Effect of water stress on nutrient uptake, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under subtropical conditions

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Einfluss von Wasserstress auf Nährstoffaufnahme, Ertrag und Fruchtqualität von Tomaten (*Lycopersicon esculentum* Mill.) unter subtropischen Bedingungen

1. Introduction

Tomato is an important, popular and nutritious vegetable all over the world. It plays a vital role in providing a substantial quantity of vitamins C and A in human diet. In Bangladesh, the average yield of tomato is 7.42 t/ha, 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. Variety is an important factor for maximizing the yield of tomato.

Water plays an important role in plant life. In many localities, it is the limiting factor for agricultural crops and hence increasing yield. Therefore for judicial use of water, attempts should be made to obtain maximum yield with minimum water supply.

Under conditions of drought the free energy of water available to the plant is reduced well below that of pure free water. The osmotic adjustment as accumulation of solutes within the cell helps in maintaining turgor at decreasing water potentials.

Plant water status controls the physiological processes and conditions which determine the quality and quantity of growth (KRAMER, 1969). 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.

Therefore the objectives of this experiment were to assess osmotic adjustment, nutrient uptake, yield and quality of tomato under stress.

Zusammenfassung

In einem Topfversuch in Bangladesh wurde der Einfluss von Wasserstress auf Tomatenpflanzen und Ertrag und Qualität der Früchte untersucht. Ertrag und Trockenmasseproduktion zeigen gegensätzliche Beeinflussung durch 100 % und 40 % der Feldkapazität. Wasserstress verringerte signifikant die Aufnahme von Stickstoff, Natrium, Kalium, Schwefel, Kalzium und Magnesium. Dagegen gab es signifikante Zunahmen bei den Gehalten von Glukose, Fruktose, Saccharose in den Früchten und von Prolin im Blatt. Durch die stressbedingte Zunahme von Zucker und organischen Säuren (Ascorbin-, Apfel- und Zitronensäure) in den Früchten ergab sich eine Verbesserung der Qualität.

Schlagworte: Tomate, Wasserstress, Ertrag, Qualität, Bangladesh.

Summary

The influence of water stress on tomato plants and fruit quality was investigated in a pot experiment (Bangladesh). Yield and dry matter production were adversely affected at 100 % and 40 % of the field capacity. The uptake of nitrogen, sodium, potassium, sulphur, calcium and magnesium was significantly reduced by water stress in the plants. Significant increases in glucose, fructose, sucrose in fruits and proline content in leaves showed some tendency of this crop to adjust osmotically to water stress. Water stress increased the sugar and acid contents (ascorbic, malic and citric acid) of the tomato fruits and thus improved the fruit quality.

Key words: Tomato, water stress, yield, quality, Bangladesh.

2. Materials and methods

The experiments were conducted with four tomato varieties in the net house of the Department of Soil Science, Dhaka University, during the period from November 1998 to March 1999.

Earthen pots were filled with 8 kg air dried soil of the Demra soil series from Katchpur Dhaka, which was screened through a 2 mm sieve. It had the following composition: Sand 5.8 %, silt 60.2 %, clay 34.0 %, pH 7.2, organic matter 1.14 %, field capacity 33 %, CEC 17.9 meq/100 g soil and N 0.06 %.

Tomato plants, 24 days old and of uniform size were transplanted single to each pot. The pots were arranged in a completely randomized block design with three treatments and replications. The water stress treatments were 100 %, 70 % and 40 % of the field capacity (F.C.). After harvesting the ripe tomatoes, the weight was recorded and the visual quality and physical damage of tomatoes were determined according to the rating scale of GRIERSON and KADER (1986). Three tomatoes from each pot were cut into pieces for application of the rating scale for internal tissue damage due to bruising, the rest of the fruits was frozen for other investigations.

The total fresh weight of the tomatoes was calculated by summing up the fresh weight of all the harvests. Three frozen tomatoes from each pot were minced separately by an electric mixer and extracted with water (60 °C). In the extract, after clarifying with Carrez solutions, the contents of glucose, sucrose, citric acid and malic acids were analysed by enzymatic methods (BOEHRINGER MANNHEIM, 1989). For the assay of ascorbic acid, fruit samples were well minced with an electric mixer and homogenized in meta phosphoric acid (15 % W/W). The pH of the mixture was adjusted to 3.7 with KOH and ascorbic acid was determined by enzymatic methods (BOEHRINGER MANNHEIM, 1989). Proline was estimated by the method outlined by BATES et al. (1973).

After the last fruit harvest, tomato plants were harvested, dried at 65 °C and dry weights of the plants were recorded. Finally the plant samples were finely ground. The powdered plant samples after wet digestion in a HNO_3-$HClO_4$ (5:1) mixture were used for the determination of total Na, K, P, S, Ca and Mg.

Nitrogen was determined in the plant samples after digestion with sulphuric acid. Finally the results were analyzed statistically employing the Duncan's New Multiple Range Test (DMRT).

3. Results and discussion

The reduction of the water content in the soil caused increases and decreases in different characters as will be shown in the following 6 tables.

3.1 Effect of water stress on yield and dry matter production of plants

The statistically evaluated results of dry matter and yield in different cultivars and at different water stress treatments were presented in table 1 and 2.

Table 1: Dry matter production and yield of tomato cultivars over all treatments
Tabelle 1: Trockenmasseproduktion und Ertrag der Tomatensorten im Mittel aller Behandlungen

Cultivars	Dry matter (g/pot)	Yield (g/pot)
BR-1	11.37a	204.4a
BR-2	8.79ab	173.2b
BR-4	6.52b	207.9a
BR-5	9.07ab	214.0a

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

Table 2: Effect of water stress on dry matter production and yield of tomatoes over all cultivars
Tabelle 2: Einfluss von Wasserstress auf die Trockenmasseproduktion und den Ertrag von Tomaten im Mittel aller Sorten

Treatment	Dry matter (g/pot)	Yield (g/pot)
100 % F.C.	6.04b	132.60c
70 % F.C.	11.43a	281.10a
40 % F.C.	9.35a	185.90b

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

The dry matter produced by the plants due to stress was dependent on variety. In dry matter production the highest dry matter was obtained by BR-1, followed by BR-5, BR-2 and BR-4. However BR-2, BR-4 and BR-5 did not show significant difference among themselves (table 1).

The results also revealed that 70 % F.C. was the best treatment. However there was no significant difference between the two treatments, 70 % and 40 %, but the dry matter production was lower at 40 % compared to 70 % field capacity (table 2).

The interaction effect of water deficit and cultivars was highly significant in dry matter production. In most of the cultivars deficit water gives lower dry matter production. This result confirms the findings of others (ARAGON, 1988; INGRAM and YAMBAO, 1988) where they observed lower dry matter production due to stress.

Fresh weights of tomatoes were significantly affected by the treatments. The yield parameters are presented in table 1 and 2.

The data in table 1 and 2 show that there was no significant difference in yield among the cultivars (except BR-2) but difference among the treatments. The three cultivars BR-1, BR-4 and BR-5 contributed better yields compared to BR-2. These three cultivars did not show significant differences among themselves. The results in table 2 clearly demonstrate that water stress reduced the yield of tomatoes (40 % F.C.). However the results revealed the lowest yield per plant in the control treatment (100 % F.C.).

The yields of tomatoes were significantly affected both by (control) 100 % field capacity and stressed condition at 40 % field capacity. 100 % F.C. probably reduced oxygen availability or increased anaerobic toxins affecting tomato fruit production. In contrast, at 40 % F.C. the plants do not get enough water for physiological functioning. 70 % F.C. gave the highest yield. Probably water at field capacity was in excess for tomato plants, while 40 % field capacity was insufficient for physiological functioning of tomato plants in the production of fruits.

This result agrees with the findings of others (SINGH et al., 1988; LAL et al., 1988 and HAMID et al., 1990) who observed the lowest yield per plant in the control treatment and showed susceptibility to the lower soil moisture regimes.

3.2 Effect of water stress on nutrients content

The concentration of different nutrients, namely nitrogen, potassium, phosphorus, sulfur, sodium, calcium and magnesium in tomato plants were determined under different field moisture capacities. The results were obtained at the harvesting stage of growth and were evaluated on a percentage basis.

The nutrient concentrations among the cultivars and among the treatments are presented in table 3 and 4.

Nitrogen:
The varieties did not have any influence on nitrogen uptake in tomato plants. Table 3 shows that the percent nitrogen in tomato plants grown on silty clay loam did not differ significantly among the cultivars, but it was significantly affected by water stress (table 4).

The highest concentration was found at 100 % F.C. (1.47 %) and the lowest at 40 % (1.10 %) F.C. The percentage of nitrogen in plants showed the following sequence: 100 % F.C. > 70 % F.C. > 40 % F.C. At 40 % of the F.C. the concentration of nitrogen was decreased by 34 % compared with 100 % F.C. treatments. The results also indicated that the concentration of nitrogen was higher than that of all other nutrients.

Table 3: Nutrient content in different tomato cultivars over all treatments
Tabelle 3: Nährstoffgehalte der verschiedenen Tomatensorten im Mittel aller Behandlungen

Cultivars	% N	% K	% Na	% P	% S	% Ca	% Mg
BR-1	1.17a	0.48b	0.38a	0.19b	0.99a	0.76a	0.58a
BR-2	1.25a	0.59a	0.32a	0.21ab	1.00a	0.68ab	0.63a
BR-4	1.49a	0.62a	0.36a	0.18b	0.56b	0.44b	0.68a
BR-5	1.36a	0.64a	0.33a	0.26a	0.79a	0.55ab	0.69a

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

Table 4: Effect of different water stress treatments on nutrients content in plants over all cultivars
Tabelle 4: Einfluss der verschiedenen Wasserstressbehandlungen auf den Nährstoffgehalt im Mittel aller Sorten

Treatment	% N	% K	% Na	% P	% S	% Ca	% Mg
100 % F.C.	1.47a	0.64a	0.41a	0.25a	0.91a	0.70a	0.70a
70 % F.C.	1.38ab	0.59ab	0.35ab	0.23a	0.81a	0.64a	0.64a
40 % F.C.	1.10b	0.51b	0.28b	0.22a	0.80a	0.48a	0.59a

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

Potassium:
The concentration of potassium showed that there was no significant difference among the cultivars BR-5, BR-4 and BR-2, which contained the highest concentration, while it decreased significantly in BR-1 (table 3). Like for nitrogen, moisture stress also influenced significantly the uptake of potassium. Its concentration was the highest at 100 % F.C. (0.64 %) and the lowest at 40 % F.C. (0.51 %) (table 4).

Sodium:
The result showed that the concentration of sodium did not differ significantly among the cultivars (table 3). It decreased with increasing moisture stress. The highest amount of Na was found at 100 % and the lowest at 40 % field moisture capacity (table 4). Na contents at 100 % F.C. differed significantly by the moisture contents at 40 % F.C. The concentration of sodium at 40 % F.C. was 46 % lower compared to 100 % F.C.

Phosphorus:
The concentration of phosphorus showed that there were significant differences among the cultivars. The highest concentration was found in BR-5 and the lowest in BR-4 (table 3). Moisture stress treatments in this experiment did not influence significantly the uptake of phosphorous, its concentration showed a slight decrease from 100 % to 40 % F.C. (table 4).

Sulphur:
The concentrations of sulphur revealed that there was no significant difference among the cultivars BR-1, BR-2 and BR-5. However BR-4 differs significantly from the other three cultivars (table 3). Like phosphorous its concentration also showed no significant variation among the treatments (table 4).

Calcium:
Calcium concentrations differed significantly among the cultivars. The highest concentration was found in BR-1, followed by BR-2, BR-5 and BR-4 (table 3). The result showed that water stresses reduced the uptake of calcium concentration but not significantly from 100 % to 40 % F.C. (table 4).

Magnesium:
Like for calcium, there is also no significant difference for magnesium among the water stress treatments, although its concentration decreased with increasing stress (table 4). The result also revealed that there was no significant variation among the cultivars (table 3).

DUNHAM and NYE (1976) reported when plants are stressed to a low internal water potential, uptake of nutrients usually decreased due to diminishing absorbing power of roots.

BHARAMBE and JOSHI (1993) found that the uptake of N, P, K, Ca and Mg was adversely affected under the irrigation treatments of decreasing soil water potential below –33 kpa. HONDA (1971) reported that water stress in soil or sand hindered the nutrient uptake process.

The current investigations are corroborated with these findings and show a tendency of diminishing concentrations of N, P, K, S, Na, Ca and Mg with increasing water stress by the tomato plants.

Table 5: Content of organic solutes in different cultivars over all treatments
Tabelle 5: Gehalt an gelösten organischen Substanzen der verschiedenen Sorten im Mittel aller Behandlungen

Cultivars	% Proline	% Crude protein	% Glucose	% Fructose	% Sucrose	% Ascorbic acid	% Malic acid	% Citric acid
BR-1	3.46ab	7.33a	0.64c	0.76b	0.83c	0.02b	0.30b	0.26b
BR-2	4.17a	7.86a	0.97a	0.98a	1.40b	0.02ab	0.37ab	0.46a
BR-4	3.23b	9.31a	0.77b	0.85ab	1.67a	0.03a	0.44a	0.44a
BR-5	3.40ab	8.54a	0.89ab	0.97a	1.43b	0.03a	0.40ab	0.31b

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

Table 6: Effect of different water stress treatments on organic solutes content in plants over all cultivars
Tabelle 6: Einfluss der verschiedenen Wasserstressbehandlungen auf den Gehalt an gelösten organischen Substanzen im Mittel aller Sorten

Treatment	% Proline	% Crude protein	% Glucose	% Fructose	% Sucrose	% Ascorbic acid	% Malic acid	% Citric acid
100 % F.C.	2.36c	9.23a	0.61b	0.72b	0.89c	0.021c	0.26b	0.26b
70 % F.C.	3.54b	8.63ab	0.71b	0.78b	1.13b	0.028b	0.39a	0.41a
40 % F.C.	4.80a	6.92b	1.13a	1.17a	1.97a	0.037a	0.48a	0.44a

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

3.3 Effect of water stress on osmotic adjustment and quality parameters

Concentrations of proline, glucose, fructose, sucrose, malic acid, ascorbic acid and citric acid increased with increasing water stress. Results of these parameters among cultivars and treatments are presented in table 5 and 6.

Proline:
Proline contents in tomato leaves showed that there was a significant difference in concentration among the cultivars. The highest concentration was found in BR-2, followed by BR-1, BR-5 and BR-4 (table 5).

Water stress also had great influences on the synthesis of proline. With the increase in water stress, proline contents in tomato plants were also increased (table 6).There was more than 100 % increase in proline content at 40 % F.C. compared with 100 % F.C. treatment.

Crude protein:
Different to proline was the trend observed in crude protein content. The concentration was maximum at 100 % F.C. and decreased significantly with decreasing water status of the soil (table 6). At 40 % F.C. it was decreased by 33 % compared to 100 % F.C. No significant difference was observed among the cultivars (table 5).

Glucose:
Among the cultivars BR-2 contained the highest and BR-1 contained the lowest concentration of glucose with BR-5, followed and BR-4 intermediate (table 5).

The highest concentration of glucose (1.13 %) in tomato fruits was obtained at 40 % F.C. followed by 70 % and 100 % field capacities (table 6). There was an 85 % increase in glucose content at 40 % F.C. compared with 100 % F.C. treatment.

Fructose:
Like glucose, fructose contents in tomato fruits differed significantly among the cultivars. The highest concentration was observed in BR-5 and BR-2 and the lowest in BR-1 (table 5). There was no difference between BR-2 and BR-5, but these two cultivars differed significantly from BR-1 and slightly from BR-4.

The water stressed tomato plants differed significantly and the highest concentration of fructose (1.17 %) was found at 40 % water stress treatment which was 62 % higher than that of 100 % F.C. However there was no difference between the treatments 70 % and 100 % of the F.C. (table 6).

Sucrose:
Sucrose concentrations in four tomato cultivars showed that there was a significant difference in concentration among the cultivars. The highest concentration was observed in BR-4, followed by BR-5, BR-2 and BR-1 (table 5).

Sucrose concentration was also affected by water stress. The highest concentration was found at 40 % and the lowest at 100 % field capacity (table 6). The tomato plants significantly accumulated more sucrose with increasing water stress. There was about 120 % increase of sucrose content at 40 % F.C. compared with 100 % F.C. treatment.

Ascorbic acid:
Ascorbic acid concentration was also affected by water stress. The concentration in fruit increased with water stress: The highest amount was observed at 40 %, followed by 70 % and 100 % field capacity (table 6). An increase of 76 % of ascorbic acid concentration was observed at 40 % F.C. compared with 100 % F.C.

The concentration among the cultivars also differed significantly. BR-4 and BR-5 contained the highest amount followed by BR-2 and BR-1 (table 5).

Malic acid:
Malic acid concentration was also dependent on variety and treatment. There was a significant difference in concentration among the cultivars: BR-4 contained the highest concentration of malic acid, followed by BR-5, BR-2 and BR-1 (table 5). Malic acid concentration was also influenced by the different levels of water stress (table 6). There was an increase of about 85 % malic acid concentration at 40 % F.C. compared with 100 % F.C.

Citric acid:
Citric acid concentration was highest in BR-2 and BR-4 followed by BR-5 and BR-1 (table 5). Like malic and ascorbic acids, the concentration increased with increasing water stresses. About 69 % increase in citric acid was noticed at 40 % F.C. compared with that of 100 % F.C. treatment (table 6).

A lowering of water potential due to stress causes a wide range of changes in physiological responses from a decrease in photosynthesis to closing of stomata. Turgor pressure decrease is thought to be one of the controlling factors in these changes (OSMOND, 1980). For this reason osmotic adjustment is regarded to be important under stressed conditions. The obvious advantage of osmotic adjustment is the enhancement of the capacity of a plant to maintain positive turgor, particularly in roots during water deficits (OOSTERHUIS, 1987).

Organic molecules such as glucose, fructose, sucrose, proline etc. act as osmotica and play an important role in osmotic adjustment in plants (GREENWAY and MUNNS, 1980; FLOWERS et al., 1977; MCCREE, 1986; TORRECILLAS et al., 1995 and ULLAH et al., 1993, 1994, 1997).

The result of the current experiment revealed that the concentration of proline in tomato leaves increased with increasing water stress. This result confirms the findings of SONG and CHENG (1992) and KUNDU and PAUL (1997) who postulated that drought stress increased the leaf proline content.

According to ROSE (1988) water stress decreased protein contents in plants. The results of present investigations were inconsistent with the findings, which implies that soluble protein did not contribute to osmotic adjustment.

In this experiment, the content of glucose, fructose, sucrose, malic acid, ascorbic acid and citric acid increased significantly with water stress.

These results agree with the findings of ULLAH et al. (1993, 1994) who reported significant increases in glucose, fructose, in some cases sucrose, ascorbic acid and citric acid in faba bean and tomato by salt stress.

Ripeness classes of tomatoes were determined according to GRIERSON and KADER (1986). The tomatoes being red over 90 %, were classified as red and scored 6 of GRIERSON and KADER's table 6.5 (GRIERSON and KADER, 1986) in all treatments. No difference was found between the control and water stress treatments.

With regard to internal tissue damage due to bruising, no degree of severity and no visible internal tissue damage were observed. The tomatoes had score 1 of GRIERSON and KADER's table 6.6 (GRIERSON and KADER, 1986) in all treatments. Overall visual quality of tomatoes under all treatments was also excellent, essentially no symptoms of deterioration were noticed. They had the score 9 of table 6.7 (GRIERSON and KADER, 1986).

Also no symptoms of physical damage could be detected in any of the treatments [Score 1 of table 6.8 (GRIERSON and KADER, 1986)].

Ripening and fruit quality studies showed that none of the stress-treated tomatoes deteriorated in their quality. On the other hand, water stress enhanced the sweetness of the tomatoes by increasing glucose, fructose and sucrose contents and improved the quality by increasing the concentrations of important acids such as ascorbic acid, malic acid and citric acid.

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