity. Deep sea water treatment had a strong effect on fruit enlargement when fruits were in rapid growth until reaching the final size.

Fruits Properties. Reduced water uptake during DSW treatment decreased the final size of fruits and it's linearity with the duration of treatment. For 1st truss, control fruits had diameter 76.8 mm meanwhile treated tomatoes had 67.5, 60.8, and 57.6 mm, for 2, 3, 4 weeks treatment respectively (Figure 3a). The average of fresh weight decreased with treatment duration for 1st, 2nd, and 3rd truss. The fresh weights of tomato for 1st truss were 200.65, 135.24, 106.71, and 94.61 g fruit^{-1}, for control to 4 weeks treatment respectively. In the same plants, fresh weight increased from 1st truss to 3rd truss (Figure 3b). The volume of tomato decreased with treatment duration. The volume for 1st truss fruits was 0.217, 0.146, 0.110, and 0.096 l from control to the beds of 2, 3, 4 weeks treatment, respectively (Figure 3c).

Inversely, DSW treatment increased density of tomato. The density of treated tomato was below 1,000 kg m^{-3} but still higher than control tomatoes (Figure 3d). The values were 921.40, 928.51, 969.63, and 981.90 kg m^{-3} for control, 2, 3, and 4 weeks treatment, respectively (1st truss).

Deep sea water treatment produced small size fruits with their skins are stronger than the control but still lower than the fruits that commonly sold in markets (Figure 4). The puncture strength of skin tomato tended to increase from stem end to blossom end. For 1st truss of 4 weeks treatment, puncture strength of tomato skin were 3.59, 3.95, and 4.06 MPa for stem end, middle and blossom end, respectively. Meanwhile, 1st truss of control tomatoes, strength of tomato skin were 2.33, 2.38, and 2.80 MPa for stem end, middle and blossom end, respectively.

Tomato plants grown and treated with DSW treatment showed higher soluble solids content, which increased with treatment duration (Figure 5a). The highest soluble solids

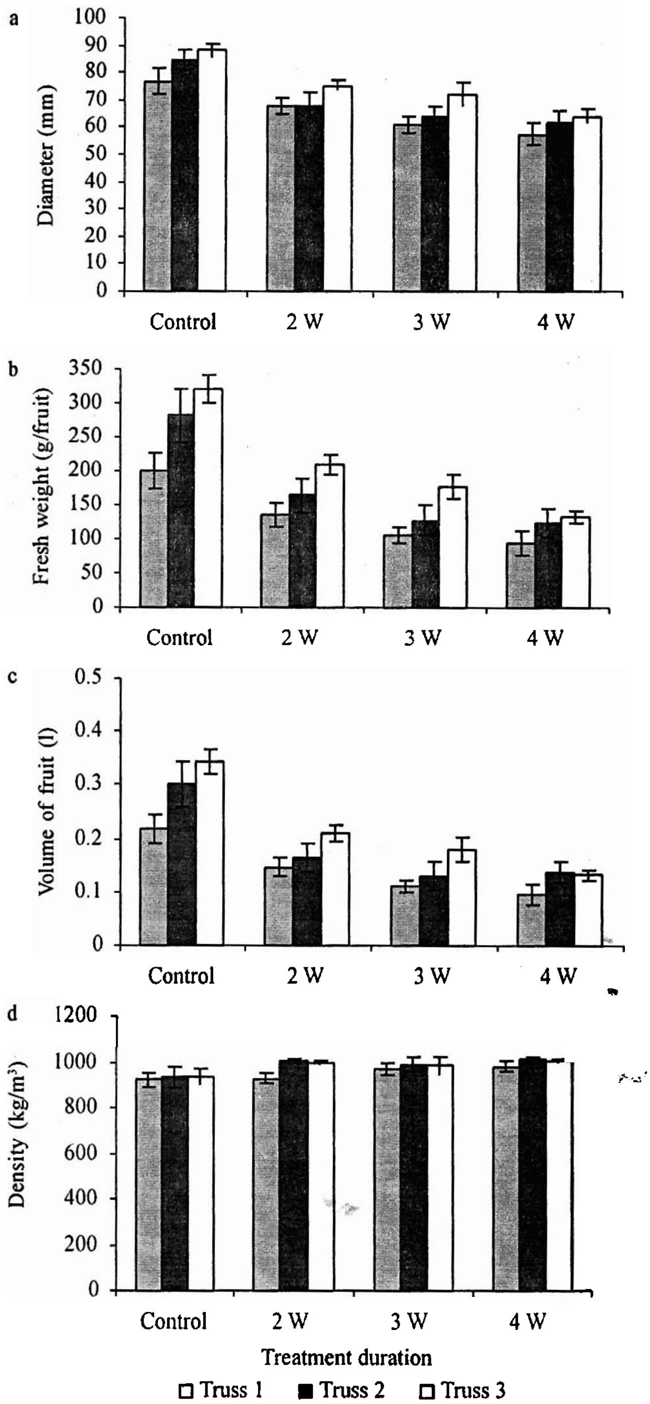

Figure 3. Effect of treatment duration on diameter (a), fresh weight (b), volume (c), and density (d) of tomato fruits. Values are mean ± SD (n = 10).

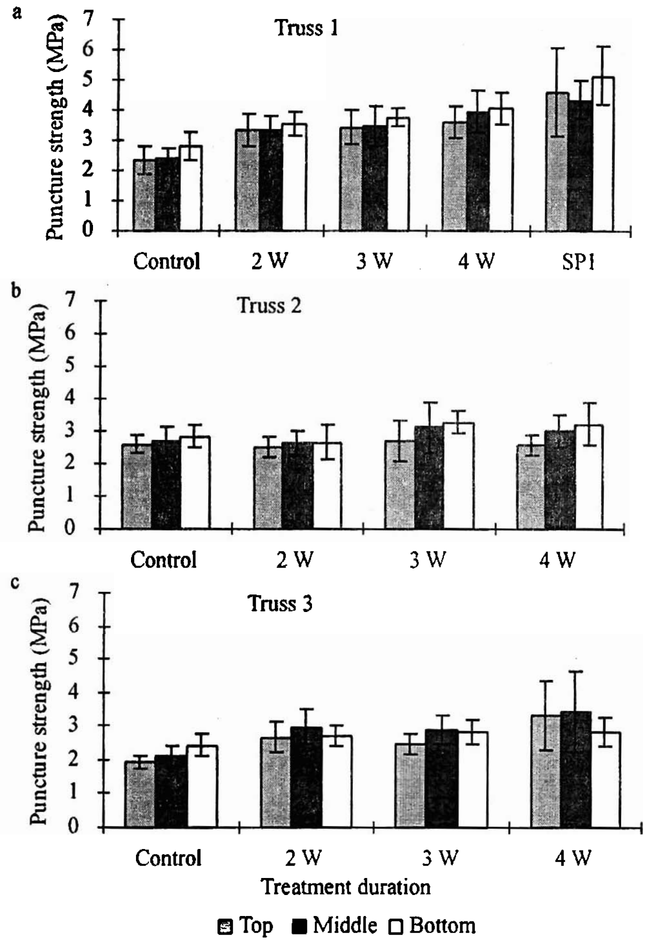

Figure 4. Effect of treatment duration on puncture strength of tomato skin. Values are mean of ten fruits. SP1 is measurement value of tomato fruits that sold in super market.

content was obtained from 1st truss on 4th week of treatment, which is 7.7% Brix. The lowest was obtained from 1st truss of control fruits, which is 4.7% Brix.

Treated tomatoes had higher acidity than the control and the acidity of fruits increased with treatment duration (Figure 5b). Treated tomatoes had acidity above 0.60% w/v meanwhile control tomato was 0.38% w/v (1st truss).

Similar to both soluble solids content and acidity, dry matter content of tomatoes also increased with treatment duration (Figure 5c). The values were above 6.00% w/w.

Minerals such as K^+, Mg^{2+}, and Na^+ from treated fruits were higher than the control (Table 1). It shows that supplemented DSW into nutrient solution caused increasing ion of minerals. Even though DSW contained many ions Ca^{2+}, treated fruits contained Ca^{2+} less than the control. This was due to higher EC level of nutrient caused a reduction in Ca^{2+} uptake.

Tomato yield decreased with treatment duration. Yields were 141.31, 86.73, 67.28, and 57.22 kg/4 beds, respectively for control, 2, 3, and 4 weeks treatment. The lowest yield was obtained from 4 weeks treatment which is 57.22 kg (41% of control). The longer treatment duration resulted into the lower yields (Figure 6a).

Small size fruits and physiological disorders such as blossom end rot (BER) and cracking fruits might have caused yields reduction. Figure 6b shows that most of BER tomatoes were obtained from the longest treatment especially at 3rd truss. Among the treatment beds, percentage of cracking fruits decreased with duration of treatment.

DISCUSSION

Enhancing total solar radiation always increases water uptake, whereas increase of EC level of nutrient solution lead to the opposite effect. This experiment revealed that the higher the radiation the higher the negative effect of DSW treatment on the water uptake. Similar results were stated elsewhere (Adam & Ho 1993), although climate conditions and varieties were different (Schwarz & Kuchenbuch 1998). Reduction of water uptake was associated with a reduction of leaf area index and the general growth of the plant independent of the total solar radiation. Fruit expansion was also affected by reduction water uptake because water flow into fruit was also decreased thus it influenced final size of fruit.

Deep sea water treatment had similar effect with salinity, it can improve fruit quality but it can also lead to reduce growth and yields. In this experiment, fruit growth follows a sigmoidal curve, which is being slow up to 10 days, and very rapid afterwards until reaching almost its final size (Ho & Hewitt 1986). The fruits from treated plants grew normally during the cell division phase (first 10 days) and it was during the cell expansion phase when deleterious effects of salt are observed.

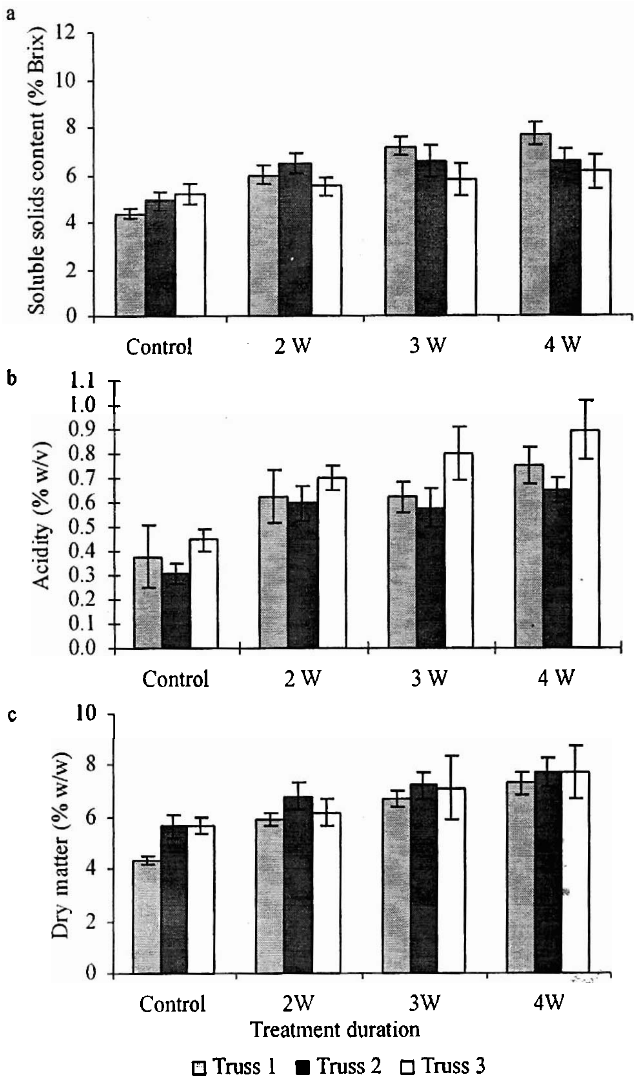

Figure 5. Effect of treatment duration on soluble solids contents (a), acidity (b), and dry matter (c) of tomato fruits. Values are mean ± SD (n = 10).

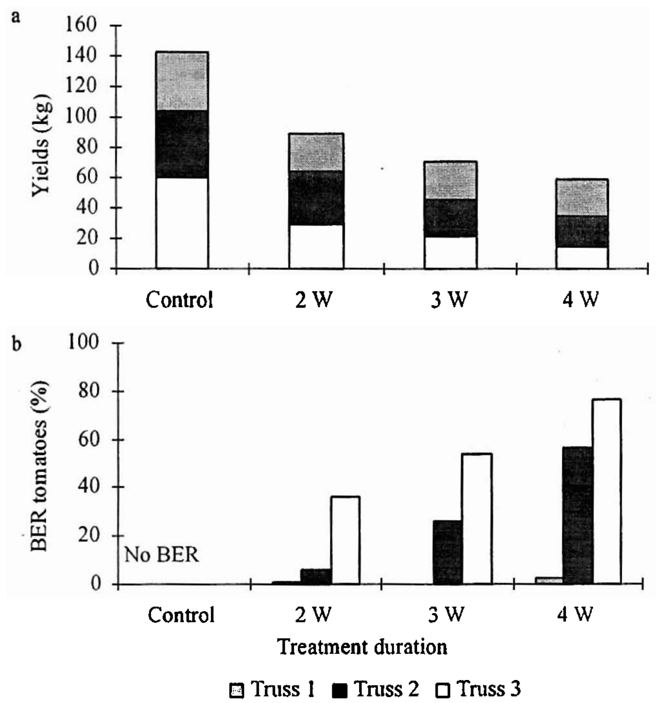

Figure 6. Effect of treatment duration on yields (a) and BER occurrences (b).

Table 1. Effect of duration of DSW treatment on fruit mineral content of tomato

	$[Na^+]$ ppm	$[K^+]$ ppm	$[P^{5+}]$ ppm	$[Mg^{2+}]$ ppm	$[Ca^{2+}]$ ppm
Truss 1					
Control	4.625 (0.768)	205.420 (16.16)	29.985 (3.348)	5.648 (0.586)	2.536 (0.497)
2 Weeks	7.550 (0.858)	253.527 (16.89)	34.962 (2.364)	8.351 (0.503)	0.643 (0.071)
3 Weeks	8.800 (0.900)	264.672 (17.65)	38.259 (0.802)	9.266 (0.853)	1.619 (0.352)
4 Weeks	10.100 (0.990)	279.615 (12.12)	38.946 (1.190)	10.507 (1.101)	1.714 (0.247)
Truss 2					
Control	3.200 (0.500)	110.797 (28.11)	17.232 (3.421)	3.196 (0.855)	1.667 (0.454)
2 Weeks	7.733 (0.907)	147.372 (19.09)	25.859 (2.315)	4.583 (0.526)	1.048 (0.297)
3 Weeks	8.667 (1.436)	165.594 (26.07)	28.249 (1.321)	4.643 (0.449)	0.768 (0.213)
4 Weeks	10.633 (0.379)	186.555 (13.94)	25.106 (2.658)	4.382 (0.506)	1.143 (0.000)
Truss 3					
Control	3.500 (0.141)	176.102 (20.22)	27.580 (5.436)	4.181 (0.821)	2.738 (0.768)
2 Weeks	5.050 (0.569)	172.117 (10.04)	29.297 (1.138)	5.487 (0.829)	2.190 (0.768)
3 Weeks	4.875 (1.050)	155.044 (20.59)	31.495 (6.686)	4.623 (0.592)	1.929 (0.768)
4 Weeks	6.350 (0.676)	183.740 (19.41)	31.888 (3.615)	5.527 (0.923)	2.262 (0.768)

Values are mean of three fruits, number in parentheses is standard deviation.

It was in line with report of Cuartero and Munoz (1999). Volume of fruits during growth decreased when saline condition was applied. This result was in line with results of Okano *et al.* (2002). The strong effect of DSW treatment of fruit development was observed when fruits were in rapid growth stage.

Treated tomatoes enlarged slowly than control tomatoes thus the treated tomatoes had compact skin. It caused treated tomatoes have higher puncture strength value. During fruit growth, rate of maximal growth of proximal fruits is higher than those distal fruits (Ho 1980 in Ho & Hewitt 1986). This differences of fruit growth rate caused difference on puncture strength of tomato skin.

Supplementation of DSW into nutrient solution increased EC level of nutrient solution and enriched ion mineral of nutrient solution. Thus, DSW treatment has effect on salinity, increasing soluble solids content, acidity, and dry matter content of fruits however fruit weight, size and volume were decreased meanwhile treated fruits contained K^+, Mg^{2+}, Na^+, and P^{5+} higher than the control. Similar results were also reported by other researchers in experiment of high EC level effect on tomatoes (Stanghellini *et al.* 1998; Eltez *et al.* 2002; Okano *et al.* 2002). Deep sea water treatment produced better flavor of tomatoes than the control, since it has higher acidity and higher soluble solids content. High soluble solids content together with relatively high acids are required for best flavor; low soluble solids content and high acids produce a tart tomato, high soluble solids content and low acids bland taste and both low soluble solids content and acids results in a tasteless fruit.

The accumulation of organic acids in tomato fruits seems to counter balance the cation (K^+ and Na^+) excess relative to anions (Cl^- and SO_4^{2-}) and maintains fruit pH (Davies 1964). The difference between cation and anion uptake is wider in salt-treated fruit and hence higher concentration of organic acids were found in fruits grown at high EC. It has been shown that tomato maintains turgor when under salt stress by accumulation of organic solute in the leaves to achieve osmotic balance between the increased concentration of inorganic in the growing medium and the osmotic condition of the plant tissues (Rush & Epstein 1976). A substantial increase in acid content would be expected when increased salinity was caused by a higher concentration of K in nutrient solution since most of the acid in the fruit is associated with K (Davies & Winsor 1967). Fruit acidity is closely associated with the K status of the plants and a high K concentration in fruits results in high acidity (Adams & Ho 1995).

Yields reduction was due to the smaller fruits size and physiological disorders, such as BER and fruits cracking. This research showed that BER appeared because of reduction in Ca^{2+} uptake. It is shown by low concentration of Ca^{2+} in fruit although the DSW enriched the nutrient solution. BER is affected by interactions between water ability, salinity and nutrient ratios in the root zone, solar radiation and air temperature, root temperature, and air humidity (Ehret & Ho 1986; Adams & Ho 1992, 1993). It has been shown that high salinity reduces Ca uptake mainly by restriction of water uptake (Ehret & Ho 1986; Ho *et al.* 1993). BER can be induced in tomato by osmotic stress as result of high EC or restricted water supply in the root zone (Adams & Ho 1992). Under osmotic stress, the uptake of Ca by roots is reduced and the distribution of Ca to the distal end of fruits is decreased and leads to local deficiency of Ca. BER appeared because of reduction in Ca^{2+} uptake. It is shown by low concentration of Ca^{2+} in the treated fruits although the DSW enriched the nutrient solution.

Regarding calcium as immobile nutrient, blossom end rot disorders are related to the inability of the plant to translocate adequate calcium to the affected plant part. Calcium moves in the xylem along with the water that "feeds" the transpiration needs and ends up in leaves rather than fruit. Once in the leaves, calcium is immobile, and will not move back to fruit.

The highest BER appearances were obtained from 4 weeks treatment at upper inflorescences (3rd truss). It is because of reduction in Ca^{2+} uptake occurred for long time and upper inflorescences are especially sensitive to salt effects (Cuartero & Munoz 1999). When DSW treatment was applied, 3rd truss were flowering and pollinated 3 days after treatment started. Thus treatment applied at early growth stage fruit caused high BER appearances.

The results of this study show conclusively that DSW treatment applied for 3 trusses tomato cultivation produced tomatoes with better organoleptic, high soluble solids content, acidity, dry matter content, a thicker and more resistant cuticle, healthy fruits and also obtained yields higher than in single truss tomato cultivation. Even the advantageous effect of DSW treatment decline from 1st to 3rd truss, the longest treatment (4 weeks treatment) could maintain high quality of fruits from 1st to 3rd truss evenhough there was higher BER occurrence.

In order to decrease the number of BER tomatoes, it's necessary to apply DSW treatment by intermittent method in further experiment. DSW treatment should be applied when fruits of 1st and 2nd truss are in rapid growth stage and then released when 3rd truss is pollinated. And then DSW treatment should be continued after fruits of 3rd truss are in rapid growth stage. It's necessary to conduct an experiment about a technique to reduce occurrences of BER tomatoes combined with intermittent method that may produce high quality tomatoes with high yield.

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