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Susceptibility of *Solanum melongena* L/Solanaceae to Drought at Different Growth Stages

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ABSTRACT

The study on the susceptibility of Solanum melongena to drought at different growth stages was conducted in the 2019 and 2020 growing seasons. S. melongena is one of the most relevant agricultural crops in the tropics and subtropical regions of Africa. However, drought has a significant effect on the rate of growth and fruit yield of the crop. However, the growth stage at which S. melongena is vulnerable to the effect of drought needs detailed research and clarification which is the focus of this study. Key morphological traits such as shoot height, number of leaves and branches, and leaf area and water-related physiological indices such as leaf area ratio, net assimilation rate, root shoot ratio, tissue water content including aboveground biomass, leaf relative water content, chlorophyll pigments, osmolytes accumulation, and antioxidants were observed and measured to find the effect of drought at different growth level. The result revealed that the morphological traits, water-related physiological indices, aboveground biomass, leaf relative water content, photosynthetic pigments, antioxidants such as alkaloids and flavonoids of S. melongena were drastically reduced under drought throughout the growth period, associated with vegetative, flowering, and fruiting stage. Osmolytes such as phenol and proline were more enhanced. Across the growth stages, S. melongena subjected to drought at the vegetative stage has exhibited the lowest performance in the measured parameters and has the lowest critical value. S. melongena at the vegetative stage was more vulnerable to drought than the flowering and fruiting stage. Susceptibility to drought of the crop at the vegetative stage can lead to poor growth and yielding.

Keywords: Critical stage, Drought, Eggplant, Growth, Osmolytes, Yield, Nigeria.

1. INTRODUCTION

S. melongena is one of the most important and commonly used vegetables in tropics and subtropical climates of Africa. It is known as egg plants due to its long club shaped edible plant and white, green, yellowish colors, through grades of purple pigment to black colour (Sihachkr et

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al., 1993). The fruit of *S. melongena* is glossy with white flesh and a spongy, meaty texture. It is native to India and China, and thereafter to Africa, but its currently grown all over the world (Sekara et al., 2007; Bhaskar and Ramesh 2015). In a warm area, *S. melongena* is a perennial, with bushy, ligneous plants. It is grown as an annual plant in mild climates, and in temperate areas. *S.S. melongena* is a delicate tropical perennial plant that is commonly cultivated at a tender age or as a half-hardy annual (Chong, 2005; Krisban, 2013). *S. melongena* is ranked amongst the most top ten vegetables that provide the healthiest food with low calories and contain high phenolic contents that are helpful to cure diseases such as arthritis, osteoporosis, diabetes, bronchitis, stroke, and heart diseases (Cao et al., 1996; Sekara et al., 2007; Seneff et al., 2011; Caguiat and Hautea, 2014). *S. melongena* is a host of various minerals, vitamins, iron, potassium, calcium, magnesium, and phytochemicals that contain phenolic components such as caffeine and chlorogenic acid and flavonoids (Matsuzoe et al., 1999). The matured fruit of the plant contains certain important nutrients like vitamin A, vitamin C, sugar, ascorbic acid, protein, and iron. The leaves parts are most frequently consumed and contain certain important nutrients such as fat, high in dietary fiber, and rich in folic acid, vitamin C, potassium, and magnesium, as well as containing a host of phytochemicals (Chong, 2005; Cassidy et al.,2013; Krisban, 2013; Bhasker and Ramesh,2015).

S. melongena is vulnerable to a variety of environmental challenges, including high temperatures, drought, salinity, and pollution, and there is a need to produce cultivars that can tolerate these stresses (Noda et al., 2000; Plazas et al., 2013; Durst and Bayasgalanbat, 2014). Water shortage has been an important restriction to produce *S.S. melongena*. Drought has been shown to reduce growth, yield, and quality, even though different physiological pathways have been proposed to account for yield loss in different species (Sarker and Hara, 2004; Stiven and Sanaratna, 2006; Sekara et al., 2007; Ishibashi et al., 2011; Ashraf, 2014; Sun et al., 2016; Freschet et al., 2018). Compared to some other categories of crop plants, such as tomato (*Solanum lycopersicum)* (Okunlola et al., 2015), chickpea (*Cicer arietinum*) (Mafakheri et al., 2010), soybean (*Glycine max*)(Okunlola et al., 2022), maize (*Zea mays*) (Ashraf, 2014) and rice (*Oryza sativa*) (Kato et al., 2012; Lin et al., 2012), *S. melongena* is more sensitive to water deficit **(**Delfin et al., 2021**)**. *S. melongena* has been shown to be adversely affected by drought causing reduction on the plant height, total dry weight, and fruit yield (Sarker et al., 2003; Delfin, 2015). Reduction in leaf stomatal conductance, transpiration rate, and photosynthetic rate

of *S. melongena* were also observed upon exposure to different durations of drought stress (Noda et al., 2000; Sarker et al., 2003**)**. Preliminary work with Philippine *S. melongena* genotypes showed a reduction of 21–29% in fruit yield when exposed to short-term drought stress (Mibei et al., 2017; Amiri et al., 2020).

A major strategy for breaking drought events is selection and cultivation of drought resistant genotypes and germplasm (Sarker and Hara, 2004**)**. In this regard, generating water-stress tolerant genotypes has become a high-cost and less efficient technique in areas where water is scarce. Meanwhile, over the years, the areas under cultivation of *S. melongena* have expanded, specifically in the tropics and subtropics and arid and semi-arid areas where drought is frequent (Sarker and Hara, 2004**;** Delfin et al., 2021). Hence, due to high susceptibility of *S. melongena* to water deficit, there is a significant decrease in the yield and quality of this crop (Mibei et al., 2017). Understanding the adaptability of *S.S. melongena* by exploring growth stage at which *S.S. melongena* is vulnerable to drought is of utmost importance for sustainable production in water-limited areas.

2. MATERIALS AND METHODS

2.1. Materials for the Study and Raising of Seedlings

Seeds of *S. melongena* variety gilo used for this study were obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Oyo state, Nigeria. The experiments were carried out in the screen house (to minimize extraneous factors such as pests, insects, rodents, and water) of the Department of Botany, Obafemi Awolowo University, Ile-Ife, Nigeria. The average temperature of the screenhouse was 28 to 32^{o}C, and the relative humidity ranged between 50 to 55%. The seedlings were first raised in a nursery for a period of two weeks and further transplanted into planting bags.

Seventy-two planting pots, each 20cm in diameter and 20cm in height, were obtained. The planting pots were perforated to allow for proper drainage of water. The pots were filled each with 10kg of loamy soil. The seedlings of *S. melongena* were transplanted from the nursery after 14 days of establishment and sown at the rate of three seedlings per planting pot and at a depth of 2 cm below the soil level. Drought treatments were carried out at one week after transplanting and lasted for 8 weeks across the regimes. Drought plants received 40% of water holding capacity of the planting bags daily for the first week, and thereafter every 5 days for

short-term drought. The seedlings were thereafter split into four regimes, with the control receiving 40% of water holding capacity every 5 days throughout the growth periods. The seedlings subjected to short-term drought at vegetative were made to receive 40% of water holding capacity up till 70% of plants start flowering. The seedlings subjected to short-term drought at flowering stage were made to receive 40% of water holding capacity up till 70% of the plants start fruiting. The fruiting stage lasted when about 70% of the fruits become matured. The experimental setup was established in a complete randomized design (CRD) by assigning each stage of growth into groups separately and independently to reduce experimental error. Each stage of growth was thereafter repeated six times.

2.2. Determination of Morphological Traits and Water-related Physiological Indices

Sampling was carried out at a five-day interval after water application for each regime (Okunlola et al., 2015). Key morphological traits such as shoot height, number of leaves and branches, leaf length and width with a correction factor (0.75) (used to find out the leaf area) were determined. Above ground biomass such as fresh and dry weights from each regime were measured using digital weighing balance (model SES620C, Saffron, Industrial Ltd., China). Fresh weights of drought treated plants were determined at the termination of drought at each stage, and thereafter plants were oven dried in a Gallenkhamp oven (model DZF-6020, Zhengzhou Keda Co., Ltd., China) at 45^{o}C for 72 hours for dry weight (Olowolaju and Adelusi, 2017). Water-related physiological indices such as leaf area ratio (LAR), net assimilation rate (NAR), root to shoot ratio (RSR), tissue water content (TWC), and leaf relative water content (LRWC) were determined according to Olowolaju and Adelusi (2017) using leaf area and dry matter data as indicated.

$$\text{LAR} = \frac{(\text{A2}-\text{A1})(\ln\text{W2}-\ln\text{W1})}{(\text{W2}-\text{W1})(\ln\text{A2}-\ln\text{A1})}$$

$$\text{NAR} = \frac{(W2-W1)\ (\ln A2-\ln A1)}{(A2-A1)\ (t2-t1)}$$

$$\text{RSR} = \frac{\text{Root dry weight}}{\text{Shoot dry weight}}$$

$$\text{TWC} = \frac{\text{Fresh weight}-\text{Dry weight}}{\text{fresh weight}} \times 100$$

$$\text{RWC} = \frac{\text{Leaf fresh weight}-\text{Leaf dry weight}}{\text{Leaf total weight}-\text{Leaf turgid weight}} \times 100$$

Where, W_1 = dry weight at the beginning of each growth stage.
W_2 = dry weight at the end of each growth stage.
LA_1= leaf area at the beginning of each growth stage.

LA_2 = leaf area at the end of each growth stage; t = time (in days).

2.3. Estimation of Chlorophyll Pigments

Eight grams of leaves of *S. melongena* were harvested from each regime, and the leaves were ground with mortar and pestle. To prevent the chlorophyll from degrading, a pinch of Sodium bicarbonate was added to the mix. A total of 16 mL of 80% acetone was added. A Whatman's No 1 filter paper was used to filter the combined components. The samples' absorbance was measured using a digital spectrophotometer at wavelengths of 646 nm, and 663 nm. The amounts of chlorophyll 'a', chlorophyll 'b' and total chlorophyll in the leaf extract were determined using the equations mentioned below (Combs et al., 1990).

$$\text{Chlorophyll a (µg/mL)} = 12.21A_{663} - 2.81A_{646}$$

$$\text{Chlorophyll b (µg/mL)} = 20.13A_{646} - 5.03A_{663}$$

$$\text{Total chlorophyll (µg/mL)} = 07.93A_{663} + 19.53A_{646}$$

A_{663} represents the absorbance at wavelength 663 nm while A_{646} represents the absorbance at wavelength 646 nm.

2.4. Estimation of Osmolytes Accumulation and Antioxidants

2.4.1. Proline Accumulation

In a pestle and mortar, 500 mg of leaves harvested from each treatment was homogenized with 10 mL of 3% aqueous sulfosalicylic acid. After that, Whatman's No. 2 filter paper was used to filter the homogenate. The residue was pooled after being re-extracted twice with 3% sulfosalicylic acid. Filtrates containing 3% sulfosalicylic acid were generated up to 20 mL, this filtrate was then used for quantitative analysis of proline. In a test tube, 2 mL extract was mixed with 2 mL acid ninhydrin reagent and 2 mL glacial acetic acid. The mixture was incubated for an hour in a water bath at 100°C. The tubes were placed in an ice bath to halt further reactions. Then, using a test tube, 4 mL of toluene was added to each test tube and aggressively stirred for 10 to 20 seconds. A separating funnel was used to separate the chromophore-containing toluene from the aqueous phase, and the absorbance was measured at 520 nm using an appropriate blank in a UV-Spectrophotometer (Hitachi U-2900). The proline content was determined using a proline standard curve and the results were expressed in µmol/L according to Bates et al. (1973).

2.4.2. Estimation Total Phenol

The method ascribed by Julkunen-Tiitto (1985) was used for the estimation of total phenolic content in leaf samples. Leaf samples (0.5g) were homogenized in 80% acetone. The supernatant

obtained after centrifugation at 1000 µg for 10 min was used. An aliquot (100 µL) was reacted with 2 mL of distilled water and 1 mL of Folin–Ciocalteau's phenol reagent. The triturate was then mixed with 5.0 mL of 20 % Na_2CO_3 solution and the final volume of the mixture was measured to 10 mL with distilled H_2O. After mixing well with a vortexer, the absorbance of the final solution was read at 750 nm using a UV-visible spectrophotometer (Hitachi U-2100).

2.4.3. Estimation of Alkaloids

Acetic acid (200 mL of 10 %) in ethyl alcohol was added to the leaf extract sample. The mixture was covered and allowed to stand for 4 hr. The mixture then filtered, and the extract was allowed to become concentrated in a water bath until it reached one quarter of the original volume. Concentrated ammonium hydroxide was added until the precipitation was complete. The whole solution was allowed to settle, and the precipitate was collected and washed with dilute ammonium hydroxide and then filtered. The residue was dried and weighed (Mustapha and Harun, 2014).

2.4.4. Test for Flavonoids

Leaf extract (0.5 mL) of *S. melongena* was added to 1.5 mL methanol and mixed well. After that 0.1 mL of $AlCl_3$ (0.1 mg/mL) and 0.1 ml of 1M CH_3COONa reagents were added to the above solution. This reaction mixture was added to 2.8 mL of distilled water, mixed and allowed to stand for 30 minutes in dark. The absorbance of reaction mixtures was measured at 415 nm. The total flavonoid content was expressed as mg rutin equivalents / 100g d.w. of the extract (Pourmorad et al., 2006).

2.5. Determination of Critical Level

The critical growth stage of *S. melongena* sensitivity to drought was determined from the data obtained from plant biomass of the plant species at each stage of growth using the below formula.

$$\text{Critical Level} = \frac{\text{Plant biomass of plant species at each stage of growth}}{\text{Total plant biomass}} \times 100 \text{ (Olowolaju, 2019)}$$

2.6. Statistical Analysis

Statistical analysis was carried out using statistical analytical software (SAS) version 9.2. A one-way analysis of variance was carried out to investigate the morphological traits and water-related physiological indices of *S. melongena* at different growth stages in response to drought. Fisher's

LSD was used to separate the significant mean values among the treatments at 0.05 confidence limit (alpha level).

3. RESULTS

3.1. Morphological Response of *S. melongena* to Short-term Drought at Different Growth Stages

Drought significantly affects the shoot height, number of leaves, number of branches and leaf area of *S. melongena* (Table 1). Lowest shoot height, fewer number of leaves, few number of branches and small leaf area were obtained from *S. melongena* subjected to drought throughout the experimental period (control) compared to the shoot height, number of leaves, number of branches and leaf area of *S. melongena* subjected to drought at vegetative, fruiting, and flowering growth stage. At the different growth stages, shoot height, number of leaves, number of branches and leaf area of *S. melongena* subjected to drought at vegetative stage was the least while those subjected to drought at fruiting stage had the highest shoot height, more leaves number, well developed branches, and better leaf area. There were significant differences in the shoot height, number of leaves, number of branches and leaf area of *S. melongena* among the treatments at $p \leq 0.05$ (Table 1).

Table 1. Morphological traits of *Solanum melongena* L. (Egg Plant) at different growth stages responsive to short-term drought.

	Morphological traits			
Growth Stage	***Shoot height***	***Number of leaves***	***Number of branches***	***Leaf area***
Vegetative stage	33.27^{b}	9.56^{b}	1.83^{bc}	95.56^{ab}
Flowering stage	42.24^{b}	11.20^{ab}	2.83^{b}	134.48^{a}
Fruiting stage	60.13^{a}	12.38^{a}	5.17^{a}	131.27^{a}
Control	19.26^{c}	7.36^{c}	1.14^{c}	84.16^{b}
LSD	10.10	1.74	2.20	27.28

Note: Means with same letter along the column are not significantly different $p \leq 0.05$.
LSD = Least Significant Difference.

3.2. Water-related Physiological Response of *S. melongena* to Short-term Drought at Different Growth Stages

The total fresh and dry weight of *S. melongena* was substantially affected by drought. The total fresh and dry weight of *S. melongena* in which drought was imposed at vegetative stage had

higher total fresh and dry weight than the *S. melongena* imposed throughout the experimental period, flowering, and fruiting stage. Meanwhile, those subjected to drought throughout the experimental period had the lowest total fresh and dry weight. In contrast among the growth stages, the highest total fresh and dry weight of *S. melongena* was obtained in *S. melongena* in which drought was imposed at fruiting stage. The lowest total fresh was observed in *S. melongena* in which drought was imposed at vegetative stage while total dry weight in those in which water stress was imposed at flowering stage.

S. melongena subjected to water deficit at vegetative stage had the highest leaf area ratio (LAR), Net Assimilation Rate (NAR), Root Shoot Ratio (RSR), Tissue water content (TWC), leaf relative water and content (LRWC)followed by *S. melongena* subjected to water deficit at flowering stage while *S. melongena* subjected to water deficit throughout the course of the experiment had the lowest leaf area ratio, root shoot ratio, tissue water content, leaf relative water content and leaf turgid weight. There was significant difference in physiological growth indices among the treatments at $p \leq 0.05$ (Table 2).

Table 2. Water-related physiological indices and plant biomass of *Solanum melongena* L. (Egg Plant) at different growth stages responsive to short-term drought.

	Water-related Physiological Indices						
Growth Stage	***TFW***	***TDW***	***LAR***	***NAR***	***RSR***	***TsWC***	***LRWC***
Vegetative stage	25.07^{b}	4.05^{a}	46.47^{a}	0.0042^{c}	85.75^{a}	76.82^{a}	7.75^{a}
Flowering stage	25.49^{b}	3.79^{b}	42.80^{b}	0.0037^{d}	85.83^{a}	67.16^{b}	7.02^{b}
Fruiting stage	31.03^{a}	4.25^{a}	31.56^{c}	0.0051^{a}	83.92^{ab}	65.28^{b}	5.92^{c}
Control	21.94^{c}	2.73^{c}	30.17^{c}	0.0049^{b}	81.56^{c}	57.50^{c}	4.56^{c}
LSD	0.56	0.18	3.08	0.0001	3.43	4.50	0.41

Note: Means with same letter along the column are not significantly different $p \leq 0.05$.
LSD = Least Significant Difference; TFW=Total fresh weight; TDW=Total dry weight; LAR= Leaf Area Ratio; NAR= Net Assimilation Rate; RSR=Root Shoot Ratio; TWC=Tissue Water Content, LWRC= Leaf Relative Water Content.

3.3. Chlorophyll Pigments Accumulation of *S.melongena*Response to Short-term Droughtat Different Growth Stages

A significant decrease in chlorophyll **b** and total chlorophyll pigments of *S. melongena* was observed when drought was imposed throughout the course of the experiment. There was a significant reduction in chlorophyll pigments accumulation of *S. melongena* in response to drought at different growth stages. Chlorophyll **a** content of *S. melongena* was highest in *S. melongena* subjected to drought at vegetative stage followed by flowering and least in *S.*

melongena subjected to drought at fruiting growth stages. There was no significant difference in chlorophyll **a**, chlorophyll **b** and total chlorophyll of *S. melongena* subjected to drought at vegetative, flowering, and fruiting stage, but were significantly different from *S. melongena* which were imposed to drought throughout the course of the experiment (control)at $p \leq 0.05$ (Table 3).

Table 3. Chlorophyll pigments accumulation of *Solanum melongena* L. (Egg Plant) at different growth stages responsive to short-term drought.

	Chlorophyll pigments		
Growth Stage	***Chlorophyll a***	***Chlorophll b***	***Total Chlorophyll***
Vegetative stage	17.47[a]	26.58[a]	45.19[a]
Flowering stage	17.80[a]	24.77[a]	47.69[a]
Fruiting stage	17.47[a]	21.53[a]	43.14[a]
Control	13.72[a]	21.05[a]	40.70[a]
LSD	0.26	1.01	0.55

Note: Means with same letter along the column are not significantly different $p \leq 0.05$.
LSD = Least Significant Difference.

3.4. Osmolytes accumulation and Antioxidants of *S. melongena* response to Short-term Drought at Different Growth Stages Responsive

S. melongena subjected to drought throughout the experimental period shows lowest alkaloids and flavonoids contents and highest content of phenol and proline compared to other treatments. Meanwhile, at different growth stages, alkaloids and flavonoids content were more enhanced in *S. melongena* subjected to drought at flowering stage compared to *S. melongena* subjected to drought at vegetative and fruiting stage. Phenol contents of *S. melongena* were highest in those subjected to drought at fruiting stage and lowest at vegetative stage. Proline was highest in *S. melongena* subjected to drought at flowering stage and lowest in those subjected to drought at vegetative stage. There was significant difference in the flavonoid, alkaloid, phenolics and proline content of *S. melongena* among the treatments ($p \leq 0.05$) (Table 4).

3.5. Critical Level of *S. melongena* at Different Growth Stages to Short-term Drought

The critical level of *S. melongena* in response to water stress at different growth stages was less than 50%. The lowest percentage critical level was observed in *S. melongena* exposed to drought at vegetative stage and highest in *S. melongena* exposed to water deficit at fruiting stage. There was no significant difference in the critical percentage of *S. melongena* at vegetative and flowering stage. Meanwhile, the critical percentage of *S. melongena* at fruiting stage was

significantly different from the critical stage of *S. melongena* at vegetative and flowering stage ($p \leq 0.05$) (Table 5).

Table 4. Osmolytes and antioxidants accumulation of *Solanum melongena* L. (Egg Plant) at different growth stages responsive to short-term drought.

	Osmolytes and Antioxidants			
Growth Stage	***Alkaloids***	***Flavonoids***	***Phenols***	***Proline***
Vegetative stage	1.13^{c}	0.11^{c}	12.13^{d}	0.0057^{d}
Flowering stage	2.44^{a}	0.47^{a}	13.58^{c}	0.0067^{b}
Fruiting stage	2.04^{b}	0.15^{b}	14.21^{b}	0.0063^{c}
Control	1.11^{c}	0.07^{d}	15.59^{a}	0.0087^{a}
LSD	0.086	0.038	0.49	0.0011

Note: Means with same letter along the column are not significantly different $p \leq 0.05$.
LSD = Least Significant Difference.

Table 5. Critical level of *S. melongena* L. (Egg Plant) at different growth stages responsive to short-term drought.

Growth Stage	***Critical Level***
Vegetative stage	24.61^{c}
Flowering stage	24.74^{b}
Fruiting stage	29.81^{a}
LSD	0.068

Note: Means with same letter along the column are not significantly different $p \leq 0.05$.
LSD = Least Significant Difference.

4. DISCUSSION

The study clearly showed that drought markedly inhibited the morphological traits and water-related physiological indices such as shoot height, number of leaves, number of branches, leaf area, fresh and dry weights, leaf area ratio, net assimilation rate, root shoot ratio, tissue water content, leaf relative water content of *S. melongena*. Data obtained for shoot height, number of leaves, number of branches and leaf area of *S. melongena* as measured under water drought conditions revealed that parameters were higher when water stress is imposed at vegetative, flowering, and fruiting stage as compared to those exposed to drought throughout the experimental period. Fresh weight and dry weight, leaf area ratio, net assimilation rate, root shoot ratio, tissue water content, leaf relative water and content were also observed to be lowest in *S. melongena* stressed throughout the experimental period. Though, this inhibition caused by

drought on these morphological attributes and water-related physiological indices can directly be linked to the unavailability of moisture and nutrients brought about low water potential which poses strong effects on cell division, cell elongation and turgidity maintenance of plants which in turns led to poor plant growth, reduce photosynthetic active parts and assimilation of more photosynthates thereby resulting in lower shoot height, number of leaves, number of branches and plant biomass. The reduction in leaf area ratio, net assimilation rate, root shoot ratio, tissue water content, leaf relative water content in *S. melongena* exposed to water deficit throughout the experimental period can be attributed to lower plant biomass function of both stomatal and non-stomatal factors, as well as the light capturing ability by photosynthetic pigments to drive the photosynthetic process efficiently. All these causes disturbance in the assimilation mechanism that is directly involved in better growth and yielding. These results are similar with the findings of Anyia and Herzog (2004) and Chowdhury et al. (2015), who observed decrease in plant biomass of cowpea underwater deficit throughout the experimental periods. The findings of this study are comparable with the study of Ashraf and Ashraf (2012); Orabi et al. (2018), who reported a drought-triggered reduction in biomass production of maize and canola.

Morphological and water-related physiological indices measurement showed that the most sensitive period of *S. melongena* to drought was found at the vegetative stage. The effects of drought at vegetative stage might be attributed to the internal and external physio-biochemical alterations which markedly decreased the morphological traits and water-related physiological indices of *S. melongena* under this stress condition. This might also qualitatively relate to a reduction in cell turgor or a reduction in the extensibility of the cell wall. Cell turgor reduces with any dehydration or decrease in cell water potential which leads to disturbance in the protoplasmic functions that decrease cell division and resulted in reduction in plant growth (Liao et al., 2012; Zhao et al., 2015).

Drought causes disruption in accumulation of chlorophyll a, chlorophyll b and total chlorophyll in *S. melongena.* This disruption in accumulation of chlorophyll pigments due to drought has been observed among several crops, such as soybean (Ishibashi et al., 2011), wheat (Stiven and Sanaratna, 2006), maize (Ashraf et al., 2014), and cucumber (Sun et al., 2016). This adaptation was effective in maintaining stabilization of sub-cellular structures and membranes as well as proteins and maintenance of cellular functions in plants under water drought. Further, decrease in the chlorophyll pigments in *S. melongena* was more pronounced at vegetative stage

with those obtained at flowering and fruiting stage. This might be as result of reduction in leaf relative water content which subsequently leading to reduction in chlorophyll biosynthesis and damaged to chloroplastic membrane.

The study showed that the activities of antioxidants such as alkaloids and flavonoids were observed to be lower in *S. melongena* subjected to drought throughout the experimental period, and vegetative stage. Moreover, an increase in the accumulation of these osmolytes was obtained in *S. melongena* subjected to drought at flowering stage. This increment helps the plants at this stage to avoid the effect of drought subsequently leading to better performance of the plants. Drought induced factors improve the activities of osmolytes such as proline and phenol in *S. melongena* subjected to drought throughout the experimental period. Similar studies showed that such induced factors help the plant to deal with the deleterious impacts of drought (Arasimowicz-Jelonek et al., 2009; Xiong et al., 2012). Antioxidative defense systems help in improving tolerance of plants to drought (Mittler et al., 2004; Cirulis et al., 2013; Ali et al., 2018). Similarly, increased accumulation of phenol and proline might be because phenol and proline might have acted as a direct scavenger of reacting oxygen species and defense molecule in plant under drought conditions (Hossain et al., 2014).Hossain et al., (2014) revealed that increase in the synthesis of potential osmolytes such as proline, total soluble proteins and phenolic compounds helps to boost the antioxidation mechanism by playing a key role as a signaling molecule. Such mechanism brings about effectiveness in maintaining better stabilization of sub-cellular structures and membranes, stabilization of proteins, as well as the maintenance of cellular functions in plants cell under drought. (Wang et al., 2014; Ali et al., 2018). Meanwhile, phenols and proline help in regulating several plants metabolic processes (Habib et al. 2016), including playing a role in reducing ROS-induced oxidative impairment, maintain the membrane's integrity, by improving the activities of key enzymatic antioxidants such as catalase, super oxide dimuatse and peroxidase under water-stressed conditions.

The critical level of *S. melongena* response to drought at vegetative, flowering, and fruiting stage is less than 50%. This implies its sensitivity to drought even at short spell, although the sensitivity was observed to be critical at vegetative stage. However, some high-yielding plant species or cultivars are sensitive to water deficit at vegetative growth stage, some at flowering growth stage while some at fruiting growth stage (Olowolaju et al., 2020).

5. CONCLUSION

Drought induces changes in the morphological attributes and water-related physiological indices of *S. melongena*. It showed varying growth, morphological, and physiological responses under drought at different growth stages and throughout the growth stage. Across the growth stages, *S.S. melongena* subjected to drought at vegetative stage exhibited the lowest performance in the measured parameters and has the lowest critical value. *S. melongena* at vegetative stage was more vulnerable to drought to vegetative, flowering, and fruiting stage of growth. Susceptibility to drought of the crop at vegetative stage can lead to poor growth and yield. To obtain optimal growth and yield of *S. melongena* under drought at short spell, a major strategy for breaking drought events is simulation should be done at this stage by applying appropriate measure such as constant irrigation to overcome the menace of drought.

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7. CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

8. REFERENCE

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