Effect of Moisture Stress on Fruit Quality and Yield of Selected Tomato (Solanum lycopersicum L.) Cultivars

Begam, M. S. K.1, Mahendran, S.1 and *Puvanitha, S.2

1Department of Agricultural Biology, Faculty of Agriculture, Eastern University, Sri Lanka
2Department of Biosystems Technology, Faculty of Technology, Eastern University, Sri Lanka
**spuvani@gmail.com*

Abstract - Tomato (Solanum lycopersicum (L.) H. Karst.) is one of the most nutritionally and economically important vegetable plant in the world and the good productivity of tomato requires availability of water throughout the cycle, as the tomato plant is very sensitive to soil water deficit. Therefore, an experiment was conducted at the Crop Farm of the Faculty of Agriculture, Eastern University, Sri Lanka to determine the effect of moisture stress on fruit quality of selected tomato cultivars viz. 'Roma', 'Thilina' and 'KC1' such as the vitamin C, total soluble solids (TSS), acid contents and yield of tomato fruits during fruit ripening stage. The experiment was conducted in Randomized Complete Block Design with six treatments and four replications. Moisture stress was imposed for a period of six days for the treated plants during the flowering stage. The control plants were irrigated daily to the Field Capacity. The result showed that moisture stress reduced the vitamin C contents of fruits. The highest (18.2 mg/100 g) ascorbic acid content was obtained in cv. 'KC-1' while the lowest (8.7 mg/100 g) was obtained in cv. 'Roma'. The TSS and acid contents of the fruits were slightly affected by moisture stress when the stress was imposed during the flowering stage. The highest (6.7%) TSS content was recorded in cv. 'Thilina' while the lowest (1.8%) was observed on cv. 'Roma' and there were no significant differences between treatments in the acidity of 'Roma', 'Thilina' and 'KC-1' under stressed condition. Moisture stress significantly ($p<0.05$) reduced the yield of 'KC1', 'Roma' and 'Thilina' tomato cultivars. The highest yield (5252 kg ha-1) was obtained in the 'KC-1' with low (14%) yield reduction and the lowest yield (4080 kg ha-1) was found in 'Thilina' with high (31%) yield reduction under moisture stress. Among the tested tomato cultivars, 'KC-1' was identified as the most moisture stress tolerant and showed potential for cultivation in drought prone areas that focus on the production of higher yield with better fruit quality.

Keywords - Soil Water Deficit, Tomato, Total Soluble Solids, Vitamin C, Yield

I. INTRODUCTION

Tomatoes, which consume large quantities of water in semi-arid climate conditions and are one of the most planted vegetables in Sri Lanka. The commercial value of the table tomato is defined by the characteristics and quality of the fruit [1]. Soil moisture stress is common threat in the production of most crops and it has a substantial negative impact on the growth and development [2]. Therefore, water scarcity is one of the most widespread limitations to crop production. Plants respond to soil water-deficit conditions by disrupting cellular pathways or whole plant functions [3]. Water deficit affects every aspect of plant growth, including anatomy, morphology and biochemistry [4]. and will mostly reduce the crop production. Crop growth is frequently subjected to water stress during the course of its life time. Stress imposed during these periods drastically affects crop growth, ultimately leading to a massive loss in yield and quality [5]. Fruit quality, mainly total soluble solids, vitamin C, acid contents and yield are changed by moisture stress [6]. Soil moisture stress can affect plant growth, development and yield. Water deficit leads to the perturbation of most of the physiological and biochemical processes and consequently reduces plant growth and yield [7]. Abscission of reproductive organs like flower buds and flowers is a major yield limiting factor in vegetable crops [8]. The major constrain in expand tomato cultivation in the dry zone of Sri Lanka is the different patterns of environmental stresses such as drought and high temperature. These stresses constitute some of the most serious limitations to tomato growth, productivity and distribution. For high yield and good quality, the tomato needs a controlled supply of water throughout the growing period [9]. Therefore, efficient water management in relation to critical periods of stress is essential to optimize yield with available moisture. Present study was conducted with the objectives of determining the changes in the internal fruit quality of tomato with moisture stress and find out the effect of moisture stress on yield of tomato to determining the most suitable tomato cultivar which can be grown under the moisture stressed condition.

II. MATERIALS AND METHODS

1. Location

This experiment was conducted in the Crop Farm of the Eastern University, Sri Lanka which is situated at 100 m above the mean sea level to study the effect of effect of moisture stress on fruit quality and yield of selected tomato (Solanum lycopersicum L.) cultivars. Tomato cvs. 'Roma', 'Thilina' and 'KC-1' were used for this study.

2. Seedling Planting

The 10 g of selected tomato seeds were treated with 'Captan' solution (2g l-1). The seedlings were managed in the nursery beds according to the recommended practices of the Department of Agriculture [10]. The 28 days old vigorous and uniform seedlings were selected and transplanted on the main field at a spacing of 80 cm x 50 cm [10]. The experiment was laid out in Randomized Complete Block Design (RCBD) with five treatments and four replicates.

3. Treatments

The treatments were as follows:

T1 - Regular watering – Cv. ‘Roma’ cultivar of tomato.
T2 - Moisture stress – Cv. ‘Roma’ for 6 days.
T3 - Regular watering – Cv. ‘Thilina’ cultivar of tomato.
T4 - Moisture stress – Cv. ‘Thilina’ for 6 days
T5 - Regular watering – Cv. ‘KC-1’
T6 - Moisture stress – Cv. ‘KC-1’ for 6 days

The stress cycle was single in which water was withheld completely at once for a period of six days during the flowering stage.

4. Data Collection and Analysis

Five fruits were randomly plucked from each replicate of all the treatments during the fruit ripening stage. These fruits were blended by a blender and the juice was extracted. The fruits were collected on the 5th day from the commencement of the stress and were analysed for vitamin C, TSS and acid content by using standard methods of analysis [11]. For the yield, fruits were weighed and the yield was determined. The collected data were analysed statistically by using the analysis of variance (ANOVA) and the differences between treatments were compared by Duncan’s multiple range test (DMRT).

III. RESULTS AND DISCUSSION

Drought provokes a number of physiological changes in plants including oxidative damage. Ascorbic acid, also known as vitamin C, is one of the most abundant water-soluble antioxidant compound present in plant tissues. In the current work, the effects of water deficit on the stability of ascorbic acid by measuring its content, in one of the major vegetable crops, tomato (Solanum lycopersicum L.) was detected. In human health the vitamin C plays a major role as an antioxidant and necessary for collagen synthesis.

Effect of Moisture Stress on Ascorbic acid content (Vitamin C) of selected Tomato Cultivars

There were significant differences between treatments in the ascorbic content of ‘Roma’, ‘Thilina’ and ‘KC-1’ under the stressed condition (Table 1). It was also found that there was no interaction between cultivars and stress factors on ascorbic acid (vitamin C) content of fruits in all three cultivars during the flowering stage. The moisture stress decreased the vitamin C content of fruits when the stress was imposed during the flowering stage. The highest (18.2 mg/100g) ascorbic acid content was obtained in cv. ‘KC-1’ while the lowest (8.7 mg/100g) was obtained in cv. ‘Roma’ and the reductions in ascorbic acid content in cv ‘Roma’, ‘Thilina’, and ‘KC-1’were 52%, 31%,14% respectively.

TABLE 1

Effect of Soil Moisture Stress on the Ascorbic Acid Content of Tomato Cultivars During the flowering stage

Treatments	Ascorbic Acid (mg/100g)
T_1 - Regular watering – Cv. ‘Roma’	18.3^b
T_3 - Regular watering – Cv. ‘Thilina’	16.2^b
T_5 - Regular watering – Cv. ` KC1’	21.3^a
T_2 - Moisture stress – Cv. ‘Roma’	8.7^c
T_4 - Moisture stress – Cv. ‘Thilina’	11.1^b
T_6 - Moisture stress – Cv. ` KC1’	18.2^a
S (Stress)	P = 0.0031
V (Variety)	P = 0.7563
S x V (Interaction)	P = 0.9367

*Values in the same column followed by the same letter do not differ significantly ($p<0.05$)
*Values are the means of 20 plants in 4 replications.

According to [12], that moisture stress reduced the vitamin C content of chilli fruits. As illustrated by[13], that deficit irrigation has been found to cause a significant decrease in vitamin C content. As the route for vitamin C synthesis commences from D-glucose [14], the reduction in vitamin C content might be attributed to the reduction in the D-glucose synthesis level, which would have occurred during the period of stress, which in turn may have reduced the synthesis of vitamin C. This is maybe because moisture stress could have reduced the substrate concentration for vitamin C synthesis.

Effect of moisture stress on Total Soluble Solids of selected Tomato Cultivars

Moisture stress increased the total soluble solid content of fruits when the stress was imposed during the flowering stage. It was found that there were significant differences between treatments in the Total Soluble Solids of ‘Roma’, ‘Thilina’ and ‘KC-1’ during the flowering stage of the plants (Table 2). There was also no-interaction between cultivars and stress factors. The highest (6.7%) TSS content was recorded in cv. ‘Thilina’ while the lowest (1.8%) was observed on cv. ‘Roma’ under stressed condition during the flowering stage.

TABLE 2

The effects of soil moisture stress on the total soluble solids of tomato cultivars during the flowering stage

Treatments	Total Soluble Solids (°Brix)
T_1 - Regular watering – Cv. ‘Roma’	4.1^a
T_3 - Regular watering – Cv. ‘Thilina’	3.4^b
T_5 - Regular watering – Cv. ` KC1’	3.4^b
T_2 - Moisture stress – Cv. ‘Roma’	4.2^b
T_4 - Moisture stress – Cv. ‘Thilina’	3.6^c
T_6 - Moisture stress – Cv. ` KC1’	4.9^a
S (Stress)	P = 0.0447
V (Variety)	P = 0.0001
S x V (Interaction)	P = 0.5713

*Values in the same column followed by the same letter do not differ significantly (p<0.05)
*Values are the means of 20 plants in 4 replications.

Plants respond to water-deficit conditions by disrupting cellular pathways or whole plant functions [15]. Environmental stresses affect both tomato physiology and the synthesis of secondary metabolites such as phenolic acids, flavonoids, and terpenoids [16]. However, water-deficit may benefit tomato fruit quality due to the increased levels of total soluble solids (sugars, amino acids, and organic acids) which are major compounds which accumulate in the fruit [17]. A rise of soluble solids increases the value of the fresh fruits and improves the quality of the fruits because it affects the flavour, taste, and water content of the fruits. In addition, plants growing under stress conditions react by increasing their antioxidant production from both non-enzymatic systems (e.g., flavonoids, phenolic compounds, vitamins C and E, and carotenoids) and enzymatic systems (e.g., superoxide dismutase, glutathione reductase, catalase, and several peroxidases) [18].

Effect of moisture stress on Acidity of selected Tomato Cultivars

It was found that there were no significant differences between treatments in the acidity of 'Roma', 'Thilina'and 'KC-1' when the stress was imposed during the flowering stage of the plants (Table: 3). It was also found that there was no-interaction between cultivar and stress factors in the case of acidity. According [19], the effect of moisture stress condition on the growing tomato fruits had no significant effect on their dry matter and pH and similar result was found by [20].

TABLE 3

Effect of soil moisture stress on acidity of tomato cultivars during the flowering stage

Treatments	Acidity (% Citric acid)
T_1 - Regular watering – Cv. 'Roma'	0.56^a
T_3 - Regular watering – Cv. 'Thilina'	0.56^a
T_5 - Regular watering – Cv. 'KC-1'	0.50^a
T_2 - Moisture stress – Cv. 'Roma'	0.56^a
T_4 - Moisture stress – Cv. 'Thilina'	0.53^a
T_6 - Moisture stress – Cv. 'KC-1'	0.55^a
S (Stress)	P = 0.7119
V (Variety)	P = 0.6210
S x V (Interaction)	P = 0.4455

*Values in the same column followed by the same letter do not differ significantly (p<0.05)
*Values are the means of 20 plants in 4 replications.

In tomato fruits, organic acids with sugar make a major contribution to the taste of the fruits. Most variation in flavour can be related to differences in the sugar and acid contents of the fruits [21] observed that acid concentration was unaffected by water stress in matured Valencia orange. Variation in acid content has a much dramatic effect on flavour than the limited variation in sugar content that exists among most cultivars. As stated by [22] that the acid content of the fruit is very highly correlated with the total flavour of the fruit.

Effect of Moisture Stress on Yield of selected Tomato Cultivars

It was found that there were significant differences between treatments in the yield of fruits of 'Roma', 'Thilina' and 'KC-1' tomato cultivars under the stressed conditions (Table 4). Moisture stress significantly reduced the yield of all the selected tomato cultivars. The highest (5252 kg ha-1) yield was observed in 'KC-1' while the lowest (4080 kg ha-1) yield was recorded in cv. 'Thilina'. The reduction was highest in 'Thilina' (31.7%). The Roma cultivar showed the next yield reduction (21.9%). The 'KC-1' cultivar also showed lower yield reduction of 14% compared to the control treatment. However the reduction was non-significant (p>0.05). As reported by [23], revealed that fruit yield was decreased with increasing water stress. Similarly, the research carried out by [24] reported that low stress levels resulted in maximum yields, while high stress resulted in the lowest yields thus the fruit yield is the result of the expression and association of several plant growth components. The deficiency of water leads to severe decline in yield traits of crop plants probably by disrupting leaf gas exchange properties which not only limits the size of the source and sink tissues but the phloem loading, assimilate translocation and dry matter portioning are also impaired [25].

TABLE 4

Effect of soil moisture stress on the yield of tomato cultivars during the flowering stage

Treatments	Yield (kg/ha)
T_1 - Regular watering – Cv. 'Roma'	5708^b
T_3 - Regular watering – Cv. 'Thilina'	5972^{ab}
T_5 - Regular watering – Cv. 'KC-1'	6104^a
T_2 - Moisture stress – Cv. 'Roma'	4458^b
T_4 - Moisture stress – Cv. 'Thilina'	4080^c
T_6 - Moisture stress – Cv. 'KC-1'	5252^a
S (Stress)	P < 0.0001
V (Variety)	P < 0.0001
S x V (Interaction)	P = 0.0005

*Values in the same column followed by the same letter do not differ significantly (p<0.05)
*Values are the means of 20 plants in 4 replications.

It was found that there was an interaction between cultivars and stress effects. These results can be elucidated in some previous studies that moisture stress caused reduction in many crops yields depending on both intensity and duration of stress period, type of species and type of cultivar of the same species [12]. Similar results had also been reported by [23] who recorded a substantial decrease in yield of four tomato varieties under different levels of moisture stress. The highest reduction in yield of tomato when the plants experienced moisture stress during the flowering stage indicates that the flowering stage is the most critical stage of tomato compared to the other growth stages. As reported by [26] that soil water stress during the flowering stage reduced the weight of green bean pods by 71 % while a similar stress before flowering reduced the yield by 53% and after flowering by 35%.

IV. CONCLUSIONS

This experiment revealed to what extent the biochemical parameters and the yield were affected when the tomato plants were subjected to moisture stress during the flowering stage. As the parameter which was selected to determine the responses were good stress indicator such as Total Soluble Solids, Acidity and Vitamin C, by obtaining the above values one would be able to estimate the extent of damage caused to these crops as they are important in determining the yield.

It was concluded that, the moisture stress caused the highest yield reduction in selected tomato cultivars. 'KC-1' cultivar of tomato is better stress tolerant to moisture stress compared to 'Roma' and 'Thilina' cultivars. With regard to the final yield, the selected tomato cultivars which experienced moisture stress showed significant variations. Hence, 'KC-1' cultivar of tomato could be suggested to have high stress tolerance and better yield than the rest of the cultivars grown in the sandy regosol of the Eastern Province. The frequency and quantity of irrigation thus could be adjusted properly, so that less or no moisture stress is experienced by plants during the flowering stage in order to sustain the potential yield. In the dry zone of Sri Lanka, where water availability is scarce, the stress tolerant tomato cultivar could be used for crop management programmes.

REFERENCES

1. Ferreira, K., Rodrigues, S. M., Sossela de Freitas, J. R. and Lazzari, E. N. (2004). Identity and quality standards of tomatoes (Solanum lycopersicum) for fresh consumption. Ciência Journal of Research and Development. 34(1): 329-335.
2. Asseng, S., Ewert, F., Martre, P., Reimund P., Rötter, D. B., Cammarano, L. D. and Kimball, B. A. (2015). Rising temperatures reduce global wheat production. Nature Climate Change. 5(2): 143-149.
3. Yordanov, I., Velikova, V. and Tsonev, T. (2000). Plant responses to drought, acclimation and stress tolerance. Photosynthetica, 38(2): 171-186.
4. Kazan, K. and Rebecca L. (2015). The link between flowering time and stress tolerance. Journal of Experimental Botany, 67(1): 47-60.
5. Govindarajan, M., Rao, M.R., Mathuva, M.N. and Nair, P.K. (1996). Soil-water and root dynamics under hedgerow intercropping in semiarid Kenya. Agronomy Journal. 88(4): 513-520.
6. Kozlowski T. T. (1972). Water deficit and plant growth. Academic Press, London, UK. pp. 91-111.
7. Boutraa, T. (2010). Improvement of water use efficiency in irrigated agriculture: A review. Journal of Agronomy. 9(1): 1-8.
8. Wien, H. C., Turner, A. D. and Yang, S. F. (1989). Hormonal basis for low light intensity-induced flower bud abscission of pepper. Journal of the American Society for Horticultural Science. 114(4): 231-239.
9. FAO (1996). Food and Agriculture Organization of the United Nations. Report No: 34: 12-18.
10. Anon. (2005). Techno-guide. Department of Agriculture, Sri Lanka.
11. AOAC. (1998). Official Methods of Analysis. (15th Ed). New York, USA. pp 8-14.
12. Mahendran, S. and Bandara, D. C. (2000). Effects of soil moisture stress at different growth stages on vitamin C, capsaicin and β-carotene contents of chilli (Capsicum annuum L.) Fruits and their impact on yield. Tropical Agricultural Research. 12: 95-106.
13. Vijitha, R. and Mahendran, S. (2010). Effect of moisture stress at different growth stages of tomato plant (Lycopersicon esculentum Mill.) on yield and quality of fruits. Journal of Science. 6: 1-11.
14. Giovannoni, J. J. (2007). Completing a pathway to plant vitamin C synthesis. Proceedings of the National Academy of Science. 104(22): 9101-9110.
15. Murshed, C. K., Ramzi, F. L. and Huguette S. (2013). Effect of water stress on antioxidant systems and oxidative parameters in fruits of tomato (Solanum lycopersicon L, cv. Micro-tom). Physiology and Molecular Biology of Plants. 19(3): 363-378.
16. Barbagallo, R. N., Di Silvestro, I. and Patanè, C. (2013). Yield, physicochemical traits, antioxidant pattern, polyphenol oxidase activity and total visual quality of field grown processing tomato (cv. Brigade) as affected by water stress in Mediterranean climate. Journal of the Science of Food and Agriculture. 93(6): 1449-1457.
17. Yin, Y.G., Kobayashi, Y., Sanuki, A., Kondo, S., Fukuda, N., Ezura, H., Sugaya, S. and Matsukura, C. (2009). Salinity induces carbohydrate accumulation and sugar-regulated starch biosynthetic genes in tomato (Solanum lycopersicum L. cv.'Micro-Tom') fruits in an ABA-and osmotic stress-independent manner. Journal of Experimental Botany, 61(2): 563-574.
18. Apel, K. and Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. Annual Review of Plant Biology. 55(1): 373-399.
19. Klunklin, W. and Savage, G. (2017). Effect on Quality Characteristics of Tomatoes Grown Under Well-Watered and Drought Stress Conditions. Journal of Organic Foods. 6: 56-63.
20. Tandon, K. S., Baldwin, E. A., Scott, J. W. and Shewfelt, R. L. (2003). Linking sensory descriptors to volatile and non-volatile components of fresh tomato flavour. Journal of Food Science. 68(7): 2366-2371.

21. Stevens, M. A., Adel A. K. and Marjorie, A. (1979). Potential for increasing tomato flavour via increased sugar and acid content. Journal of the American Society for Horticultural Science. 104(1): 40-42.
22. Artherton, J.G. and Rudich, J. (1986). Tomato. Chapman and Hall Ltd, UK. pp. 122-179.
23. Shinohara, Y., Akiba, K., Maruo, T. and Ito, T. (1994). Effect of water stress on the fruit yield, quality and physiological condition of tomato plants using the gravel culture. Hydroponics and Transplant Production. 36: 211-218.
24. May, D. M. (1992). Moisture stress to maximize processing tomato yield and fruit quality. International Journal of Irrigation of Horticultural Crops. 335: 547-552.
25. Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S. A. (2009). Plant Drought Stress: Effects, Mechanisms and Management. In Sustainable Agriculture. Springer Netherlands. pp. 153-188.
26. Dubetz, S. and Mahalle, P. S. (1969). Effect of soil water stress on bush beans (Phaseolus vulgaris L.) at three different stages of growth. American Society of Horticultural Science. 94: 479-481.