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Osmotic Adjustment and Quality Response of Five Tomato Cultivars (*Lycopersicon esculentum* Mill) Following Water Deficit Stress under Subtropical Climate

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Abstract: The experiment was conducted in the experimental field of Sher-e- Bangla Agriculture University, Dhaka Bangladesh to study the effect of water stress on fruit quality and osmotic adjustment in five tomato cultivars. The percentage of field capacity levels were 40-50, 53-67, 69-85 and 82-100%. The plants had a tendency to adjust against drop in potential in soil by producing organic solutes such as glucose, fructose, sucrose and proline. The quality of fruits was improved as a result of the synthesis of ascorbic acid, citric acid and malic acid. No physical damage due to stress was observed in fruits, which were over 90% red.

Key words: Water stress, tomato, osmotic adjustment, fruit quality, Malic acid

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is one of the most important vegetable crop in the world. Of more than 100 species of vegetable crop selected for intensive study in representative Asian countries, tomato ranked first (AVRDC, 1977). It plays a vital role in providing a substantial quantity of vitamin C and A in human diet. The fruits are eaten raw or cooked. It is most popular as salad in the raw state and is made into soup, juice, ketchup, pickles, sauces, puree, paste, powder and other products (Thompson and Kelly, 1983; Bose and Som, 1986). In Bangladesh, the average yield of tomato is 7.42 t ha^{-1}, which is very low compared to other tropical countries (Anonymous, 1989). This low yield may be either due to lack of high ‘yielding varieties or poor management practices. High yielding variety is an important factor for maximizing the yield of tomato.

Tomato is sensitive to a number of environmental stresses, especially extreme temperature, drought, salinity and inadequate moisture (Kalloo and Bergh, 1993).

Under conditions of drought the free energy of water available to the plant is reduced well below that of pure free water. The accumulation of solutes within the cell occurs due to osmotic adjustment and help in maintaining turgor at decreasing water potential.

Plant water status controls the physiological process and conditions, which determine the quality and quantity of its growth (Kramer, 1983). Since water is essential for plant growth, it is axiomatic that water stress, depending on Its severity and duration, will affect plant growth, yield and quality of yield.

An investigation was conducted with five tomato cultivars to assess osmotic adjustment and fruit quality under water stressed condition.

MATERIALS AND METHODS

The Field experiment was conducted with five tomato varieties during the period from November 2009 to March 2010 in the experimental field of Sher-e-Bangla Agriculture University, Sher-e Bangla Nagar, in Dhaka, Bangladesh with geographical location 20°34’N-26°38’N and 88° 01’E-92°41’E, mean humidity 79.5%, annual rainfall (average) 2000 mm and maximum annual temperature 36°C and minimum 12°C. The annual precipitation varies from 1500 mm in the north to 5700 mm in the northeast (Hussain, 1992).

The experiment was conducted to evaluate the fruit quality and osmotic adjustment in tomato plants due to water stress. Five varieties of tomato plants namely, BR-1, BR-2, BR-3, BR-4 and BR-5 were the test crops.

The soil used in the field experiment was of Tejgaon series under Madhupur tract (According to Reconnaissance Soil survey report of Dhaka District, 1965 reviewed in 1987).

For physical and chemical analysis, soil samples were collected at a depth of 0-15 cm from experimental field of Sher- e -Bangla Agriculture University and the analysis were done in the Laboratory of the Department of Soil, water and Environment at Dhaka University, Dhaka.

The collected soil samples were air-dried ground to pass through 2 mm sieve and then mixed thoroughly to

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make a composite sample. Dry grasses and other vegetative residual parts were discarded form the soil.

The general physical and chemical characteristics of the soil were:

- Textural class of soil-loam, sand-35.80%, clay- 24.0%, Moisture at field-32% Moisture at wilting-10%, Maximum water holding capacity-45%, Hygroscopic moisture-1.73%, Bulk density-1.39g cc^{-1}, Particle density-2.63g cc^{-1}, Porosity-47%, pH-5.1, EC-90 µS, OM-1.1%, CEC-14.88 meq $100g^{-1}$ soil and N-0.07%

The experiment was carried out in a randomized complete block design with four treatments and three replications for each cultivar. Unit plot size was 1mx1m with four plants per plot.

The land was prepared well harrowing followed by laddering. The grasses, weeds and other vegetative residual parts were removed from the land.

Cowdung was applied at the rate of 6 t ha^{-1} at the time of final land preparation. N, P_2O_5 and K_2O were applied at the rate of 260-200-150 kg ha^{-1}, respectively. The entire amount of phosphate, potash and half of the nitrogen were mixed at the time of the preparation of land. The rest half of the nitrogen was applied in two splits, one at 21 days after sowing of plants during vegetative stage and another at flowing stage.

Seeds were sown at BADC (Bangladesh Agriculture Development Corporation) farm and after 25 days of germination, healthy seeding of uniform size was transplanted in the field. After transplantation, Plants had been shaded for 4 days to protect them form sunlight. In this experiment spacing were 75 cm between plots, 50 cm between rows and 45cm between plants.

Twenty one days after transplantation, each row of tomato plant was supported with bamboo stick to prevent lodging. Weeding in the plots was done where necessary.

As growth progressed, the tomato plants were attacked by insects. It was therefore, necessary to spray the plants with Malathion (1 ML in 1 L water) as insecticide. The insecticide was sprayed as and when required.

Five cultivars were used and the effect of 4 levels of irrigation regimes were studied. The stress period commenced from 28 days after transplantation. The water stress treatments were imposed at 82-100% (T0), 69-85% (T1), 53-67% (T2) and 40-45% (T3) of the field capacity, respectively.

Soil samples were collected at 6 days intervals for measuring the soil moisture percentages from the plots and were measured gravimetrically by drying the soil samples at 105°C for 24 h. To maintain the above mentioned moisture levels, the soil was irrigated with the amount of water lost by evaporation and transpiration. By addition of irrigation water after six days, the soil moisture levels were within the following ranges: 26-32% (T0), 22-27% (T1), 17-2% (T2), 13-16% (T3).

After the end of the experiment, data were recorded. The data reported in the table are the average of three replications. The ripening of the tomatoes were also observed and recorded.

Young and fresh leaves were taken for biochemical analysis. Three leaves of tomato plants of each plot were plucked, wrapped in aluminum foil and stored in the deep freeze. These were done just after plucking the leaves from the plants.

The ripped tomatoes were collected and visual quality and physical damage of tomatoes were determined according to the rating scale of Grierson and Kader (1986). Three tomatoes from each plot were cut into pieces for application of the rating scale for internal tissue damage due to bruising, the rest of the fruits were frozen for other investigations.

Three frozen tomatoes from each plot were minced separately by an electric mixture and extracted with water (60°C). In the extract the contents of glucose, fructose, sucrose, (with carrez-solutions) citric acid and malic acid were analyzed by enzymatic methods (Mannheim, 1989). For the assay of ascorbic acid, fruit samples were well minced with an electric mixture was adjusted to 3.7 with KOH and ascorbic acid was determined by enzymatic methods (Mannheim, 1989). Glucose, fructose, sucrose, malic acid, L-ascorbic acid and citric acid in tomatoes were determined by enzymatic methods described by Mannheim 1989. Proline in leaves was estimated by the method outlined by Bates *et al*. (1973). For determination of proline in tomato leaves, Purified Proline was used to standardize the sample values.

Finally the results were analyzed statistically employing the Duncan's new multiple range test (DMRT) at 5% level of significance.

RESULTS

Effect of water stress on osmotic adjustment and quality parameters: Concentrations of Proline, Crude protein, Glucose, Fructose, Sucrose, Malic acid, Citric acid and L-Ascorbic acid.

Results of these parameters among varieties and treatments are given in Table 1 and 2.

Proline: The proline contents in tomato leaves showed that there was a significant difference in concentration

Table 1: Content of organic solutes in different cultivars overall treatments

Cultivars	Proline	Crude protein	Glucose	Fructose	Sucrose	Ascorbic acid	Malic acid	Citric acid
	(%)							
BR-1	5.21ab	11.61a	0.66b	0.93ab	1.11b	0.049a	0.32c	0.66a
BR-2	5.79a	12.40a	0.92a	0.97a	1.84a	0.050a	0.36c	0.70a
BR-3	5.53ab	12.62a	0.80ab	0.91ab	1.29b	0.051a	0.50a	0.70a
BR-4	5.53ab	12.62a	0.80ab	0.91ab	1.29b	0.051a	0.50a	0.70a
BR-5	4.69b	12.33a	0.71b	0.86b	1.22b	0.053a	0.45b	0.68a

In a column, means followed by a common letter are not significantly different at the 5% level by DMRT

Table 2: Effect of water stress treatments on organic solutes content in plants overall cultivars

Cultivars	Proline	Crude protein	Glucose	Fructose	Sucrose	Ascorbic acid	Malic acid	Citric acid
	(%)							
T0	2.06d	121.95a	0.53c	0.79b	0.99b	0.028c	0.26d	0.42d
T1	3.89c	11.96ab	0.67c	0.97a	1.84a	0.050a	0.36a	0.70a
T2	6.12b	12.27ab	0.83b	0.93a	1.47ab	0.059b	0.47b	0.81b
T3	9.16a	11.78b	1.06a	1.03a	1.71a	0.077a	0.54a	0.94a

In a column, means followed by a common letter are not significantly different at the 5% level by DMRT

among the cultivars. The highest concentration was found in BR-2 and the lowest in BR-5. There was no significant difference between BR-4 and BR-1 (Table 1). The concentration of proline increased significantly with increasing water stresses. The highest concentration of 9.16% was observed at T3 which was about 345% higher than that of control (T0) treatment (Table 2).

Crude protein: Reverse phenomenon was noticed in crude protein concentration in tomato plants. The highest content of protein was determined at T0 and decreased significantly with decreasing water status of the soil, that is at T3 treatment.

In comparison among the cultivars the result demonstrated that there was no significant variation was observed among the entries (Table 1, 2).

Concentration of Glucose: The glucose concentration of fruits among the cultivars differed significantly and was found the highest in BR-2 followed by BR-4, BR-5 and BR-1 (Table 1). The contents of glucose in tomato fruits increased significantly with the increase in water stress (Table 2). There was about 100% increase in glucose contents at T3 compared with T0 treatment.

Concentration of Fructose: Like glucose, fructose contents in tomato fruits were also affected by water stresses. The lowest concentration of fructose was observed at T0 (Table 2), which had about 30% lower fructose content than that of T3 treatment.

Concentration of fructose is also dependent on variety and was found the highest in BR-2 and the lowest in BR-5. There was no significant difference between BR-1 and BR-4 (Table 1).

Concentration of sucrose: The result of this experiment demonstrated that the sucrose contents in fruits were much higher than glucose and fructose. The concentration was highest in BR-2. However there was no significant variation among the three varieties (Table 1).

The results also revealed that water stress increased the concentration of sucrose than glucose and fructose. The highest concentration was measured at T3 and the lowest at T0 treatment (Table 2). More than 72% increase in sucrose was notice at T3 compared with that on the control (T0).

Malic acid concentration: Malic acid concentration of fruits among the cultivars differed significantly. The highest concentration was found in BR-4 followed by BR-5. There was no significant difference between BR-2 and BR-1 (Table 1). Malic acid concentration was also affected by water stresses. Increased water stress also increased the synthesis of malic acid. The highest concentration was observed at T3 and the lowest was measured at T0 treatment (Table 2). An increased of 100% malic acid concentration was observed at T3 compared with T0 treatment.

Ascorbic acid concentration: The result of ascorbic acid concentration showed that there was no significant different among the cultivars (Table 1). However the treatments differed significantly. Its concentration increased with increasing water stress.

The highest amount of ascorbic acid was found at T3 treatment, while the lowest was at T0 treatment (Table 2). Water deficit significantly increased acid contents in tomato fruits to more than 175% at T3 compared with T0 treatment.

Citric acid concentration: Citric acid concentrations in tomato fruits showed that there was no significant difference among the cultivars, but the treatments differed significantly from each other.

The highest concentration was found at T3 while the lowest was at T0 treatment. There was an increase of about 124% citric acid was noticed at T3 compared with T0 treatment. The results also indicate that tomato fruits accumulated more citric acid than malic and ascorbic acids (Table 1, 2).

DISCUSSION

Osmotic adjustment is a key mechanism by which plants adapt to water shortages resulting from an increased solute concentration of cells in order to maintain the water potential gradients needed to ensure continued uptake of water during the stress period. In addition, osmotic adjustment allows cell to maintain the turgor, which is essential for plant growth and various other physiological processes.

According to Nahar and Gretzmacher (2002), Greenway and Munns (1980), Flowers *et al.* (1977), McCree (1986), Torrecillas *et al.* (1995), Ullah *et al.* (1993, 1994, 1997), Cahn *et al.* (2002) and Lobato *et al.* (2008) plants synthesize and accumulate organic solutes such as glucose, fructose, proline etc, which act as osmotica and play important role in osmotic adjustment in plants at reduced potential.

In this experiment, the proline concentration in tomato leaves increased with increasing water stress. This result is in agreement with others (Aloni and Rosenshtein, 1984; Wilfried, 2005; Tatar and Gevrek, 2008; Pakniyat and Armion, 2007; Gholami and Rahemi, 2010) who reported that proline accumulation during water and salt stress was the greatest in tomato and other crops.

According to Foroud *et al.* (1992) and Rose (1988), water stress decreased protein contents in plant.

The present result is also in consistent with that finding. It implies that soluble protein did not contribute to osmotic adjustment.

In this experiment, the content of glucose, fructose, sucrose, ascorbic, malic and citric acid in tomato increased significantly with water stress. This result confirms with the findings of Hai-Tao *et al.* (2006), Li *et al.* (2007), Adejare and Umebese (2008) and Ullah *et al.* (1993, 1994, 1997) who reported a significant increase in glucose, fructose, in some cases sucrose and organic acids contents in tomato, faba beans and soybean by water and salt stress improving fruit quality.

Ripeness classes of tomatoes were determined according to Grierson and Kader (1986). The tomatoes were red over 90%, classified as red, in all treatments. Regarding the internal tissue damage due to bruising, no degree to severity and no visible internal tissue damage were observed in all the treatments. Overall visual qualities of the fruits were found excellent and essentially no symptoms of deterioration were noticed in all the treatments. No symptom of physical damage in any of the treatments could be detected. Ripening and fruit quality studies showed that none of the stress treated tomatoes deteriorated in quality. On the other hand water stress enhanced the sweetness of the tomatoes by increasing their glucose, fructose and sucrose contents and improved the quality by increasing the amount of important acids such as ascorbic acid, malic acid and citric acid.

CONCLUSION

From the experiment it can be concluded that water stresses has significant impact on plants and improves the quality of fruits by increasing different solutes and organic acids. No physical and internal tissue damages in fruits were detected due to water stresses and tomatoes were over 90% red.

It is was observed that drought resistant cultivars enhanced the root system development (deep root system) which enabled plant to take up water from the lower depth of soil for their wide adaptation and internal physiological process during drought. These cultivars also produce organic solutes to adjust osmotically to survive against adverse conditions.

The result suggests that it is possible to use water stress tolerance a selection criteria in tomato breeding programs for drought resistant.

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