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Deficit Irrigation for Improving the Postharvest Quality of Lowland Tomato Fruits

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ABSTRACT

Arable lands are facing serious water scarcity due to climate change and available resources are depleting at an alarming rate which necessitate efficient use of water for agriculture. Deficit irrigation is an on farm strategy which is widely used in many crops to maximise crop productivity in drought prone areas. The present study was initiated to assess the effect of deficit irrigation at different growth stages of tomato (*lycopersicon esculentum*) on yield and fruit quality traits under greenhouse condition. Four regimes of irrigation: (T1) regular watering to field capacity (as control), (T2) irrigation every four days during vegetative stage, (T3) irrigation every four days throughout flowering stage and (T4) irrigation every four days during fruiting stage were evaluated in this study. The experiment was set up in a Randomized Complete Block Design (RCBD) with four replications. Data were collected from three fruit maturity stages: M3 (stage three, matured green), M4 (stage four, pink) and M6 (stage six, red) for yield, fruit weight, fruit number and the fruit quality parameters viz, firmness, soluble solids concentration, titratable acidity, pH, ascorbic acid and lycopene content. The results showed variable effects of deficit irrigation on most parameters studied. Soluble solids concentration were significantly increased under deficit irrigation at the flowering stage and increased from 5.25 brix (control) to 7.7 brix (fruiting) at stage three maturity index. The pH increased from 3.83 (control) to 3.97 (flowering) and 3.94 (fruiting) when fruits were harvested at stage three maturity index. In addition, the highest fruit firmness (3.4 N) was observed when fruit was harvested at stage three maturity under deficit irrigation (vegetative growth stage). Furthermore, lycopene content increased from 62.06 mg/kg in control plants to 67.91 mg/kg in plants which subjected to DI (vegetative) at stage six maturity index. However, water stress had no significant effect on titratable

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acidity, ascorbic acid and fruit weight. From the observations of this study, it can be concluded that T3 and T4 were adequately appropriate DI practices for MT1 tomato plants that could be recommended to tomato growers as deficit irrigation strategy for higher yield and quality.

Keywords: Deficit irrigation, fruit quality, growth stages, tomato, yield

INTRODUCTION

Tomato (*Lycopersicon esculentum*) belongs to the family of Solanaceae (Costa & Heuvelink, 2005). It is the main vegetable crop that has attained tremendous popularity during the last century. Its popularity stems from the fact that it can be eaten fresh or in multiple processed forms (Kole, 2007). Tomato fruits are rich sources of valuable nutrients, particularly vitamins and minerals. Vitamin A and C, total soluble solids (TSS) and acid contents are commonly considered as fruit quality properties in tomato fruits (Ilahy, Hdider, Lenucci, Tlili, & Dalessandro, 2011). Lycopene is one of the important carotenoids in tomato, normally regarded as a vital factor for cardiovascular protection and helps to reduce reactive oxygen species (Abete et al., 2013). Tomato is also valuable as a model crop for physiological, cellular, biochemical, molecular and genetic studies because it is easily grown, has a short life cycle and is easy to manipulate (Kinet & Peet, 1997). It is used as a model plant species to study the physiology and biochemistry of seed development, germination and dormancy (Suhartanto, 2002). Therefore, the tomato is an excellent tool to improve knowledge on horticultural crops (Kinet & Peet, 1997; Taylor, 1986).

Considering its versatility and wide acceptability, fruit yield and quality are critical factors to be considered in its production. However, it has been reported that fruits produced in tropical regions have lower yield than those produced in temperate regions (Muhammad & Singh, 2007). One of the important factors that has hampered productivity in most third world countries is poor management of water resources.

Globally, water resources have been observed to be declining at an alarming rate, leading to fear of future widespread scarcity. According to Escobar (2010), by 2025 about half of the population in the world would be facing water scarcity. Water deficit or drought is the most common stress condition globally and is increasingly of concern worldwide (Mahajan & Tuteja, 2005; Reddy, Chaitanya, & Vivekanandan, 2004).

Tomatoes are very sensitive to drought stress, initially during vegetative development and, later, when the tomato is in the reproductive stage (Wudiri & Henderson, 1985). Agada (2016) however, pointed out the growing decline in water resources is real but poor management is in most cases the real cause of water related low productivity in agriculture and is also a major factor in the growing scarcity of water. In line with this opinion, Boutraa (2010) stated that only about 50% of all

water available for agricultural purposes is utilised. The optimum requirements of irrigation lead to efficient management of water resources in such a way to enhance crop productivity. Water management practices are tools which can serve to protect our natural capital in water resources and avoid critical situations for the survival and sustainability of agriculture and economic activities which would prevent decline (Postel, 2000). Although the development of irrigation has contributed greatly to increased crop productivity as well as improvement in overall agricultural performance (Hussain & Wijerathna, 2004), it is not without its cost, including negative environmental and health consequences, such as increased water logging, scarcity, salinisation and water-borne diseases. Some of these problems can be remedied by better management strategies like deficit irrigation. Deficit irrigation is a water management method in which water is saved with accepting little yield reduction without any severe damage to the plant (English, 1990). Geert and Raes (2009) recommend it as a water saving technology in arid regions and other water scarcity prone areas. Although deficit irrigation strategies have the potential to optimise water productivity in horticulture, nevertheless, its effects on yield or harvest quality are crop-specific. Knowledge of how different crops cope with mild water deficits is the basis for a successful application of deficit irrigation into practice (Costa, Ortuño, & Chaves, 2007). This study describes the effect of limiting water supply to emulate water stress during plant development on postharvest qualities of tomato fruits with the aim of identifying the effects of water stress at different phenological stages of tomato on yield and quality of fruits harvested at different fruit maturity stages. This will enable us to look at the benefits that can be derived with controlled stress imposed as management practice.

MATERIALS AND METHODS

The influence of different irrigation regimes on the yield and quality of tomato under greenhouse was conducted in Ladang 15, Faculty of Agriculture, Universiti Putra Malaysia. The experiment consisted of four irrigation regimes replicated four times in a Randomized Complete Block Design (RCBD). The total plants used were 48. The treatments were regular watering to field capacity (T1), as control group, irrigation every four days during vegetative stage (T2), irrigation every four days throughout flowering stage (T3), and irrigation every four days during fruiting stage (T4). Water stress treatments were imposed 40 days after sowing (T2), 54 days after sowing (T3) and 63 days after sowing (T4). For imposition of water stress, water amount was determined based on the percentage of field capacity. To calculate the field capacity, at the beginning of the experiments, pots were filled with known weight of mixture of coco peat: burnt paddy husk, saturated with water and allowed to drain freely for a period of two hours, until there was no change in weight.

The difference between this weight and soil dry weight (DW) was used to calculate 100% of water holding capacity. Plants were grown in poly bags, 24 cm by 28 cm in dimension. Each bag was placed on a black plastic sheet laid on the ground of the greenhouse, in order to trap soil material escaping from the drainage holes at the base of the bags as well as weed control. Any soil material escaped from the pot was returned to the bag, thus maintaining as much amount of soil as possible throughout the experiment. In each of the four blocks, plants with different treatments were randomly arranged at spacing of 50 cm between each bag.

Planting Media

The media consisted of a mixture of coco peat and burnt paddy husk (2:1 v/v). The dry media was placed in the bags and manually compacted. Media weight was approximately 1 kg per polybag.

Growing Conditions

The seeds were germinated on peat medium in trays with drainage holes. Seeds of MT_1 tomato variety produced by Malaysia Research and Development Institute (MARDI) were used for the experiment. A single seed was sown per hole and covered with ~8 mm peat. The tray was placed on a raised platform and watered daily with a sprinkler. After three weeks, vigorous and uniform seedlings were selected and transplanted into the polybags. Fertiliser [N: P: K: Mg + TE (12:12:17:2+B)] was used by side placement at transplanting and between two and six weeks after transplanting (WAT). Polybags were kept weed free through manual weeding. Control of pest, mainly white flies was done by spraying plants with Malathion (2.5 $mLliter^{-1}$ of water) every week, from transplanting (21 days after sowing) to end of harvesting (75 days after transplanting).

Growth Parameters

Three plants were randomly selected from each replicate of the treatment and data were collected for the following parameters: plant height, number of leaves, fruit weight and number, fresh and dry shoots, as well as fresh and dry roots.

Plant Height (cm) and Number of Leaves

Plant height was measured from ground level to the tip of growing point using a meter ruler and the number of leaves was determined by counting.

Total Fruit Weight (g) and Number

The total yield and number of fruits were recorded at each sequential harvest. The fruits were harvested after they reached the mature green, pink and red stages. Fruit maturity stage was determined according to the USDA standard classification using human visual inspection. The fruits were counted and weighed accordingly on a weighing balance.

Fresh and Dry Weight of Shoots and Roots (g)

The fresh weight of the shoots and roots samples were determined separately using a weighing balance. Thereafter, the samples were placed in an oven at 70° C for 72 hours before dry weight determination.

Analysis of Physicochemical Parameters

Fruit firmness, soluble solids concentration (SSC), titratable acidity, pH, ascorbic acid and lycopene contents were determined and recorded. All readings were taken in three replicates.

Fruit Firmness Determination

The firmness of fruits was evaluated using Instron penetrometer (model 5543, USA). Constant force was applied to the plunger vertically on 1-cm thick fresh tomato fruit slice at a uniform speed, and the penetrometer reading was recorded in Newton (N).

Total Titratable Acidity (TA) Determination

Titratable acidity is a measure of the percent of citric acid in fruits and is an important criterion in the evaluation of fruit quality.

Preparation of Reagents

1. Phenolphthalein (1%) indicator was prepared by dissolving 0.5 g phenolphthalein in 50 ml ethanol.
2. The 0.1 sodium hydroxide solution was prepared by dissolving 4 g NaOH in 500 ml of distilled water in a 1 L measuring cylinder and the volume made up to 1 L with distilled water. Both solutions were prepared, stored in sealed containers and refrigerated for two days before chemical analysis was carried out.

Preparation of Samples

Twenty grams of fruit sample was homogenised in 80 ml of distilled water using a blender and filtered, using cotton wool plugged funnel. From the filtrate collected, five (5) milliliter was measured into a beaker and two drops of phenolphthalein indicator was added before being titrated against 0.1M NaOH. Titration was done until the solution changed to pink, consistent for 20 seconds. The volume of titrate added was recorded and the result was expressed as percentage of citric acid using the following formula.

$$\text{Cirtic acid} = \frac{\text{mL NaOH} \times 0.1\text{M NaOH} \times \text{vol. of product (100 mL)} \times 64\text{g(equivalent weight of citric acid)} \times 100}{\text{weight of samples (20g)} \times \text{vol. of sample for titration (5mL)} \times 100}$$

Source: (Ahmad & Ding, 2008)

Fruit Soluble Solid Concentration (SSC) Determination

SSC was measured using a digital refractometer (Digital Pocket Refractometer Pal-1 Japan). One drop of fruit juice obtained by squeezing a slice of tomato fruit was placed on the glass lens of refractometer. The refractometer reading was recorded in Brix˚ degree.

Determination of pH

pH was measured using a digital pH meter (CRISON pH meter GLP 21). Sample of filtrate prepared for determination of titratabile acidity (TA) was used for pH. The pH value of juice was obtained by immersing electrode into the juice until the reading of pH meter was stable.

Determination of Ascorbic Acid (mg/100g)

Ascorbic acid was measured by homogenising 10 g of sample with 40 ml cool metaphosphoric acid using blender for one minute at high speed. This was then filtered with cotton and 5 ml from the filtrate was taken and titrated with dye solution until it turned pink. The volume of titrate added was recorded and the result was expressed as ascorbic acid (mg/100 g) using the following formula:

$$Ascorbic\ Acid\ \left(\frac{mg}{100g}\right) = \frac{\text{mL\_dye used} \times \text{dye factor} \times \text{vol.of product (100mL)} \times 100}{weight\ of\ sample\ (10g) \times vol.of\ sample\ for\ titration\ (5mL)}$$

Source: (Ahmad & Ding, 2008)

Lycopene Content

Lycopene content was determined following the low volume spectrophotometric method developed by Anthon and Barrett (2005). Sample was prepared by transferring 0.1 mL of well homogenised tomato into scintillating bottles using a 100 µL micro pipette. Eight mL of mixture of reagent grade hexane, absolute ethanol and acetone were then added in the ratio 2:1:1. This was vortexed and 1 ml distilled water added to separate the phases. It was again vortexed and left to stand for about two hours. The spectrophotometric reading was taken using the thermo scientific Multiscan GO spectrophotometer, model 1510 at a wavelength of 503 nm. Lycopene content was then calculated using the formula below (Anthon & Barrett, 2006).

$$\text{Lycopene mg.Kg}^{-1}\text{freshweight} = \frac{(A503 * 537 * 8 * 0.55)}{(0.10 * 172)} = A503 * 137.4$$

537 $gmol^{-1}$ is the molecular weight of lycopene, 8 ml is the volume of mixed solvents, 0.55 is the volume of the upper layer of the extraction mixture which contains the extracted lycopene, 0.10 g (0.1 ml) is the weight of tomato added and 172 mm is the extinction coefficient for lycopene in hexane.

Statistical Analysis

Results obtained were analysed using SAS (Version 9.4). One way independent Analysis of Variance (ANOVA) was conducted to measure the significant effects of the different types of irrigation treatment on the growth parameters measured, while a two way Anova was used to measure the significant effects of the differences of fruit maturity stages and treatments on the postharvest attributes for tomato fruit. The mean scores and standard deviations were also calculated. Fisher's LSD multiple comparison was also performed to indicate where the differences exist at $p<0.05$.

RESULTS AND DISCUSSION

Growth Parameter

Plant Height and Number of Leaves. The results of the effect of different deficit irrigation treatments on plant height and number of leaves are presented in Table 1. The results show that water stress treatments have no significant effect on plant height and number of leaves under different water stress timings ($p>0.05$), similar to the results reported by Nangare, Singh, Kumar and Minhas (2016), who observed growth parameters monitored in terms of plant height to follow similar trends.

Fresh and Dry Weight Measurements. The highest fresh shoot weight of tomato was observed when water stress was imposed at flowering stage (T3) 432.25 (g/plant), which was not significantly different from the application at vegetative stage (T2). The highest significant fresh root weight gain was observed on plants experiencing water stress imposed at vegetative stage (T2) while the highest reduction was noted in T4 (fruiting), as illustrated in Table 1. However there was no significant different between T1 (control) and T3 (flowering). Dry shoot weight of plants imposed with water stress at fruiting stage was significantly lower than imposition at flowering stage but not significantly different from vegetative and control treatments. However, for the root, water stress applied at fruiting significantly reduced the dry weight compared to other treatments which were not much different. Since dry shoot weight was more distinct than dry root weight, total dry biomass of the plants followed the trend of dry shoot weight. The results of the present study are in line with the findings of Seng (2014), who reported that water stress decreased all the components of dry matter but the reductions were more pronounced in plants subjected to drought stress at fruiting growth stage. These dry matter components increased with developmental stages (higher at flowering and fruiting stages).

Plants in the vegetative growth stage had reduced DM attributes under drought (39 to 82%). At flowering, DM attributes were lowered by water deficit. At fruiting, only leaf DM was lowered by 6%. Furthermore, root - shoot ratios increased in plants subjected to drought stress but decreased in plants subjected to full irrigation (control plants) and with developmental stages.

Yield and Fruit Number. The results on the effect of different deficit irrigation treatments on yield and number of fruits are presented in Table 1. The results show that there are significant differences ($p<0.05$) between deficit irrigation imposed at different developmental stages on total fruit yield of tomatoes. Imposition of water stress at fruiting stage seems to be more sensitive compared to other stages. Significant total fruit weight reduction is observed when the plants are stressed at fruiting stage compared to other treatments which are not obviously different. Optimum water supply at fruiting period is highly crucial in determining the final yield of tomato fruits (Chen et al., 2013). Generally, a similar deficit irrigation (DI) effect was reported by Patanè, Tringali, and Sortino (2011), who found that DI at 50% evapotranspiration (ET) did not induce any losses in tomato total fruit yield when treatment started at flowering stage. Also these results were in line with the finding by Nuruddin (2001), who reported that tomato yield was effected significantly by water deficit timing, and deficit irrigation at flowering growth stage gave the highest fresh yield whereas impositions of water stress at fruiting growth stage caused reduction in total fruit yield. The yield reduction in the plants when experienced moisture stress during the early fruiting stage, would have been due to reduced fruit size and fruit number. Furthermore, Wang, Du, Qiu and Dong (2011) reported that fruit maturation and harvesting stage is the most sensitive stage for tomato growth and yield, at which applying 1/3 or 2/3 irrigation amount of field capacity significantly reduces fruit yield. However, applying 1/3 or 2/3 irrigation amount of field capacity at either seedling growth stage or flowering stage has no negative impact on tomato yield. On fruit numbers, higher counts were observed when stress was applied at flowering and control treatment. On the contrary, when irrigation was reduced during vegetative and fruiting stage, the numbers were lower. There seems to be a contradiction for stress imposed at fruiting stage where the total fruit weight is high. This may be due to bigger fruit size obtained from this treatment. These results agree with the findings of Wang et al. (2011) who observed a clear response of the tomato fruit number related to irrigation treatments, compared to control treatment (full irrigation). Vegetative and fruiting stages significantly affected tomato fruit number while other treatment did not. Compared to control treatment, water deficit irrigation at vegetative and fruiting stage significantly decreased fruit

number by 38.1% and 28.2% and fruiting stage was significantly different from full irrigation treatment. The reduction in the fruit number is due to falling of immature fruits (Vijitha & Mahendran, 2010) when the plants are under water stress.

Table 1
Effect of deficit irrigation (di) imposition at different growth stages on plant height, leaves number, biomass, shoots dry weight, dry root weight, shoots to root ratio, fruit weight and fruit number of tomato plants

Irrigation treatments	Plant height (cm)	Leaves number	Fresh shoot wt (g)	Fresh root wt (g)	Shoots dry wt *(g)*	*Root dry wt (g)*	*Shoots: root ratio*	*Fruit weight (g/plant)*	*Fruit number*	*Dry biomass (g/plant)*
T1 No stress (control)	65.50a	93a	336.50b	72.25b	116.75ab	17a	6.60b	3414.3a	147.75a	133.7ab
T2 Vegetative	70.50a	84.8a	356.00ab	97.75a	150ab	18a	8.30b	2837.3ab	114.75b	168ab
T3 Flowering	69.75a	94a	432.25a	83.25b	170a	18.8a	9.45b	3382.8a	152.75a	188.7a
T4 Fruiting	69.75a	91a	297.50b	37.25c	100.50b	6.5b	14.95a	2423.8b	103.25b	107b

Note. Means followed by the same latter in column are not significantly different at $p \leq 0.05$

Physicochemical Parameter

Firmness. Firmness is one of the important indices used in determining the suitability of a fruit for harvest, transportation, storage and marketing. It is also a good measure of fruit quality as it is directly related to fruit development, maturity, ripening and storage potential. Fruit firmness is fundamentally affected by moisture content (Agbemafle, Owusu-sekyere, Bart-plange, & Otchere, 2014). The results showed that the effect of water deficit irrigation treatments was statistically not significant on fruit firmness while the effect of maturity fruit stages was statistically significant on fruit firmness. The interaction between water deficit irrigation treatments and maturity fruit stages was significant at 0.05 level (Figure 1). The results showed that fruits harvested at stage 3 maturity index (turning), from plants subjected to water stress treatment at the three growth stages were not significantly firmer than control treatment ($p \leq 0.05$). Indeed water deficit at the fruiting stage reduced fruit firmness significantly ($p \leq 0.05$). This trend was maintained at stage 4 maturity index (pink). However, fruits harvested at the sixth stage fruit maturity index (red) indicated significant ($p \leq 0.05$) enhancement in firmness when plants were subjected to water stress at the flowering and fruiting stage. Water stress imposed at vegetative growth stage enhanced firmness by 72.15 % over the value for the control. This indicates that for the management of fruit firmness, the best timing for water stress and harvesting is at vegetative growth stage and stage 3 fruit maturity. This result is in agreement with the findings of Wang et al. (2011),

who reported deficit irrigation to have a positive effect on firmness of the tomato fruit. In addition, Kumar et al. (2015) also observed that in very early (before the start of flowering) and late (from fruit set) cut off irrigation gave a high fruit quality in the firmness of tomato fruit. This stress induced positivity in firmness is due to the lower pressure on the cell wall and higher epidermal elasticity with decreased internal turgor, according to Guihard et al. (1999, as cited in Kumar et al., 2015).

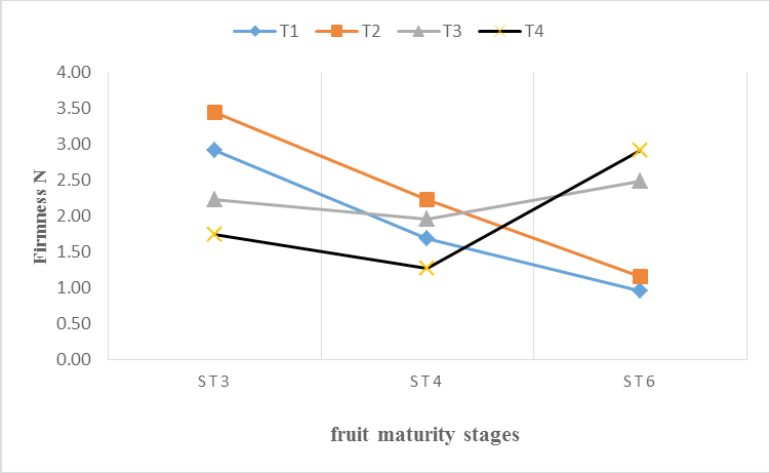

Figure 1. The interaction between water deficit irrigation treatments and maturity fruit stages on fruit firmness

Soluble Solid Content (SSC). The content of soluble solids in the fruit is an important quality factor for tomatoes grown for processing. The SSC is the principal parameter affecting paste yield (Johnstone, Hartz, LeStrange, Nunez, & Miyao Hartz, 2005; Patanè & Cosentino, 2010). It is desirable to have high values of SSC in the fruit because it improves the quality of the processed product. Cemeroglu et al. (2003) (as cited in Kucsçu, Turhan, & Demir, 2014) reported the average SSC content in industrial tomatoes to be at least 5 ˚Brix. Results shows that the SSC is significantly ($p<0.05$) affected by soil water deficit. As expected, the SSC was higher in the water stressed plants. In this study, the mean SSC was 7.7 ˚Brix for the deficit irrigation water level (T4 fruiting) and 5.25 ˚Brix for the maximum water application (T1 control treatment). Similarly, other researchers also reported that DI positively influenced the SSC values of tomato fruit (Helyes, Lugasi, & Pek, 2012; Kucsçu et al., 2014; Zegbe-Dominguez, Behboudian, Lang, & Clothier, 2003). Garcia and Barrett (2006) reported that yield is inversely related to the SSC of tomato. In this study, higher values of SSC were obtained from the treatments with irrigation omitted in the

yield formation and/or ripening stage, but total yield values were significantly reduced.

The results show that the effect of water stress treatments and maturity stages are statistically significant ($p \leq 0.05$) on soluble solids concentration, as shown in Figure 2. The interaction between deficit irrigation treatments and maturity stages is significant at ($p \leq 0.05$), as seen in Figure 2. The results also show that deficit treatment significantly enhances SSC in fruits harvested at the third and fourth stages of maturity index (turning and pink), from plants subjected to water deficit at the fruiting stage. These results agree with previous studies of imposed soil water deficit during fruiting stage (Behboudian et al., 2007; Johnstone et al., 2005; Kucsçu et al., 2014; Nuruddin, Madramootoo, & Dodds, 2003; Patanè & Cosentino, 2010) who reported that deficit irrigation treatment improves SSC accumulation in tomatoes. Increases in SSC in fruits grown under soil water deficits are related primarily to a decrease in fruit water content and to slight increase in soluble sugar accumulation (Mitchell, Shennan, Grattan, & May, 1991). Reduced irrigation may increase the starch concentration during early stage of fruit growth, hence a possible higher conversion of starch into sugars at fruit maturity. There was however no significant difference ($p \leq 0.05$) in SSC of fruits harvested at sixth stage of maturity index (red). Other researchers also found that deficit irrigation positively influences the soluble solids content of tomatoes, determining higher values for these parameters in comparison with those obtained in conditions of full irrigation (Nangare et al., 2013; Zegbe-Dominguez et al., 2003). Water stress imposed in the treatment could promote the translocation of photosynthates and improve fruit quality. The value for total soluble solids was 5.52 ˚Brix with DI (0.6 ET) throughout the period whereas 1.0 ET irrigation throughout the period recorded TSS of 3.47 ˚Brix (Kumar et al., 2015).

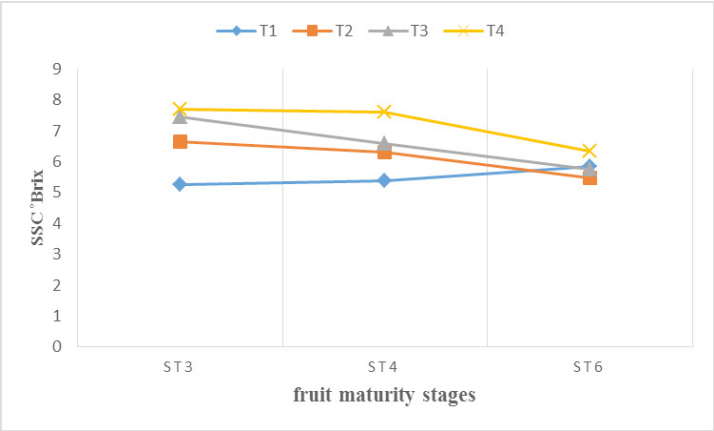

Figure 2. The interaction between water deficit irrigation treatments and maturity fruit stages on fruit SSC

Titratable Acidity (TA). Tomato acidity is dependent on several factors such as cultural practices, varieties and growing conditions (Kumar et al., 2015). The results of analysis of fruit TA is presented in Table 2. It shows that the effect of deficit irrigation treatments and fruit maturity stages on TA were not significant ($p \leq 0.05$). The interaction between water deficit irrigation treatments and maturity fruit stages was also not significant ($P \leq 0.05$). Thus, the treatments did not have any significant effect on the titratable acidity of the tomato. These findings are supported by Agbemafle et al., (2014) who reported no significance differences ($p > 0.05$) in the level of titratable acidity with under water deficit tomatoes and well irrigated ones.

pH. Among the parameters analysed for the assessment of tomato quality, pH is very important because acidity influences the thermal processing conditions required for producing safe products. Although the pH of mature tomatoes may exceed 4.6, tomato products are generally classified as acid foods ($pH < 4.6$), which require moderate conditions of processing to control microbial spoilage and enzyme inactivation. In addition, tomato product flavor depends on the accumulation and balance between sugar and organic acid content (Hobson & Grierson 1993, as cited in Garcia & Barrett, 2006). The result of analysis of the effect of water deficit irrigation treatments and fruit maturity stages on pH is presented in Table 2. It shows the effect of water deficit irrigation treatments and fruit maturity stages on pH value were statistically significant ($p \leq 0.05$). The interaction between water deficit irrigation treatments and fruit_maturity stages was not significant ($p \leq 0.05$). This result is in agreement with the findings of Nuruddin et al. (2003) and Amor and Amor (2007) who reported that fruit quality, especially pH was significantly affected as a result of lower water availability for the roots, while Wahb-Allah and Al-Oman (2012) reported deficit irrigation treatments had significant positive effect on pH. The highest mean values of pH was attained by water stress treatments.

Ascorbic Acid (AA). Ascorbic acid (AA) in plants is necessary to offset oxidative stress, in addition to regulation of other plant metabolic processes. It has been detected in the majority of plant cell types and organelles. AA becomes the main antioxidant due to its ability to donate electrons in a wide range of enzymatic and non enzymatic reactions, thus detoxifying reactive oxygen species (ROS) (Kumar et al., 2015). The results of analysis of fruit AA is presented in Figure 3. It shows that the effect of deficit irrigation treatments and fruit maturity stages on AA were not significant ($p \leq 0.05$). The interaction between water deficit irrigation treatments and maturity fruit stages was also not significant ($p \leq 0.05$). Thus, the treatments did not have any significant effect on the ascorbic acid content of tomato fruits subjected to deficit water treatment. This result is in agreement with the findings

of Helyes et al. (2012), who reported no significant differences on ascorbic acid content between water deficit treatments.

Lycopene Content. The result of analysis of the effect of water deficit irrigation treatments at different fruit maturity stages on lycopene content is presented in Figure 3. There is a significant effect on lycopene content between treatments and fruit maturity stages and also on their interaction. In contrast to this, Helyes et al. (2012) reported that the lycopene content of tomato fruits subjected to deficit irrigation treatment is not significantly different from those produced with regular (full) irrigation treatment. They found that fruits produced with irrigation cut-off had lycopene content of 115±8.6 while fruit with regular irrigation had 119±17.2 mg/kg. Agreeing with this observation, Giannakoula, Anastasia, & Ilias (2013) concluded that drought stress maintain the lycopene content in tomato fruits. The effect of fruit maturity stages on lycopene content was however statistically significant. The interaction between water deficit irrigation treatments and fruit maturity stages was also significant ($p \leq 0.05$) figure (3). The results show that harvesting fruits at stage 6 maturity index from vegetative T2 and fruiting T4 were more beneficial and had the highest content of lycopene, of 67.90 and 67.76 mg/kg respectively, lycopene wise, than harvesting at stage 3 and 4, under the same water deficit conditions.

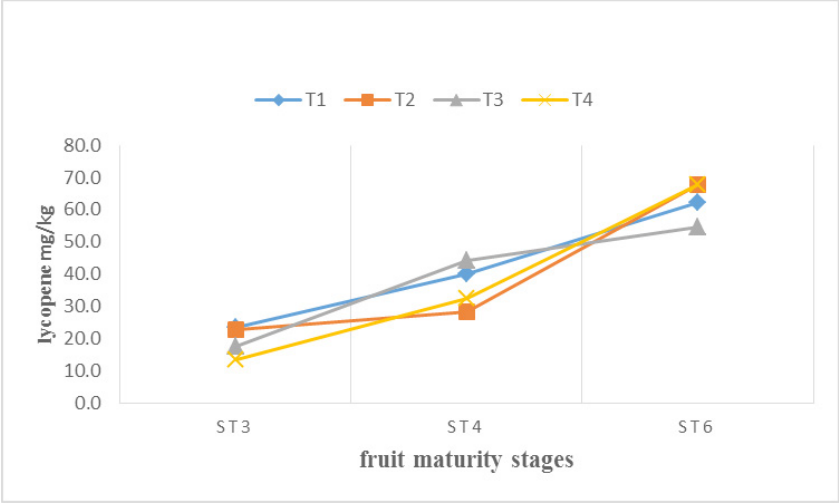

Figure 3. The interaction between water deficit irrigation treatments and maturity fruit stages on fruit lycopene content

Table 2
Effect of deficit irrigation (di) timing on firmness, soluble solids concentration (ssc), titretable acidity (ta), ph, ascorbic acid (aa) and lycopene of tomato fruits at different fruit maturity stages (mf)

DI treatments	MF stages	Firmness (N)	SSC (˚Brix)	T A(%) citric acid	pH	A A (mg/100g)	Lycopene (mg/kg)
T1 Control	ST3	2.91 ab	5.25 e	0.49a	3.83d	45.87a	23.58 fg
T1 Control	ST4	1.68 cde	5.38 de	0.48a	4.0ab	63.94a	40.08 cd
T1 Control	ST6	0.96 e	5.85 cde	0.42a	3.92bcd	65.33a	62.06 ab
T2 Vegetative	ST3	3.45 a	6.65 bc	0.59a	3.93bcd	64.87a	22.83 fg
T2 Vegetative	ST4	2.23 bcd	6.30 cd	0.56a	3.93bcd	55.25a	28.21 ef
T2 Vegetative	ST6	1.16 e	5.48 de	0.60a	3.98abc	55.60a	67.91 a
T3 Flowering	ST3	2.23 bcd	7.45 ab	0.59a	3.97abc	49.69a	17.61 gh
T3 Flowering	ST4	1.96 bcde	6.60 bc	0.48a	4.02ab	50.74a	44.14 c
T3 Flowering	ST6	2.48 abc	5.75 cde	0.51a	4.06a	55.60a	54.65 b
T4 Fruiting	ST3	1.74 cde	7.70 a	0.56a	3.94bc	63.25a	13.39 h
T4 Fruiting	ST4	1.27 de	7.60 ab	0.63a	3.9cd	62.20a	32.67 de
T4 Fruiting	ST6	2.91 ab	6.35 cd	0.59a	3.94bc	57.34a	67.77 a

Note. Means followed by the same letter in column are not significantly different at $p \leq 0.05$

CONCLUSION

Based on the results of this study, it can be concluded that deficit irrigation strategy has positive effects on some physicochemical quality of the greenhouse tomato fruits variety, MT1. Deficit irrigation at different growth stages caused significant ($p<0.05$) increase in fruit firmness, soluble solids concentration, lycopene content and maintained the ascorbic acid, titratable acidity and pH value when compared to full irrigation (control). Effects of imposition of deficit irrigation on growth and yield parameters were variable, as there was no statistically significant difference in the plant height and leaves number due to water stress treatment. However, fruit weight and the number of fruits increased significantly under deficit irrigation treatments. Applying water stress at fruiting stage also decreased the fruit yield and number in tomato. In, addition, water deficit irrigation at fruiting stage significantly decreased the fresh and dry weight of shoots and root. The vegetative and flowering growth stages could be considered as the most tolerant to deficit irrigation, and the fruiting growth stage may be considered as the most critical growth stage. On the other hand, considering the effect of water deficit treatments on the physicochemical qualities of the tomatoes in this study, it is concluded that a reduction in the volume of water applied at vegetative and fruiting stage of the MT1 tomato variety would produce tomato fruits of higher quality

than that of regularly watered plants. It could therefore be used as a strategy for enhancing fruit quality with reduced cost of production, from water and energy compensating for the yield losses due to the stress treatment.

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