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INFLUENCE OF DROUGHT STRESS ON THE FRUIT AND YIELD QUALITY OF THREE DIFFERENT VARIETIES OF TOMATO (*Lycopersicum esculentum* L.)

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ABSTRACT

Drought impacts various physiological processes in plants, ultimately affecting yield. The study aimed to determine the influence of drought stress on the fruit and yield quality of three different varieties of tomato namely; Rio, Dan Syria and UTC. The plants were subjected to four treatments which were subjected to 80-85% WHC (water holding capacity) (control, T1), 55-60% WHC (light drought stress, T2), 40-45% WHC (moderate drought stress, T3) and 30-35% WHC (severe drought stress, T4) and each replicated three times. The data generated were subjected to Analysis of Variance (ANOVA). According to the findings, Rio outperformed the other varieties in terms of fresh fruit weight (21.59g), fruit pericarp thickness (3.96mm) and drought tolerance index (56.17%) under severe drought conditions. However, under severe drought conditions, the highest average number of fruits (2.33) was produced by the UTC, closely followed by Dan Syria (2). The results also showed that under severe drought stress, Rio outperformed the other varieties in terms of fresh and dry weight of shoot, as well as fresh and dry weight of root (18.82g, 3.47g and 3.34g, 1.29g) closely followed by Dan Syria measuring 12.47g, 1.66g, 3.10g, and 0.62g respectively. Under conditions of severe drought stress, Rio, UTC, and Dan Syria exhibit drought tolerance indices of 56.17%, 37.49%, and 20.44% respectively. These suggest that Rio is the most resilient to drought compared to the other varieties. Therefore, farmers should consider using Rio, which has a high level of drought resistance, as a means to mitigate the impact of drought.

Keywords: Drought stress, Tomato varieties, Drought-tolerant, Yield, Physiological processes

INTRODUCTION

Plants can undergo water scarcity as a result of several environmental factors, such as high temperatures, excessive salt, low temperatures, and droughts. This can lead to physiological stress in plants when there is an imbalance or excess of any of these abiotic factors (Skiyez and Inze, 2010). Water deprivation disrupts several plant functions, such as reducing photosynthetic activity (Flexas *et al*., 2006), leading to less assimilates and ultimately resulting in lower dry matter and plant production (Vurayai *et al*., 2011). Water deficit stress, whether it is continuous or transitory, has the greatest impact on the growth and spread of natural vegetation and the production of cultivated plants (Hong-Bo *et al*., 2009). Stress is a deleterious condition in which plants suffer negative consequences due to exposure to adverse factors, such as excessive or insufficient water, severe temperatures and light (Kumar *et al*., 2012). When it comes to water shortages, drought poses the most significant threat to global food security. It acted as the catalyst for the momentous famine. The expected increase in global population will intensify the impact of droughts on food consumption in the future, as the availability of water resources is constrained (Somerville and Briscoe, 2017). Insufficient water negatively impacts plant growth at several phases of development, leading to reduced germination rates and hindered plant development (Yigit *et al*., 2016). Drought stress in plants, such as oxidative stress, is a major factor that triggers plant responses and leads to various negative effects. These effects include damage to the cell membrane, changes in membrane integrity, physiological and biochemical disturbances, acute metabolic disorders, reduced plant productivity, and even plant death (Wang *et al.*, 2019). Tomatoes are a highly eaten and important crop in the world economy. Due to its antioxidant and anticancer properties, tomatoes are consistently consumed and produced (Raiola *et al*., 2014). According to the FAO (2016), tomatoes are the second largest vegetable in terms of both production and consumption. Tomatoes are considered a leading model for genetics, breeding, and genomics research due to their significant agricultural and commercial value, as well as their whole genome sequencing (Choudhary *et al*., 2018). Drought is the main threat to tomato production. Acquiring drought-resistant tomato varieties can help solve this worry, including in Gombe State and other areas in Nigeria impacted by drought. Hence, the objective of this study was to assess the impact of drought stress on the fruit and yield characteristics of three distinct cultivars of tomato (*Lycopersicum esculentum* L.).

MATERIALS AND METHODS

Study area

The study was carried out in the green house of the botanical garden of the Federal University Kashere, Gombe State. Kashere in Gombe State, lies within latitude 9^{0}52'40"N and longitude 11^{0}0'37"E. The town is located in the northern Guinea Savanna region of Nigeria (Kolawole *et al*., 2021).

Collection of plant samples

The three local varieties of tomato seed (Rio, Dan Syria and UTC) were obtained from Tashan-Gwari in Gombe main market, Gombe state and the seeds were taking to the head of botanical garden for clear authentication.

Nursery Beds and Transplanting

Nursery bed was prepared in the Botanical garden of Federal University of Kashere, and three local varieties of tomato seeds namely Rio, Dan Syria and UTC were broadcasted on the soil in separate seeds tray, the trays were watered daily for three weeks. The seedlings were transplanted in different pots when they reached a height of about 6-7cm. The soil used for both the nursery and individual pots consisted of the mixture of loam, sandy soil, and organic manure in the ratio of 3:2:1.

Drought Stress induction

Once the seedlings reached a height of approximately 6-7cm, they were moved into 36 polythene pots. During this process, the number of seedlings in each pot was reduced to two. Four treatments were applied to the plants to assess the impact of drought stress. The stress was induced 25 days after transplanting using a method modified from Al-Maskri et al. (2016). Drought conditions were applied at different levels of water holding capacity: 80-85% (control, T1), 55-60% (light drought stress, T2), 40-45% (moderate drought stress, T3), and 30-35% (severe drought stress, T4). These levels correspond to daily watering, watering every 3 days, watering every 6 days, and watering every 9 days, respectively.

Experimental Design

The study design was complete randomized block design (CRBD). The experimental set-up comprised three varieties of tomatoes, each having four treatments and three replicates making a total of 36 polythene pots. Measurement of parameters such as drought tolerance index etc was taken at plant maturity.

***Number of fruits per plant at maturity*:** Fruits were harvested at their optimal ripeness. The total amount of tomatoes collected was tallied and documented for each variety of tomato plant.

***Fresh weight of fruit at maturity*:** The fresh fruits were measured using an electronic weighing scale of the ae ADAM model. The weights of the fruits were recorded in grams (g) at the time of maturity.

***Thickness of pericarp*:** The transverse pieces of fully ripened fruits per plant were acquired by horizontally cutting through the fruits using a slicing knife. The weight of each fruit's pericarp was measured using a calibrated meter rule and recorded in grams (g).

***Shoot fresh weight (g)*:** At the end of the experiment, individual plant shoots were harvested by uprooting and rinsed from any adhering particles and shoot were weighed using electronic weighing balance (ae ADAM model).

Shoot dry weight (g): Plant shoots were collected by uprooting and cleaned of any attached particles. They were then dried in an oven at a temperature of 70^0 C for duration of two days. The weight of the dried shoots was measured using an electronic weighing balance (specifically, the ae ADAM model).

Root fresh weight (g): At the end of the experiment, individual plants root were harvested by uprooting and rinsed from any adhering particles, root were detached from shoot and weighed using electronic weighing balance (ae ADAM model).

Root dry weight (g): Plant roots were collected by uprooting and cleaned of any attached particles. They were then dried in an oven at a temperature of 70^0 C for duration of two days. The weight of the dried shoots was measured using an electronic weighing balance (specifically, the ae ADAM model).

***Drought tolerance index*:** The drought tolerance index was calculated by dividing the total above-ground dry weight (shoot) of the plants subjected to various drought durations by the shoot dry weight of the control, and then expressing it as a percentage. This calculation was performed using a slightly modified approach based on Christos *et al*. (2015). The mature tomato shoots, which refer to the complete above-ground portion of the plants, were measured in terms of weight and the fresh weights of the shoots were recorded. The dry weight was measured by drying the above-ground portions of the tomato plants in an oven at a temperature of 70 degrees Celsius until the samples reached a consistent weight. The Drought Tolerance Index was computed using the following formula:

$$D.T.I. = W_T/Wo \times 100$$

Where,

W_T = Dry weight of shoots of the stressed plants

Wo = Dry weight of shoots of unstressed plant

Statistical Analysis

Data generated from the study was imputed in IBM statistical package version 20 and analyzed using Analysis of Variance (ANOVA). Duncan's multiple range test was also used to determine the difference between the treatment means.

RESULTS AND DISCUSSION

Effects of varying levels of drought stress on the fruit quality per plant of different tomato varieties (*Lycopersicum esculentum* L.) at the time of maturity

The effects of varying levels of drought stress on the fruit quality which comprises number of fruits, fresh fruit weight and fruit pericarp thickness of the three varieties of tomato were determined. The total number of fruits per plant across the three varieties at maturity was slightly significantly different $p<0.05$. Rio variety recorded the highest number of fruits at T1, T2 and T3 levels of drought stress while at extreme drought stress (T4), UTC variety performed better (Fig. 1). Evidently Rio variety demonstrates superior fruit yield performance compared to others in light (T2) and mild (T3) drought, but its yield drastically reduced in severe drought condition. There was significant difference in the total fresh weight of fruits per plant due to the different drought stress levels. Fresh fruit weight of Rio variety had a substantial increase in weight compared to UTC and Syria respectively on control medium while at extreme drought stress level, Rio variety still performed better and significant differences was recorded at $p<0.05$ across all the drought stress levels of the three varieties tested (Fig. 2). Figure 3 shows the effects of different levels of drought stress on the fruit pericarp thickness at maturity of the three tested varieties. It is interesting to note that as the fresh fruit weight of plant increases, fruit pericarp thickness also increases and vice versa. At extreme drought stress application, Rio and UTC variety produced thicker fruit pericarp than Syria. No significant difference ($p<0.05$) was recorded for fruit pericarp thickness on Syria variety while significant difference was recorded on Rio and UTC across the levels of drought stress in comparison with control ($p<0.05$).

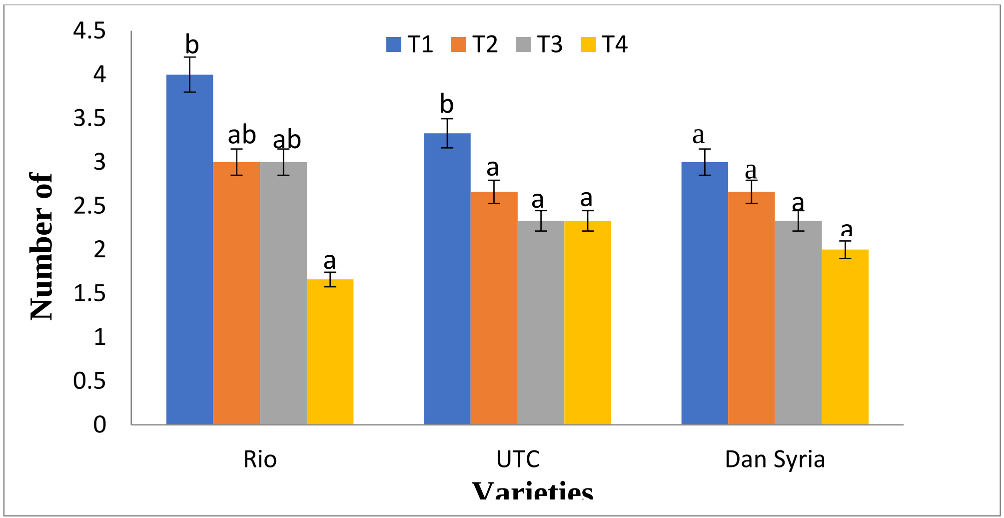

Figure 1: Effect of varying levels of drought stress on the number of fruits of three varieties of tomato (*Lycopersicum esculentum* L.)

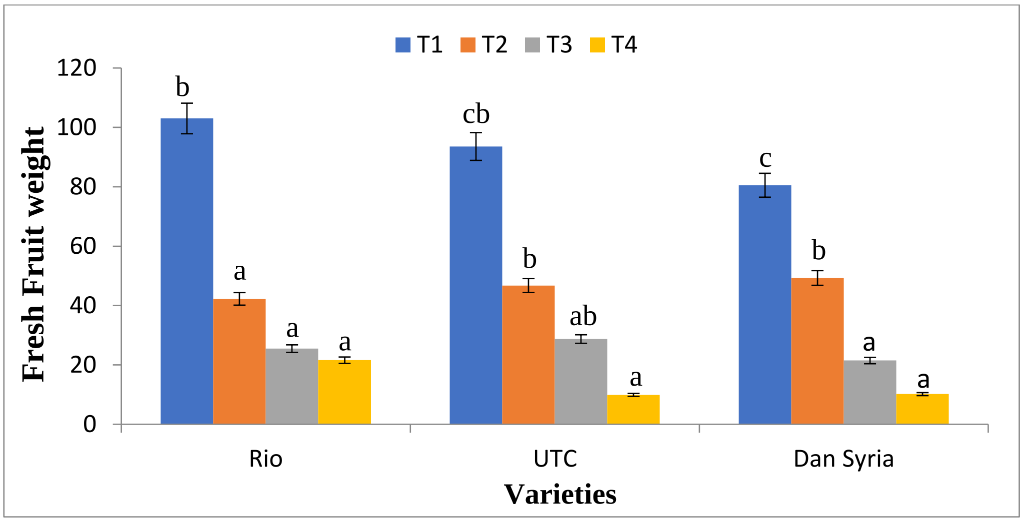

Figure 2: Effect of varying levels of drought stress on the fresh fruit weight of three varieties of tomato (*Lycopersicum esculentum* L.)

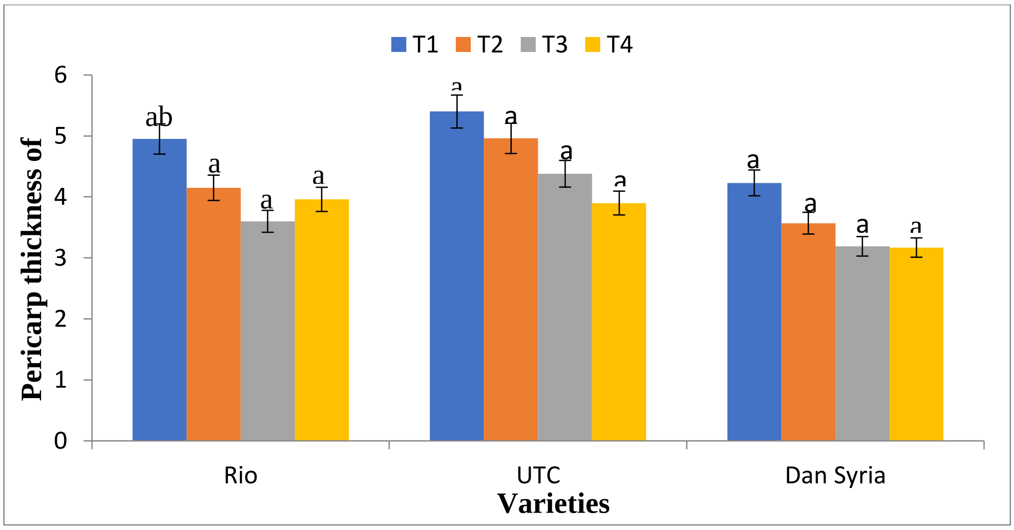

Figure 3: Effect of varying levels of drought stress on the thickness of fruit Pericarp of three varieties of tomato (*Lycopersicum esculentum* L.)

Effects of varying levels of drought stress on the fresh and dry matter weight and drought tolerance index of different varieties of tomato (*Lycopersicum esculentum* L.) at the time of maturity

The effects of varying levels of drought stress on fresh and dry matter weight and drought tolerant index of the three varieties of tomato is presented in table 1. Fresh and dry shoot weights of the three varieties of tomato at harvest showed significant difference ($p<0.05$), Dan Syria variety produce significantly higher fresh and dry weight of shoot at T1 and T2 levels of drought stress while at (T4) extreme level of drought stress, Rio variety produce the highest value of fresh and dry shoot weight across all the three varieties which was closely followed by Dan Syria variety.

Fresh and dry root weight of the three tomato varieties across different level of drought stress is presented in table 1. Dan Syria variety produced plant with the highest value of fresh root weight across all the levels of drought stress followed by Rio and UTC variety respectively. For dry root weight, Syria variety produced plants with the highest weight of dry root on T1 and T2 with Rio variety producing plant with the highest weight of dry root at extreme level (T4) of drought stress. There were significant differences ($p<0.05$) observed in the fresh and dry root weight of all the three varieties across the different levels of drought stress in comparison with the control. Drought tolerance index was recorded in Table 1 and it shows all the control recording 100% drought tolerance as they were adequately watered. Rio variety recorded a better drought tolerance across the different drought stress level and at extreme drought stress level it recorded 56.17% of drought tolerance which is above UTC and Dan Syria variety which recorded 37.49% and 20.44% respectively. Significant difference ($p<0.05$) was recorded on drought tolerance index across the different level of drought stress on the three tested varieties at maturity.

Table 1: Effects of varying levels of drought stress on the mean number of Fresh Shoot Weight, Dry Shoot Weight, Fresh Root Weight, Dry Root Weight and drought tolerance index per plant of different varieties of tomato (*Lycopersicum esculentum* L.) at maturity

Varieties	Treatment	Fresh Shoot Weight (g)	Dry Shoot Weight (g)	Fresh Root Weight (g)	Dry Root Weight (g)	Drought Tolerance Index (%)
Rio	T1	31.61 ± 2.98^{b}	6.09 ± 0.60^{c}	7.07 ± 0.17^{b}	2.12 ± 0.23^{ab}	100.0 ± 0.00^{c}
	T2	27.19 ± 0.67^{ab}	4.49 ± 0.02^{bc}	6.18 ± 0.23^{ab}	1.71 ± 0.12^{a}	75.10 ± 6.94^{b}
	T3	23.63 ± 6.01^{ab}	4.45 ± 1.01^{ab}	4.85 ± 1.53^{ab}	1.48 ± 0.59^{a}	76.10 ± 20.32^{b}
	T4	18.82 ± 4.47^{a}	3.47 ± 0.80^{a}	3.34 ± 0.62^{a}	1.29 ± 0.43^{a}	56.17 ± 9.12^{a}
UTC	T1	20.56 ± 3.99^{b}	4.32 ± 0.44^{c}	7.39 ± 1.03^{b}	2.17 ± 0.58^{b}	100.00 ± 0.00^{c}
	T2	17.85 ± 1.22^{ab}	3.45 ± 0.07^{bc}	5.80 ± 0.55^{ab}	0.99 ± 0.01^{b}	81.45 ± 7.67^{bc}
	T3	14.46 ± 1.05^{ab}	2.67 ± 0.55^{ab}	3.18 ± 0.45^{a}	0.43 ± 0.25^{a}	62.84 ± 12.50^{ab}
	T4	7.83 ± 1.04^{a}	1.51 ± 0.39^{a}	2.68 ± 1.41^{a}	0.52 ± 0.30^{a}	37.49 ± 13.58^{a}
Dan Syria	T1	40.62 ± 3.46^{b}	8.27 ± 0.22^{b}	11.35 ± 3.37^{b}	3.04 ± 0.63^{c}	100.00 ± 0.00^{b}
	T2	39.37 ± 5.61^{b}	7.50 ± 0.59^{b}	9.56 ± 1.77^{ab}	2.07 ± 0.31^{bc}	90.49 ± 5.55^{b}
	T3	23.56 ± 4.97^{ab}	3.02 ± 0.71^{a}	5.47 ± 0.55^{ab}	1.16 ± 0.20^{ab}	36.69 ± 9.25^{a}
	T4	12.47 ± 4.32^{a}	1.66 ± 0.57^{a}	3.10 ± 1.07^{a}	0.62 ± 0.20^{a}	20.44 ± 7.21^{a}

The values represent the mean ± standard error of three replications. When comparing distinct superscripts in a column, the differences are considered significant if the p-value is less than 0.05, using the Duncan's Multiple Range Test (DMRT).

Discussion

Tomatoes thrive in environments with abundant water, but they may also tolerate moderate drought stress (Karlberg *et al*., 2007). Multiple studies have demonstrated that tomato fruit production generally declines when subjected to severe drought stress conditions (Jensen *et al*., 2010). The ability of tomato plants to withstand drought stress is influenced by factors such as the specific variety, the growth stage during which the stress occurs, and the intensity of the drought stress (Patanè and Cosentino, 2010).

In this study, the result of the potting experiment shows the impact of drought stress on the fruit yield quality, wet and dry matter weight of the shoot and root and salt tolerance index of the three varieties of tomatoes. The fruit yield quality involves number of fruits, fresh fruit weight and pericarp thickness. Drought stress is the primary abiotic limitation that leads to a significant decrease in agricultural productivity, resulting in widespread yield reduction (Ghorbanli, 2013). Severe drought stress leads to flower shedding and a lack of fertilization, resulting in the production of small-sized fruits during fruit setting (Patanè *et al*., 2011).This is consistent with the claim that a decrease in the quantity and weight of fruits was observed under severe drought conditions for all three tomato varieties. However, UTC and Rio varieties outperformed Dan Syria variety in terms of number of fruit and fruit weight, respectively, under severe drought conditions. In a study conducted by Nuruddin *et al*. (2003), an experiment was carried out to examine the effects of different levels of drought stress (65% and 80%) on tomato plants. The results showed that as the amount of drought stress increase, both the number and size of fruits decreased. The outcome of this study aligns with the findings of Khan *et al*. (2020), who observed a reduction in the quantity of fruit across several tomato cultivars in response to higher levels of drought stress. This finding also aligns with the research conducted by Oti *et al*. (2023), which similarly demonstrated the considerable influence of drought stress on the growth characteristics and yield attributes of tested rice accessions.

Guichard *et al*. (2011) found that drought stress can cause a reduction in the firmness of fruit, resulting in more flexible cell walls that can impact the thickness of the pericarp. Our research findings indicate that when the amount of drought stress increases, there is a corresponding drop in the thickness of the fruit pericarp in UTC and Dan Syria varieties. However, in the case of Rio variety, there is an increase in fruit pericarp thickness at severe drought stress levels, suggesting that it is a promising drought-tolerant variety. The control-treated plants exhibited the highest biomass accumulation in terms of fresh and dry weight of shoot and root among the three tomato varieties. They were followed by the plants treated with light and moderate drought stress levels. The most severely affected plants were those treated with severe drought stress, regardless of the variety. The quantity of water accessible significantly influences the biomass yield in any crop (Medrano *et al*., 2007).

Drought tolerance index was used to evaluate stress tolerance base on crop yield under stress and non-stress situations and the result shows all the control recording a 100% drought tolerance as they were adequately watered. Rio variety recorded a better drought tolerance index 56.17% better than UTC and Dan Syria variety, which might be attributed to synthesis of stress-responsive proteins and genes leading to overall stress tolerance (Kim *et al*., 2010). Therefore Rio variety might have contained excess stress-responsive proteins and genes leading to drought stress tolerance than UTC and Dan Syria variety making it to have a better tolerant index at severe drought stress level.

CONCLUSION

Drought is one of the most critical environmental hazards of the world and this abiotic factor has led to decline in Agricultural product over time. Considering the yield performance, Rio variety performed better than the other two varieties on fresh fruit weight, fruit pericarp thickness at severe drought stress level while UTC variety at severe drought stress level produced the highest number of fruits closely followed by Dan Syria variety. The study further revealed that at moderate and extreme level of drought stress, Rio variety performed better than the two other varieties on fresh and dry weight of shoot and also fresh and dry weight of root followed by Dan Syria variety. At severe drought stress level, Rio variety possesses a drought tolerance index better than UTC and Dan Syria variety, thus portraying Rio variety to be the most drought-tolerant of the three varieties used. UTC and Dan Syria variety produced the highest fruit at severe drought stress and also proved as the best tomato variety for cultivation in severe drought condition.

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