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Climate Smart Agriculture with Drought Resistant Tomato (*Solanum lycopersicum*) Cultivars under Subtropical Climate

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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

Climate smart agriculture focus on crop production under climate stress. Climate change adaptation potential was investigated in medium textured soil to evaluate the drought/water stress effect on different cultivars of tomato. The imposed stress levels were 82 -100% (T0), 69-85% (T1), 53-67% (T2) and 40-50% (T3) of the FC (Field Capacity). In water stressed condition no significant influence was observed in production of plant dry matter and increased acids & soluble sugars and consequently improved the fruit quality. Water stresses did not show any significant effect on height, yield and increased in BR-5, probably due to its tolerance to water stress.
Also, none of the stress- treated tomatoes showed deteriorated visual quality of the fruits and were red over 90%. No bruising and internal damages in tissues were detected due to stress. Water stresses enhanced the sweetness of the fruits by increasing their organic solute contents as glucose, fructose and sucrose contents and improved the quality by increasing the amount of

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important acids such as citric acid, malic acid and ascorbic acid, showed the adaptation responses of the crop to climatic stress due to conspicuous tendency of tomato plants to adjust osmotically against drought stress.

Keywords: Climate change; adaptation; tomato; drought stress; yield; fruit quality.

1. INTRODUCTION

Concept of climate smart agriculture focus on crop production under abiotic stresses. Agricultural production all over the world is extremely sensitive to weather and climatic conditions. "Abiotic stress is one of the major constraints to crop production and thus food security worldwide. Heat including drought are the two alarming climate stresses affecting plant growth, development, reproduction and yield. Several developing countries are facing problems with food production and are at the risk of losing about 280 million tons of cereal crop production due to climate change factors, particularly increasing temperatures and prolonged dry periods" [1].

Food security including nutritional value are highly dependent on the climatic conditions and most of the crop produced for human consumption is under its threat, particularly in developing countries. Although there is continued efforts to increase food production including nutritional security, the overload of malnutrition due to deficiencies of essential nutrients linked to climate change remains alarming, particularly in low -income communities[2,3]

Climate Change, considered as multifactorial abiotic stresses [4] will project to have significant impacts on the aboveground and belowground parts of the plants, partcularly on growth, yields, fruit quality, root development including other morphological and physiological factors. In order to adequately adapt to these impacts, we must first model the consequencies on various crop species in order to identify varieties and treatments are most suitable for the harsh climatic stressed conditions. In the recent past years plants have experienced and still experiencing significant environmental fluctuations and the frequency of occurance of these changes is likely to increase in the upcoming years. "Therefore, climate change will be a major challenge to agriculture and natural ecosystems including global economies to produce nutritious food,. So adaptation to climate change is a major challange in the food security. Without adapting strategies, these changes will have a cumulative effect as time progresses" [5-8].

Drought stress due to change of climate is increasing over the years and is expected to significantly increase by the end of this century. So, adaptation, towards more drought-tolerant cultivars, is an important strategy to crop adaptation responses to climatic stress [9-12].

"Vegetable crops especially, Tomato (*Solanum Lycopersicum*) is a herbaceous vegetable fruit crop and a member of the solanaceae family, plays a vital role as a source of nutrition in human health. It provides essential nutrients required in humans such as iron, soluble sugars, vitamin A, vitamin C, vitamin K, potassium, ascorbic acid, protein and lycopene (antioxidant). Adults including children of low-income countries particularly in the sub-urban as well as rural areas generally suffer from malnutrition because of consumption of imbalanced diet and also lacking knowledge on nutritional value of important vegetables. Tomato as a popular vegetable crop widely cultivated all over the world, occupied a large area under cultivation compared to other vegetable crops with an annual value exceeding 90 billion USD. Around 100 species of vegetable crops in representative Asian countries selected for intensive study, where tomato occupied the first position" [13-15].

"In Bangladesh as a subtropical country, tomato occupies an area of about eleven thousand hectares with a total production of around eighty-one thousand tons. The average yield is very low if compared with other tropical countries of the world. As an agrarian country, depending on agriculture are particularly vulnerable to changes in the variability of climate including the reduction of moisture in the soils, as a result the growth and yield of agricultural crops suffer. To this adds high population density which needs more food production to feed for 180 million people within an area of 147570 square kilometers. So the need for crop adaptation strategies (changing to crop species or varieties that are resistant to climatic stress) is among the most cited adaptation measures to overcome the situation". [16-18].

"Tomato is vulnerable to a number of abiotic stresses, particularly drought due to high temperature, salinity, inadequate moisture and environmental pollution, and there is a need to focus on plant breeding to develop varieties those can sustain with such environmental stresses" [19].

"An important agricultural water management strategy link to deficit irrigation, where crops exposed to a level of water stress either during the entire growing season of the crop or a certain period of time, like vegetative or flower or fruiting stages" [20]. "In context of plant biomass production, yield and quality of tomato under deficit irrigation, showed mixed results. Field trials under drought stress either resulted a drastic reduction in dry mass production, or no adverse impacts on yield and quality of fruits" [21-23]."However stress affected yield of tomato when occurred throughout the reproductive stage and development period, but quality during the final or ripening stage" [24]. Till date a limited number of experiments done to evaluate the effect of drought stress on fruit yield and qualitative characteristics of vegetable species particularly tomato cultivars.Therefore, it is important to get practical research knowledge on the timing and requirment of water application for production of tomato quantitively as well qualititively.

"Plant generally response to drought and salinity stress by osmotic adjustment which is currently the focus of more researchers. Solute accumulation caused due to drought/salinity leads to a lowering of osmotic potential during stress. Maintenance or recovary of turgor under stress conditions are termed osmotic adjustment" [25-27]. "Osmotica, the organic molecules (glucose, fructose, sucrose, proline etc) a play a crucial role in osmotic adjustment of plants" [28-32].

Under drought stress, crops production could be enhanced by selecting and cultivating drought resistant cultivars, having extensive root as belowground part to extract water from subsurface or less demand of water. In the study we have selected this particular crop as it has extensive root system including it is less susceptible to drought.

2.2 Physiochemical Properties of the Soil

Therefore, the present study aimed to evaluate optimum growth, yield and quality of fruits with minimum use of water and to identify the drought resistant tomato cultivars and quality traits out of four commonly cultivated in Bangladesh, for adaptation of climate change.

2. MATERIALS AND METHODS

"A Field based experiment was conducted in Dhaka district, on tomato plants to investigate the height, dry matter, yield and quality of four cultivars under drought/water stress, during the periods from November - March, with 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, maximum and minimum annual temperature, 36°C and 12°C respectively with annual precipitation 1500 mm in the north to 5700mm in the northeast region of Bangladesh" [33].

2.1 Soil Type, Collection and the Experimental Crop

A medium textured soil as "Loam" used in the experiment, was under Madhupur tract of Tejgaon series.

For physiochemical analysis, samples were collected at a depth of 0-15 cm, dried in air, ground then pass through 2mm sieve and by mixing thoroughly made a composite sample to prepare for physiochemical analysis. The test crops used in the field trial were four Tomato cultivars namely, BARI-1, BARI-2, BARI- 4 and BARI-5.

Table 1. Physiochemical properties of the soil

Physical properties	Chemical properties
Sand:35.80%, Silt: 40.20%, Clay: 24.00%; Texture: Loam	pH: 5.1
Moisture at field capacity:32%; Moisture at wilting point: 10%,	Electrical conductivity (EC): 90µS/cm
Hygroscopic moisture: 1.73%; Maximum water holding capacity: 45%;	Cation Exchange Capacity (CEC):14.88 meq/100g soil
Porosity: 47%, Bulk density (Db): 1.39g/cc, Particle density (Dp): 2.63g/cc	N%: 0.07%
Organic matter (OM): 1.1%	

2.3 Preparation of Experimental Land and Design

The land was well prepared by harrowing and laddering. Organic fertilizer as Cow dung was added at the rate of 6t/ha at the time of final land preparation. The experiment was arranged in a completely randomized block design with 4 treatments and 3 replications. Size of the unit plot was 1m x1m, having 4 plants per plot, with spacing between plots 75cm, rows 50 cm and plants 45cm. Synthetic/Chemical fertilizers were applied as Nitrogen, Phosphorus and Potassium (N, P_2O_5, K_2O) at the rate 260-200-150kg respectively. Half portion of the nitrogen and the whole amount of potash and phosphate were added at the time of final preparation of the land. The remaining half of the nitrogen fertilizer was added in two splits, one (25%) at three weeks after sowing the plant means at vegetative stage and remaining (25%) at flowering stage.

2.4 Sowing of Seeds, Germination and Transplantation

Mature seeds were sown and after 3.5 weeks of germination, seedlings of healthy and uniform size were transplanted in the experimental field and shaded with the cutting bark of Banana plant for 3/4 days to protect young seedling from sunlight. Three weeks after transplantation, plants were supported with bamboo stick to prevent the plant from lodging. To protect the plant from insects, Malathion (insecticide) was sprayed as and when required. Weeding was also done when needed.

2.5 Application of Water Stresses at Different Percent of Field Capacities

From four weeks after transplantation, the stress period commenced with 4 levels of irrigation regimes. The different treatments were imposed at (T0) 82-100 %, (T1) 69-85%, (T2) 53-67 % and (T3) 40-50 % of the FC, respectively, to evaluate the effect of different moisture levels on biomass production, fruit yield including quality and osmotic adjustment of different tomato cultivars. Every after one week of intervals the samples were collected from the plots for measuring the soil moisture percentages (gravimetrically) by drying the soil samples at 105°C for 24 hours. To maintain the above-mentioned moisture levels, the soil was irrigated with the amount of water lost by evapotranspiration (Evaporation from the soil and transpiration from the plants). The soil moisture levels were within the following ranges: 26-32% (T0), 22-27% (T1), 17-21 % (T2), 13-16% (T3) by addition of water after seven days throughout the experimental period

2.6 Growth Measurement of Plants

Data were recorded on the plant height, dry matter and the yield of tomatoes. The ripening classes of tomatoes were also observed and evaluated by rating scales.

2.6.1 Harvesting, yield and biochemical analysis of plants

a. Collection of tomato fruit: -

“Fresh weight was recorded after the harvest of the ripened tomatoes time to time and calculated by summing up the weight of all the harvests as total fresh weight of the tomatoes. By using the rating scale, visual quality, physical and internal tissue damage of tomatoes were determined” [34].

“From each plot three tomatoes 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. Enzymatic methods were used to evaluate the quality parameters of plant”, [35].

Finally, by employing the Duncan’s New Multiple Range Test (DMRT) the results were analyzed statistically

2.6.2 Biochemical analysis

For biochemical analysis, following techniques are used for sample preparation to determine the concentration of glucose, fructose, sucrose, malic acid and citric acid in tomato fruits,

a. Preparation of sample

Frozen tomatoes (3) previously collected 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 (Boehringer- Mannheim 1989). For the assay of ascorbic acid, fruit samples were well minced with an electric mixer and homogenized in metaphosphoric acid (15% w/v), pH was adjusted to 3.7 with KOH and ascorbic acid was determined by enzymatic methods

3. RESULTS AND DISCUSSION

3.1 Water Stress Effect on Shoot Development of Plants and Yield of Tomatoes

Data recorded on plant height, dry matter production and yield of tomatoes at the end of the experimental period.

Plant heights, dry matter production and yield in different cultivars and at different stressed condition were present in Tables 2 and 3.

3.1.1 Height of plants

The plants height recorded in this experiment indicated the following sequence: BARI-5 > BARI-2, BARI-1 > BARI-4. (Table 2), among the four cultivars.

Although, the height of the plants ranged from 72.0 to 74.33 cm, but no significant difference was noticed at T3, T2, T1 and T0 treatment. (Table 3) So the result revealed that stress had statistically insignificant effect on the heights of the plants.

“This result did not confirm the findings of [36], who mentioned plants height reduced due to water stress. The height of the plants was not drastically declined due to stress because the quantity as well as quality of plant growth depend on cell division, enlargement and differentiation which are affected by water deficits but not necessarily to the same extent” [37], “when water becomes available after a short period of stress, noticed plant growth is very rapid for a short time, so there is no net reduction in tomato occurs due to stress” [38].

3.2 Dry Matter Production of Plants

The dry matter production of plants is presented in Table 2-3.

In case of dry matter production, no significant differences among the cultivars were observed, except at BARI-2 (Table 2).

The result showed that the maximum dry matter yield was contributed at T3 treatment. But statistically no significant differences were noticed among the treatments (Table 3).

Due to stress, the result of reduced dry matter production is not in consistent with others [39,40], but in agreement with [41,42], who mentioned that “dry matter production was not affected by the water stress treatments. The cultivars ability to produce dry matter under depleted soil moisture regimes might be due to the effect of osmotic adjustment” [43] and also the ability of the varieties to withstand at higher water stress condition.

3.3 Water Stress Effect on Yield of Tomatoes

The yield parameters of tomato plants are presented in Tables 2-3. The tomato varieties had different abilities to yield tomato plants.

The results mentioned in the table, demonstrate that there was no significant difference in yield was observed among the cultivars except in BARI-5 (Table 2).

Table 2. Plant heights, Dry matter and Yield of tomatoes in different cultivars

Tomato cultivars	Plant Height (cm)	Yield (g/m^{2})	Dry matter(g/m^{2})
BARI -1	77.03b	3535b	298.70a
BARI-2	83.15b	3345b	226.10b
BARI-4	65.30c	4114b	331.90a
BARI-5	88.40a	5291a	308.00a

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

Table 3. Water stress treatments effect on Height, Dry matter production and Yield of tomatoes

Treatments	Plant Height (cm)	Yield (g/m^{2})	Dry matter(g/m^{2})
T0	74.33a	4221a	288.88a
T1	72.00a	4169a	269.90a
T2	72.17a	3970a	275.07a
T3	73.67a	3924a	310.75a

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

Although, the highest yield was obtained from BARI-5, however the data presented in Table 2 indicate that there was no significant difference in yield among the treatments.

Yield was reduced due to stress but statistically no significant difference was observed (Table 3).

Therefore, Water stresses showed statistically insignificant effect on height, dry matter production of plants and also yield of tomatoes..

“This result is not consistent with other researchers, who noticed a change in moisture tension from 2 to 4 bars caused a significant reduction in tomato yield” [44]; but agreeing with others [45-48], those who reported that “under moisture stress conditions there was insignificant yield. Yield of tomatoes were found highest at soil moisture tension of 2 bar” [49]. “Therefore, considering the overall performance, two cultivars BR-2 and BR-5 contributed the best performance probably due to drought tolerance by virtue of their partitioning ability of assimilates toward fruit development. The accumulations of assimilates towards fruit development are organic solutes as glucose and fructose developing osmotic adjustment in the production of fruits” [50,51].

3.4 Water Stress Effects on Osmotic Adjustment and Quality Parameters

3.4.1 Concentrations of organic solutes and acids

Results among varieties and treatments are given in Tables 4 – 5.

3.4.2 Concentrations of glucose, fructose and sucrose

Among the 4 cultivars, the highest concentration of glucose in tomato fruits was found in BARI-2 followed by BARI-4, BARI-5 and BARI-1 (Table 4). The concentration of glucose differed significantly among the cultivars but the content increased significantly with the increase in water stress (Table 5). About 100% increase in glucose contents was found at T3 treatment compared with control (T0).

Among the cultivars, the fructose contents in fruits were also found highest at BARI-2 followed by BARI-1, BARI - 4 and the lowest at BARI -5, although there was no significant difference between BR-1 and BR-4 (Table 4), whereas the content is affected by water stresses. The lowest concentration of fructose was observed at control treatment, T0 (Table 5), which had about 30% lower fructose content than that of highest stress, at T3 treatment. Although, no significant difference was observed at T1, T2, T3 but reduced at T0 (Table 5).

The concentration of sucrose was increased than glucose and fructose due to stress. The highest concentration was noticed in BARI-2, however there was no significant variation among the other three cultivars. Under stress, the lowest concentration was measured at control, T0 treatment and the highest at T3. Around 72% increase in sucrose was detected at T3 compared with that on the control, T0 (Tables 4 and 5).

3.4.3 Malic, ascorbic and citric acid concentrations

Among the cultivars, the concentration of malic acid was noticed highest in BARI-4 followed by BARI-5. However, there was no significant differences was observed between BARI-2 and BARI-1 (Table 4), however the concentration is affected by water stresses. The highest concentration of malic acid was found at T3 and the lowest was measured at T0 treatment (Table 5). An increase of 100% malic acid concentration was observed at T3 compared with control treatment.

There was no significant difference among the cultivars in case of ascorbic acid content, (Table 4). But the concentration increased with increasing stress.

At T0 treatment, the lowest amount was found while the highest was observed at T3 treatment (Table 5). Water stress significantly increased the mentioned acid contents to more than 175% at T3 compared with control.

In case of citric acid, the concentrations showed that there was no significant difference among the 4 cultivars, but the stress treatments differed significantly from each other.

Like other above-mentioned acids, the lowest concentration was found at T0 treatment while the highest was at T3 treatment. An increase of about 124% was found at T3 compared with T0 treatment. The results from the also indicate that tomato fruits accumulated more citric acid than others like malic and ascorbic acids (Tables 4-5).

Table 4. Organic solute concentrations in different cultivars

Tomato cultivars	Glucose (%)	Fructose (%)	Sucrose(%)	Ascorbic acid(%)	Malic acid(%)	Citric acid (%)
BARI-1	0.66b	0.93ab	1.11b	0.049a	0.32c	0.66a
BARI-2	0.92a	0.97a	1.84a	0.050a	0.36c	0.70a
BARI-4	0.80ab	0.91ab	1.29b	0.051a	0.50a	0.70a
BARI-5	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 5. Water stress effects on organic solutes content in different cultivars

Treatments	Glucose (%)	Fructose (%)	Sucrose (%)	Ascorbic acid (%)	Malic acid (%)	Citric acid (%)
T0	0.53c	0.79b	0.99b	0.028c	0.26d	0.42d
T1	0.67c	0.97a	1.84a	0.050a	0.36a	0.70a
T2	0.83b	0.93a	1.47ab	0.059b	0.47b	0.81b
T3	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

3.5 Discussion

Plants accumulate solutes or organic molecules, play a crucial role in osmotic adjustment, which act as osmotica, at a level of reduced water potential [52,53]. Therefore, a significant increase in organic solutes contribute the adaptive mechanism in plants to adjust and survive under stressed condition.

Osmotic adjustment is an important mechanism to adapt plants under water shortage/stress condition by increasing the solute concentration of cells in order to maintain the water potential gradients needed to ensure continued uptake of water during the stress period. Besides, osmotic adjustment allows cell to maintain the turgor, which is required for various important physiological functions and ultimately plant growth, development and reproduction.

“The contents of solutes (glucose, fructose, sucrose) and acids (ascorbic, malic and citric acid) in tomato increased significantly in this experiment with increasing water stress. This result confirms the findings of” [54-60], who observed “a significant rise/increase in glucose, fructose, in some cases sucrose and acids contents in beans and tomato under stress and improving the fruits quality”.

“In this experiment, the visual quality of the tomatoes under stress treatments was excellent, including no deterioration of symptoms were detected. They had the Score 9 of Table 4; 34. Ripeness classes of tomatoes were red over 90%, classified as red scored 6” [34] table 4-5 in all treatments Also no symptom of physical damage could be noticed in any of the treatments, had the Score 1 of Table 5; 34. Regarding the internal tissue damage due to bruising, no degree to severity and no visible internal tissue damage was observed, Score Table 5 of 34, in all treatments. Ripening and the fruit quality studies showed that none of the stress treated tomatoes deteriorated in quality. On the other hand, water stress enhanced the sweetness by increasing their glucose, fructose, and sucrose contents and improved the quality of fruits by increasing the amount of important acids such as ascorbic acid, malic acid and citric acid.

4. CONCLUSIONS

It is believed that the cultivars those can cope up to drought have wide adaptation due to active mechanism of internal physiological process during the abiotic stress by producing organic solutes and essential acids.

The published literature on water shortage/drought stress due to climate change and its impact on agriculture is increasing in amounts, however there is very little effort to develop and analyze strategies to adapt practices for small farm holders, those who are practicing subsistence agriculture to change in climate at a landscape level, particularly in developing countries. Research in adaptation and also practice often overlooks the wider context within which climate change is experienced. Certainly, his study will be filling the gap and will serve as a valuable source of information for those who intend to conduct research or develop climate change adaptation strategies under drought stress for any type of crop cultivating in Bangladesh.

The results show how with minimum supply of water, the quality of fruits could be improved to consider as adaptive measure to cope up with climate change for future field trials.

Finally we can conclude from the finding that BARI-5 considered as drought resistant cultivars among the other 4 entities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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