



Drought Stress Effects on Plant Water Relations, Growth, Fruit Quality and Osmotic Adjustment of Tomato (*Solanum lycopersicum*) under Subtropical Condition

Kamrun Nahar^{1*} and Shah Muhammad Ullah²

¹*Department of Environmental Science and Management, North South University, Bangladesh.*

²*Department of Soil, Water and Environment, University of Dhaka, Bangladesh.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The pot experiments were conducted in 2 subsequent years in the net house of the Dept. of Soil, Water and Environment, Dhaka University to evaluate the effect of water stress on the growth, plant water relations, fruit quality and osmotic adjustment of seven tomato cultivars. The percentage of field capacity levels were 40, 70 and 100. The tomato plants subjected to water stress during their growth period had decreased relative water content (RWC) of leaves and moisture content in tomatoes compared with the plants supplied with adequate moisture. Water use efficiency (WUE) also decreased with increasing moisture stress. A significant increase in organic solutes, glucose (85%), fructose (62%), sucrose (121%) and proline (103%) at 40% F.C. compared with 100% F.C. showed a tendency of these plants to adjust osmotically. Ascorbic acid, citric acid and malic acid were also significantly enhanced by water stress treatments. The quality of fruits was improved as a result of the synthesis of these acids.

*Corresponding author: E-mail: nahar.kamrun@northsouth.edu;

Water stress did not affect the height of plants and no physical damage due to stress was observed in fruits and were over 90% red. Ripening and fruit quality 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.

Keywords: Tomato; drought stress; plant water relations; fruit quality; osmotic adjustment.

1. INTRODUCTION

Vegetable crops play an important role in human nutrition. People of Bangladesh, especially in the rural areas, suffer from malnutrition because of imbalanced diet [1].

Tomato is one of the most important and widely grown vegetable crops in the world. A lot of research [2,3,4] was done on it under irrigation in pot or greenhouse experiments. Of more than 100 species of vegetable crops selected for intensive study in representative Asian countries, tomato ranked first [5]. It is also a respectable source of some key nutrients such as vitamin A, vitamin C, sugar, ascorbic acid, some protein and iron. In subtropical climate, Tomato (*Solanum Lycopersicum*) is one of the most important and widely cultivated popular vegetables. Worldwide, tomato was the seventh most valuable commodity crop in 2013, with a gross production value of over \$60 billion [6].

Global climate changes such as increased global temperatures and changed rainfall patterns alter plant transpiration rates and affect crop water availability [7]. Drought is a major limiting factor for crop production all over the world. The effects of drought stress on tomatoes yield vary widely by soil and climatic conditions [8].

Tomato is sensitive to a number of environmental stresses, especially extreme temperature, drought, salinity, inadequate moisture and environmental pollution, and there is a need to develop varieties that can withstand such environmental stresses [9]. Crops production could be enhanced either by supplying adequate water or by growing drought-resistant crops. This could be overcome by selecting crops which have less demand for water or have root systems sufficient to utilize subsurface water.

The degree of availability of water to plants renders great influence on the whole complex physiological processes in plants. It has substantial impact on the chemical composition and physical properties of plant tissues, which in turn have decisive significance on the quality and

yield of plants [10]. Water deficits in tomato compromise fruit yield and also quality [11,12,13]. Plant sensitivity to drought stress varies at different growth stages [14,15]. Greater WUE (i.e. less water use) before reproduction allows more water to remain in the soil profile for availability later in the season when plants are more susceptible to water stress [16].

Drought stress generally becomes most critical when the plants at their maximum physiological activity. Water use efficiency is significantly affected by the timing of water application under limited water supply [17]. WUE is the units of water used per unit of dry matter produced, often using total water lost by evapotranspiration [18].

Osmotic adjustment occurs in plants in response to salinity as well in response to drought and is currently the focus of much research interest. Solute accumulation caused due to drought [19] leads to a lowering of osmotic potential during stress. Recovery and partial or complete maintenance of turgor under stress conditions are termed osmotic adjustment [20]. The organic molecules (glucose, fructose, sucrose, proline etc) act as osmotica and play an important role in osmotic adjustment [21,22,23,24,25,26,27].

In this study, an experiment was conducted to investigate the effects of stress on water relations, quality and osmotic regulation of tomato. The main aim of the present study was to find out a suitable drought resistant tomato variety commonly cultivated in Bangladesh, to evaluate fruit quality, water use efficiency, sustain optimum growth, and solute accumulation under drought stress or with minimum use of water.

2. MATERIALS AND METHODS

The pot experiment was conducted in Bangladesh; geographical location is 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 [28].

The experiment was conducted in Dhaka district and during the periods from (November-March) in 2 subsequent years.

2.1 The Experimental Crop

Seven varieties of tomato plants namely, Marglobe, Ruma VF, BR-1, BR-2, BR-3, BR-4 and BR-5 were the test crops.

2.2 Collection of Seeds

The seeds of two varieties namely Marglobe and Ruma VF were collected from Bangladesh Agriculture Development Corporation (BADC) farm and five varieties namely BR-1, BR-2, BR-4 and BR-5 from Bangladesh Agriculture Research Institute (BARI) at Gazipur. The two varieties, BR-4 and BR-5 were summer varieties but could be cultivated throughout the year, i.e. both in winter and summer.

3. EXPERIMENT TYPE - (POT EXPERIMENT)

3.1 The Experimental Soil Media

The soil used in this experiment was of Demra series under Madhupur tract (According to Reconnaissance soil survey report of Dhaka district, 1965, reviewed in 1987). Soil samples were collected at a depth of 0-15 cm from Katchpur at Demra, Dhaka.

For physical and chemical analysis, collected soil samples were air dried, ground to pass through 2 mm sieve and then mixed thoroughly to make a composite sample. Dry roots, grasses and other vegetative residual parts were discarded from the soil.

3.1.1 Physical and chemical characteristics of soil

The general physical and chemical characteristics, of the soil were:

Textural class- Silty clay loam. Sand-5.8%, silt-60.2%, clay-34.0%, Moisture at field capacity-33%, Maximum water holding capacity-46%, Hygroscopic moisture-1.40%, Porosity-49%, Bulk density-1.27g/cc, Particle density-2.57g/cc, pH-

7.2, EC-143 μ S, OM1.14%, CEC-17.9 meq / 100 g soil and N-0.06%.

The morphological characteristics of the soil are presented in Table 1.

3.1.2 Experimental design and techniques

The experiment was conducted under natural condition in a completely randomized block design with four treatments and three replications at the net house of the Department of Soil, water environment, Dhaka University. Varieties namely Marglobe, Ruma VF, BR-1, BR-2, BR-4 and BR-5 were used in this experiment in 2 subsequent years. Earthen Pots each containing 8 kg of soil were used in this experiment. The height of the pots was 23 cm, diameter 29 cm and the height of the soil in the pots was 21 cm.

The pots were rearranged once a week so that the plants could receive uniform light and temperature.

Water was added to maintain a constant level of 40, 70 and 100 percent of the field capacity throughout the experimental period. Water levels were maintained by applying water on daily basis. Compensating the loss of water obtained by weighing the pots on a top balance.

Table 1. Some morphological characteristics of the soil

Characteristics : Demra soil
1. Location Village: Katchpur
P.O: Katchpur
P.S: Demra
District: Dhaka
2. Soil: Demra
3. Soil tract: Madhupur tract
4. General soil type: Grey to olive grey terrace
5. FAO/UNESCO Legend: Eutric Regosol
6. USDA Soil Taxonomy: Aeric Haplaquept
7. Topography: Nearly level terrace
8. Vegetation: Mainly Aus and Aman paddy.

3.1.3 Sowing of seeds and transplantation of seedling

The seeds were sown (Bangladesh Agriculture Development Corporation) at BADC farm and after 24 days of germination two healthy seedlings of uniform size were transplanted to each pot. After transplantation plants were shaded for five days to protect them from sunlight.

The number of plants was thinned to one after one week of transplantation.

3.1.4 Application of water stresses

Three levels of water stresses were imposed in these experiments at the rate of 100%, 70% and 40% of the F.C. in order to investigate the effect of different moisture regimes on osmotic adjustment, relative water content, water use efficiency, moisture content of fruit and fruit quality of plants.

Water was added to maintain a constant level of 40, 70 and 100 percent of the field capacity throughout the experimental period. Water levels were maintained by applying water on daily basis. Compensating the loss of water obtained by weighing the pots on a top balance.

In the experiment, there was no loss of water through drainage as well as no extra gain of water other than the estimated irrigation water. In order to prevent the evaporation loss of water from the soil, the pots were well covered with aluminium foil.

The amount of water lost through transpiration and evaporation, if any, was supplemented by addition of water through funnel daily in the evening. The moisture regime was maintained by weighing the pots on a top balance at a regular interval till the final harvest (November-March). Compensation was allowed for the gain in weight due to vegetative growth of the plants.

Range of water added/day: For 100% F.C.=250-350ml/day, For 70% F.C.200-250ml/day, For 40% F.C.=150-200ml/day.

3.1.5 Nutrient supply

Cow dung was applied in the pot at the rate of 6t/ha and N, P and K at the rate of 260-200-150kg / ha.

The entire amount of potash, phosphorus and half of the nitrogen were mixed at the time of preparation of soil for the pot experiment. The rest half of the nitrogen was applied in two splits, one at the vegetative stage and another at the reproductive stage.

3.1.6 Spacing

Each pot was placed at 40 cm apart from another pot in the same row and each row had a distance of 40 cm.

3.1.7 Weeding

Weeds in the pots were controlled by uprooting and incorporated into the soil in order to ensure that there was no loss of nutrients.

3.1.8 Spraying of insecticide

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.

3.1.9 Observation of growth

The height of plants and ripening of tomatoes were observed and recorded.

3.1.10 Harvesting and yield analysis of plant

One plant per pot was harvested at the end of the experiment. All the plant samples were dried in an oven at 65°C and dry weight of the plants was also recorded. Finally, the plant samples were finely ground by plant sample grinder.

The amount of glucose, fructose, sucrose, ascorbic acid, citric acid and malic acid in fruits of tomato were determined by enzymatic method described by [29]. Proline was also estimated from leaves by method described by [30] Visual quality and physical damage of the ripe tomatoes was determined according to the rating scale of [31].

3.1.11 Water and plant relation studies

3.1.11.1 Determination of leaf relative water content (R.W.C)

The use of relative water content (R.W.C) or relative turgidity as an indicator of leaf water status [32]. It is readily measurable and more easily linked to plant form and functions than water potential [33]. The relative water content of the leaves was determined by the following formula.

Relative Water Content RWC% =

$$\frac{\text{Fresh weight- Dry weight}}{\text{Turgid weight- Dry weight}} \times 100$$

Leaf discs of about 10. mm. The diameter was collected from fresh leaves of the plants. These

discs were rapidly transferred into specimen bottles, preventing any loss of water from the discs. The weight of fresh leaf discs was taken and then allowed to obtain turgidity for sixteen hours [34] in distilled water in closed Petri dishes. After attaining turgidity, the discs were taken out with forceps on a tissue paper and placing another over them so that excess water adhering to the surface of the discs was quickly soaked in.

The turgid weight of the leaf discs was then taken. Finally dry weight was taken after being oven dried for at least four hours at a temperature of 60°C.

From the measured relative water content, the leaf water status may also be expressed conveniently [35] by the index relative water deficit (RWD), which is 100 RWC.

3.1.11.2 Measurement of water use efficiency (WUE)

The efficiency of water use was calculated at different moisture regime. The WUE is the units of water per unit of dry matter produced, often using total water lost by both evaporation and transpiration. [18].

$$WUE = \frac{\text{Water used in Evapotranspiration}}{\text{Dry matter}}$$

3.1.11.3 Measurement of moisture content in tomatoes

The moisture percent in tomato fruits was calculated at different moisture stress, In the experiment water content measurements involve weighing the sample, removing the water and reweighing the sample to determine the amount of water removed. When multiplied by 100, this becomes the percentage of water in the sample on fresh weight basis. The moisture content of the sample was given by the formula

% Moisture in tomatoes =

$$\frac{(\text{Wt of tomato + container}) - (\text{wt of dry tomato + container})}{(\text{Wt of tomato + container}) - (\text{wt of container})} \times 100$$

3.1.12 Biochemical analysis

3.1.12.1 Determination of proline (29)

For determination of proline in tomato leaves, Purified Proline was used to standardize the sample values.

Reagents:

Acid ninhydrin was prepared by warming 1.25 g ninhydrin in 30 ml glacial acetic acid and 20 ml 6M phosphoric acid, with agitation, until dissolved Kept cold (Stored at 4°C) the reagent remains stable for 24 hours.



Plate 1. Tomato plants with fruits in the net house

Procedure:

- Approximately 0.5 g of plant material was homogenized in 10 ml of 3% aqueous sulfosalicylic acid and the homogenate filtered through whatman # 2 filter paper.
- Two ml of filtrate was reacted with 2ml acid ninhydrin and 2ml of glacial acetic acid in a test tube for 1 hour at 100°C and reaction terminated in an ice bath.
- The reaction mixture was extracted with 4-ml toluene, mixed vigorously with a test tube stirrer for 15-20 sec.
- The chromophore containing toluene was aspirated from the aqueous phase, warmed to room temperature and the absorbance read at 520 nm using toluene for a blank.
- The proline concentration was determined from a standard curve and calculated on a fresh weight basis.

3.1.12.2 Determination of glucose, fructose, sucrose, malic acid, ascorbic acid and citric acid [29].

Sample preparation:

For determination of glucose, fructose, sucrose, malic acid and citric acid in tomato fruits, following techniques are used for sample preparation.

The sample was homogenized using a mortar; A well-mixed sample was accurately weighed and extracted with hot water (60°C). The extract was transferred quantitatively to a volumetric flask and filled up to the mark with redistilled water. Filtered and used the clear solution for the assay. For clarification (glucose, fructose and sucrose) the following solutions are used 5 ml carrez-I solution (360g potassium hexacyanoferrate-II, $K_4[Fe(CN)_6] \cdot 3H_2O/100ml$. 5ml carrez-II solution (7.20g of $ZnSO_4 \cdot 7H_2O/100ml$ and 10ml NaOH (0.1 mol/L).

L. Ascorbic acid: For the assay of ascorbic acid the tomatoes were well minced with an electric mixture and homogenized with metaphosphoric acid (15%W/V). After mincing the pH of the mixture was adjusted to 3.7 with KOH solution.

Finally the results were statistically analyzed employing the Duncan's New Multiple Range Test (DMRT).

4. RESULTS AND DISCUSSION

The objective of this study was to evaluate the effect of stress on growth, fruit quality, moisture content, water use efficiency, Relative water content and osmotic adjustment of different tomato cultivars.

4.1 Effect of Water Stress on Shoot Development of Plants

Shoot development of plants involved in measurement of plant heights during the experimental periods.

The statistical results on the final height of the plants were presented in Table 2 (1st and 2nd year) and graphically represented in Figs. 1-2.

4.1.1 Height of plants

Results obtained on the final height of plants indicated that the varieties had different heights. The maximum heights were measured in BR-5. and BR-1. Marglobe, Ruma VF and BR-2 did not differ among themselves in 1st year.

Table 2. Height of plants in different cultivars

Year	Cultivars	Height (cm)
1 st year	BR-2	47.87b
	Marglobe	47.74 b
	Ruma VF	44.32 b
	BR-1	61.87a
	BR-5	71.75a
Year	Cultivars	Height (cm)
2 nd year	BR-1	86.00a
	BR-2	79.89 a
	BR-4	84.22 a
	BR-5	91.22 a

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

Table 3. Effect of different water stress treatments on height of plants

Year	Treatment	Height (cm)
1 st year	100%F.C	56.90a
	70%F.C	53.66a
	40%F.C	55.22a
Year	Treatment	Height (cm)
2 nd year	100% F.C	75.58 b
	70%F.C	88.17ab
	40% F.C	92.25 a

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

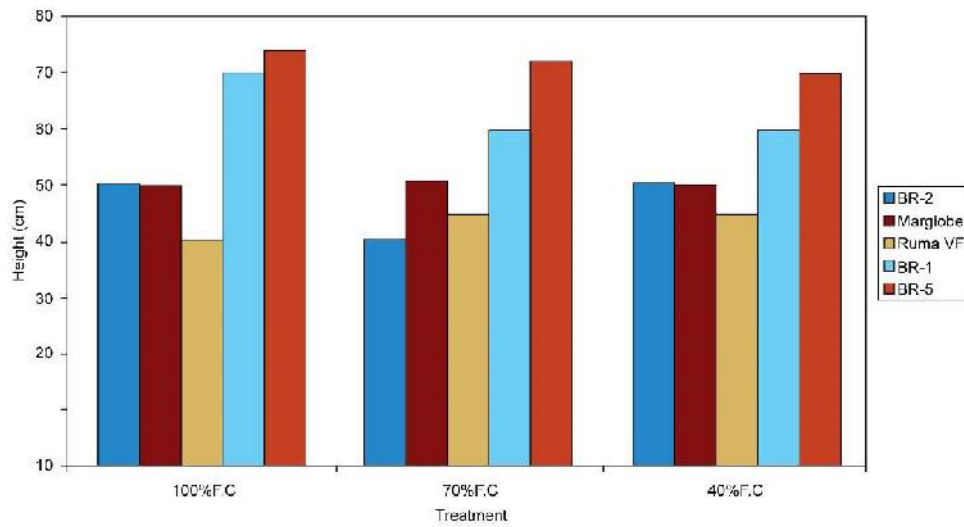


Fig. 1. Effect of water stress on height of plants (1st Year)

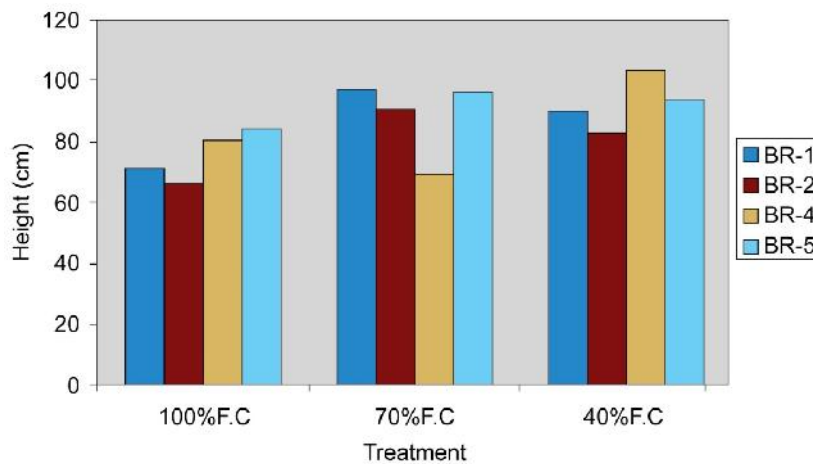


Fig. 2. Effect of water stress on height of plants (2nd Year)

But in 2nd year the results revealed that there was no significant difference in height among the cultivars. The results also showed that the maximum height was obtained at 40% field capacity in 2nd year, but no significant difference was observed among the treatments in 1st year (Table 3).

4.1.2 Discussion

This result did not confirm the findings of others [33,36] who reported the reduction of growth due to water stress. The result of the current experiment agreed with the findings of the earlier researcher [37] and also by [38] those who postulated that when water becomes available after a short period of stress, growth is very rapid

for a short time, so that no net reduction is caused by stress in tomato plant.

4.2 Effect of Water Stress on Plant Water Relations

Plant water relation includes leaf relative water content, water use efficiency in plant and moisture content in tomatoes. The study was made at three stress levels includes 100%, 70% and 40% field moisture capacity among four cultivars.

4.2.1 Results

Plant water relation parameters are presented in Tables 3-4.

Table 4. Plant water relations in different cultivars

Cultivars	Leaf relative water content %	Water use efficiency	Moisture content in tomatoes %
BR-1	70.94b	3149b	91.13b
BR-2	66.32 d	3849ab	91.11 b
BR-4	69.90c	4724 a	92.54 a
BR-5	79.35a	2885b	92.41 a

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

Table 5. Effect of different water stress treatments on plant water relations in plants

Treatment	Relative water content %	Water use efficiency	Water use efficiency in tomatoes %
100% F.C	73,86 a	5372 a	93.04 a
70%F.C	72.02b	3091 b	91.75b
40% F.C	69.0c	2492 b	90.60 c

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

4.2.1.1 Leaf relative water content

The cultivars differed significantly in their relative water content. The highest relative water content was found in BR-5 cultivars followed by BR-1, BR-4 and BR-2 (Table 4). The results also show that the relative water content decreased significantly with increasing water stress (Table 5). The maximum leaf relative water content was contributed at 100% of field capacity followed by 70 and 40% of field capacities. At 40% F.C. the leaf relative water content decreased by 7%, compared to 100% of the field capacity.

4.2.1.2 Water use efficiency

The cultivars had great variation in water use efficiency. The statistical data is shown in table 4 indicate that the highest water use efficiency was found in BR-4. There was significant difference in WUE among BR-4 and other three varieties. The results also indicated that like RWC, WUE is also profoundly influenced by water stress.

Here the maximum value was obtained at 100% F.C followed by 70 and 40% field capacities (Table 5). At 40% F.C. the water use efficiency was decreased by 115% compared with 100% F.C. treatment.

4.2.1.3 Moisture content in tomatoes

The effect of different soil moisture regime on moisture content in tomatoes revealed that there was a significant difference among the cultivars. The highest content of moisture in tomatoes was found in BR-4 and BR-5, which differed

significantly from BR-1 and BR-2. There was no difference between BR-1 and BR-2 (Table 4).

The result also revealed that like RWC and WUE, moisture content in tomatoes decreased significantly with water stresses (Table 5). It was 3% lower at 40% of the field capacity compared to 100% field capacity treatment.

Considering the Overall performance among the varieties, BR-5 and BR-4 were contributed better performance in withstanding stress condition.

4.3 Discussion

Water stress application influenced significantly plant water relations (RWC, WUE and Moisture content). The crop receiving the lowest water stress maintained higher plant water status (RWC & WUE) and highest moisture content.

The result of the experiment clearly demonstrates that the leaf relative water content seemed to be subjected to fluctuation under stress. This result confirmed the findings of others [39,40,37] who stated that the leaf relative water content decreased due to decreasing soil water availability and increasing resistance to water flow in stems and leaves.

A similar trend happened in moisture content in tomatoes. Percentage of moisture in tomatoes decreased with increasing water stress. This result was also in consistent with [41] who observed that with increasing water stress moisture content of the fruit decreased.

The result of water use efficiency indicates that it is higher in control treatment and decreased with increasing stress. This result also agrees with the findings of [42] who observed water use efficiency decreased with increasing water stress. WUE can be increased more by adjustment of timing of plant development than by increasing the photosynthetic potential [43,44]. Suggested that an increase in ratio of mesophyll cell surface to leaf surface might increase the WUE by increasing photosynthesis more than it increases transpiration.

4.4 Effect of Water Stress on Osmotic Adjustment and Quality Parameters

Concentrations of Proline, Crude protein, Glucose, Fructose, Sucrose, Malic acid, Ascorbic acid and Citric acid.

4.4.1 Results

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

Proline: Proline contents in tomato leaves showed that there was significant difference in concentration among the cultivars. The highest concentration was obtained BR-2, followed by BR-1, BR-5 and BR-4 (Table 6).

Water stress also had great influences on synthesis of proline. With the increase in Water stress, proline contents in tomato plants were also increased. There was more than 100%

increase in proline content at 40% F.C. compared with 100% F.C. treatment (Table 7).

Crude protein: A reverse trend was observed in crude protein concentration. The concentration was maximum at 100% F.C. and decreased significantly with increasing water stress (Table 7). At 40% F.C. it was decreased by 33% compared to 100% F.C. No significant difference was observed among the cultivars (Table 6).

Glucose: The concentration of glucose revealed that among the cultivars BR-2 contained the highest and BR-1 contained the lowest concentration while BR-5 contained the intermediate, followed by BR-4 (Table 6).

The highest, concentration of glucose (1.13%) in tomato fruits was obtained at 40% F.C. followed by 70 and 100% field capacities (Table 7). There was 85% increase in glucose content at 40% F.C. compared with 100% F. C. treatment

Fructose: Like glucose, fructose contents in tomato fruits showed that the concentrations among the cultivars differed significantly. The highest concentration was observed in BR-5 and BR-2 and the lowest in BR-1. There was no difference between BR-2 and BR-5, but differed significantly from BR-1 and slightly from BR4 (Table 6).

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 7).

Table 6. Content of organic solutes in different cultivars

Cultivars	% Proline	% Crude protein	% Glucose	% Fructose	% Sucrose	% Ascorbic acid	% Malic Acid	% Citric acid
BR-1	3.46 a b	7.33 a	0.64 c	0.76 b	0.83 c	0.02 b	0.30 b	0.26 b
BR-2	4.17 a	7.86 a	0.97 a	0.98 a	1.40 b	0.02ab	0.37 a b	0.46 a
BR4	3.23 b	9.31 a	0.77 b	0.85 a b	1.67 a	0.03 a	0.44 a	0.44 a
BR-5	3.40 a b	8.54 a	0.89 a b	0.97 a	1.43 b	0.03 a	0.40 a b	0.31 b

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

Table 7. Effect of different water stress treatments on organic solutes content in plants

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

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

Sucrose: Sucrose concentration in four tomato cultivars showed that there was 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 6).

Sucrose concentration was also affected by water stresses. The highest concentration was found at 40% and the lowest at 100% field capacity (Table 7). 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 increasing water stress and the highest amount was observed at 40% followed by 70% and 100% field capacity (Table 7). 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 6).

Malic acid: Malic acid concentration was also dependent on variety and treatments. There was significant difference in concentration among the cultivars and BR-4 contained the highest concentration of malic acid followed by BR-5, BR-2 and BR-1 (Table 6). Malic acid concentration was also influenced by the different levels of water stress. (Table 7). 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 found highest in BR-2 and BR-4 followed by BR-5 and BR-1. (Table 6). Like malic and ascorbic acid, 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 7).

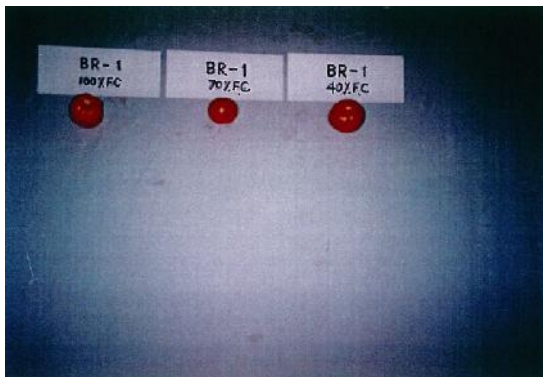


Plate 2. Colour of tomatoes (BR-1) at different water stress level

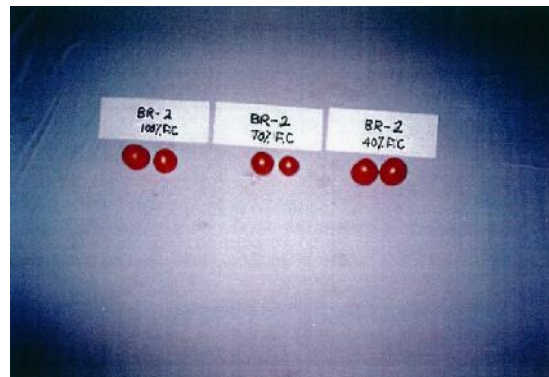


Plate 3. Colour of tomatoes (BR-2) at different water stress level

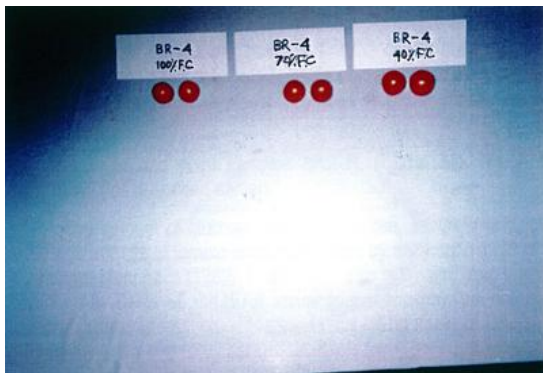


Plate 4. Colour of tomatoes (BR-4) at different water stress level

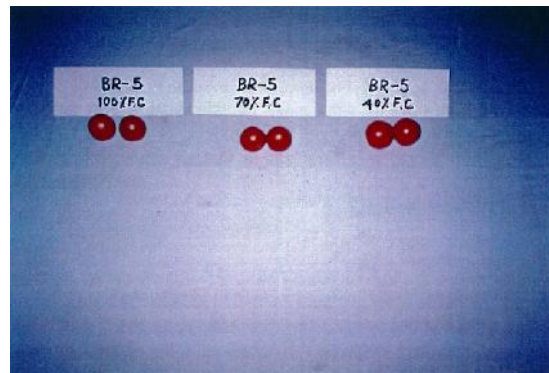


Plate 5. Colour of tomatoes (BR-5) at different water stress level

4.4.2 Discussion

A lowering of water potential due to drought stress causes a wide range of changes in physiological responses from a decrease in photosynthesis to closing of stomata and a turgor pressure, decrease is thought to be one of the controlling factors in these changes [45]. 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 [46].

The organic molecules such as glucose, fructose, sucrose, proline etc act as osmotica and play an important role in osmotic adjustment in plants [20,21,22,46,23,24,25,47,48,49].

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 [50,51,52] who postulated that drought stress increased the leaf proline content in plant.

According to [53] water stress decreased protein contents in plants. The present result is also in consistent with the findings which imply 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 against water stress.

These results agree with the findings of [23,24, 25,54,55] who reported significant increase in glucose, fructose, in some cases sucrose, ascorbic acid and citric acid in faba bean and tomato by salt and water stress.

Ripeness classes of tomatoes were determined according to [31]. The tomatoes were red over 90%, classified as red and scored 6 of Grierson and Kader's Table 6 in all treatments. No difference was found between the control and water stress treatments (Plates 2-5).

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 in all treatments. Overall visual quality of tomatoes under all treatments was also

excellently good; essentially no symptoms of deterioration were noticed. They had the score 9 of the Table 6 [31].

Additionally, no symptoms of physical damage in any of the treatments could be detected [Score 1 of Table 6 [31].

5. CONCLUSION

From the experiment, it can be concluded that under drought stress plants showed a tendency to adjust against drop in water potential in soil by producing organic solutes and important acids.

It is believed that drought-resistant cultivars have wide adaptation and internal physiological.

The process of stress by accumulation of solutes and acids. 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.

Finally, we can conclude that it is possible to use water stress tolerance selection criteria in tomato breeding program for drought resistance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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