International Journal of Plant & Soil Science

Volume 36, Issue 4, Page 89-103, 2024; Article no.IJPSS.100512
ISSN: 2320-7035

Growth and Functional Traits of Citrus (*Citrus Sp.*) Provenance as Effected by Watering Regime in the Nursery

Ademola Falade [a], Samuel Agele [a*] and Muyiwa Adegbaju [a]

[a] *Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2024/v36i44457

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/100512

Original Research Article

Received: 25/03/2023
Accepted: 30/05/2023
Published: 28/02/2024

ABSTRACT

Five citrus proevancnes were subjected to watering levels in the nursery. The effects of watering regime were evaluated on the growth, physiological and biochemical attributes while the measured variables were deployed to rank tolerance to soil moisture deficits by citrus species. The watering regimes were 100 % field capacity (1.2 litres at four days interval), moderately watered: 75% field capacity (0.9 litres at four days interval) and 50% field capacity (0.6 litres at four days interval) which imposed at 16 weeks after transplanting. Data were collected on height and leaf development, root and shoot biomass, chlorophyll content, stomata architecture, proline, membrane lipid peroxidation and antioxidant enzymes (Superoxide dismutase (SOD), Catalase (CAT), Gluthathione (GSH). Citrus provenances differed in growth traits, stomata architecture, proline, membrane lipid peroxidation and and enzymatic activities. Watering regime induced significant changes in leaf chlorophyll and phenolic contents and enzymatic activities of catalase (CAT), superoxide dismutase (SOD), membrane lipid peroxidation (malonaldehyde (MDA) and Guaiacol peroxidase (GPx) in citrus. The 75 and 50% FC watering significantly enhanced MDA and proline and activities of enzymatic antioxidant in citrus seedlings compare with 100% FC watering.

**Corresponding author: E-mail: soagele@futa.edu.ng, ohiagele@yahoo.com;*

Activities of CAT and GPx were enhanced by 75% FC while CAT, SOD and GPx were enhanced by 50 % FC watering. Under water limitations, 75% FC watering can support citrus seedling growth and 50% FC for lemon under soil moisture limitation.

Keywords: Enzymatic antioxidant; growth and functional traits; guaiacol peroxidase; soil moisture.

1. INTRODUCTION

Citrus (*Citrus species*) are native to Australia, New Guinea, New Caledonia and possibly Southeast Asia [1]. It is cultivated in tropical and subtropical climates all over the world. It has been recognized as a group of fruit tree crops of great importance for the global agricultural trade based on the number of citrus-producing countries worldwide [2]. Citrus is of great importance in human diet because it is a good source of soluble fiber that aids digestion, weight loss and maintenance due to its low calories content, lowers risk of kidney stones, protects against esophageal, stomach, breast and pancreatic cancers, lowers blood pressure and benefits the heart, boost brain function and protect the brain from neurodegenerative disorders [3].

Climate change, variability and extremity of weather manifest have increased warming and drought with consequences on growth, vigour and physiological functions in plants. Drought (water stress) impairs growth and physiological timing in plants [2]. Reduction in carbon fixation, which is associated with closure of stomata, reduction in photosynthesis and carbohydrate production as well as decrease in growth and yield of plants, is the main effect of water stress on plants [4]. The growth of plant is far more reduces by drought alone than the combination of all other environmental stresses because it causes it not to receive adequate water (rainfall or irrigation) for root zone moisture [5]. This results in reduction in vigour, biomass and yield of plants since their growth and development are on hold [6,7].

However, plants (including citrus) have developed complex morphological and biochemical mechanisms for tolerating water deficit. Plants survivals under unfavourable environmental conditions (water stress) are aided by some physiological parameters such as stomatal gas exchange and water relation [4,7]. Plant responses to drought are aimed at reducing cell water loss, protecting intracellular structures and molecules, and repairing damage caused by free radicals [8]. Plant responses to drought are intended at reducing cell water loss, protecting intracellular structures and molecules, and repairing damage caused by free radicals [8]. Stomatal closure, biosynthesis of compatible osmolytes such as proline (García-Sánchez et al., 2017) and production of antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase, as well as metabolites such as ascorbate and glutathione, to reduce reactive oxygen species (ROS) toxicity [9]. Climate change, variability and extremity of weather manifest as increased warming and drought with consequences on growth, vigour and physiological functions of plants. Knowledge is inadequate on the effects of soil moisture deficits of citrus species widely cultivated in Nigeria. Knowledge gap also exists on physiological and biochemical mechanisms of tolerance of moisture deficits in native and exotic citrus species.

The specific objectives of this study were to examine watering regime effects on growth and physiological attributes and biochemical constituents of citrus species, and deploy measured variables to rank tolerance to soil moisture deficits by citrus species.

2. MATERIALS AND METHODS

2.1 Experimental Area

The experiment was conducted at the screenhouse of the Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, Nigeria.

2.2 Planting Materials

Fruits of five citrus species were sourced from Ondo State Agribusiness Empowerment Centre (OSAEC), Akure and Ondo State Ministry of Agriculture and Natural Resources, Akure, Ondo State, Nigeria. The species are: *Citrus paradisi* = Grapefruit, *Citrus aurantium* = Bitter orange, *Citrus tangelo* = Tangelo, *Citrus limon* = Lemon and *Citrus sinesis* = Sweet orange

2.3 Experimental Design and Treatment

The experiment was a 5 x 3 factorial combinations of citrus and watering regimes arranged in Completely Randomized Design (CRD) with 8 replications. Three watering regimes were initiated 16 weeks after transplanting were: well watered: 100% Field Capacity (1.2 Litres every four days), mild water stress: 75% Field Capacity (0.9 Litres every four days), and high water stress: 50% Field Capacity (0.6 Litres of water every four days).

2.4 Data Collection

2.4.1 Growth data

Plant height, number of leaves and root (tap root length, root fresh and dry weights, number of roots and total root length.

2.4.2 Physiological data

Chlorophyll content, soil moisture content and stomata Architecture {Stomata density, stomata index, stomata size, aperture area and stomata structure (Guard-cell length and width, stomata length and width)}

2.5 Biochemical Attributes

Proline, soluble sugar content, phenolic content, membrane lipid peroxidation and antioxidant enzymes (Superoxide dismutase (SOD), Catalase (CAT), Gluthathione (GSH).

2.6 Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using Minitab statistical software. Treatment means were compared using Tukey's test at 5% level of probability.

3. RESULTS

3.1 Effect of Watering Regime and Provenance on the Growth Traits of Citrus

The data collected on growth traits of the citrus at thirty-six weeks after transplanting (36 WAP) showed there were decreases in both plant height and number of leaves with decreasing quantity of water application (Table 1). These responses of the citrus provenances were similar in terms of watering regimes imposed. Growing citrus under 50% FC watering had no significant ($P < 0.05$) impacts on citrus attributes of root and shoot height, number of leaves, root length. Other growth attributes of citrus species especially, root to shoot ratio (RSR) were influenced by 75 and 50% FC watering compared with 100% FC watering. Higher values were obtained for the 100% FC watered seedlings than 75 % FC which in turn showed higher values than the 50% FC-watered seedlings. Sole effects of watering regime and provenance as well as their interactions were significant on height and leaf development in citrus (Table 1).

Citrus produced the tallest plants and number of leaves under well watering regime (100% FC), plants were however shorter under low watering regimes (75 and 50% FC) (Table 1).

Significant differences were found among citrus provenances for height and leaf development Citrus provenances differed in plant height and number of leaves produced per plant for measurements taken at 36 weeks after transplanting (Table 1). Among the provenances, tallest plants were produced by Lemon and shortest by Grape and sweet orange. Provenances were also different for number of leaves produced at 36 weeks after transplanting.

3.2 Effect of Watering Regimes on Root Traits of Citrus

The effect of watering regime on the tap root length of citrus is presented in Fig. 1.

For grapefruit and tangelo (species A and C), plants watered at 50% FC had the longest tap roots while those under 100% FC had shortest tap root. Bitter orange had shorter the tap root at 50% FC and longest tap root under 100% FC watering. Lemon has its longest root under 100% FC and shortest under 50% FC. Sweet orange has its longest tap root under 75% FC watering regime and shortest under 100% FC. Among the provenances, tap roots were longest for grapefruit under 50% FC but tangelo has the shortest under 100% FC watering Fig. 1.

The effect of watering regime on the fresh root weight of citrus species is presented in Fig. 2. Grapefruit, bitter orange and sweet orange grown under 75% FC watering had heaviest fresh root weights while those irrigated with 50% FC had the least fresh root weight. Tangelo has its greatest fresh root weight under 50% FC and least under 75% FC. Lemon has its greatest fresh root weight under FC watering regime and least under 75% FC. The fresh root weights among citrus species were compared. Lemon has the greatest fresh root weight of all the species, which is under FC but tangelo has the least of all, which was under 75% FC watering regime.

Table 1. Effects of watering regime on height and leaf of citrus provenances at 36 weeks after transplanting

Watering regimes	Citrus species	Plant height (cm)	Number of leaves
100% FC	A	38.13q	30q
	B	32.73qr	24r
	C	40.75q	25r
	D	66.13s	27qr
	E	38.13qr	25r
75% FC	A	35.73q	30q
	B	31.03q	24r
	C	34.73q	19s
	D	53.63r	21rs
	E	33.83q	18s
50% FC	A	30.21q	23q
	B	29.23q	17r
	C	28.63q	21q
	E	26.93q	22q
	WR	*	*
	CiT	*	*
	WR x CiT	*	*

Values along the column bearing same letters are not significantly different (α= 0.05 level of significance). A = Grapefruit, B = Bitter orange, C = Tangelo, D = Lemon, E = Sweet orange, FC = Field capacity, WR = Watering regime and CiT = Citrus provenances

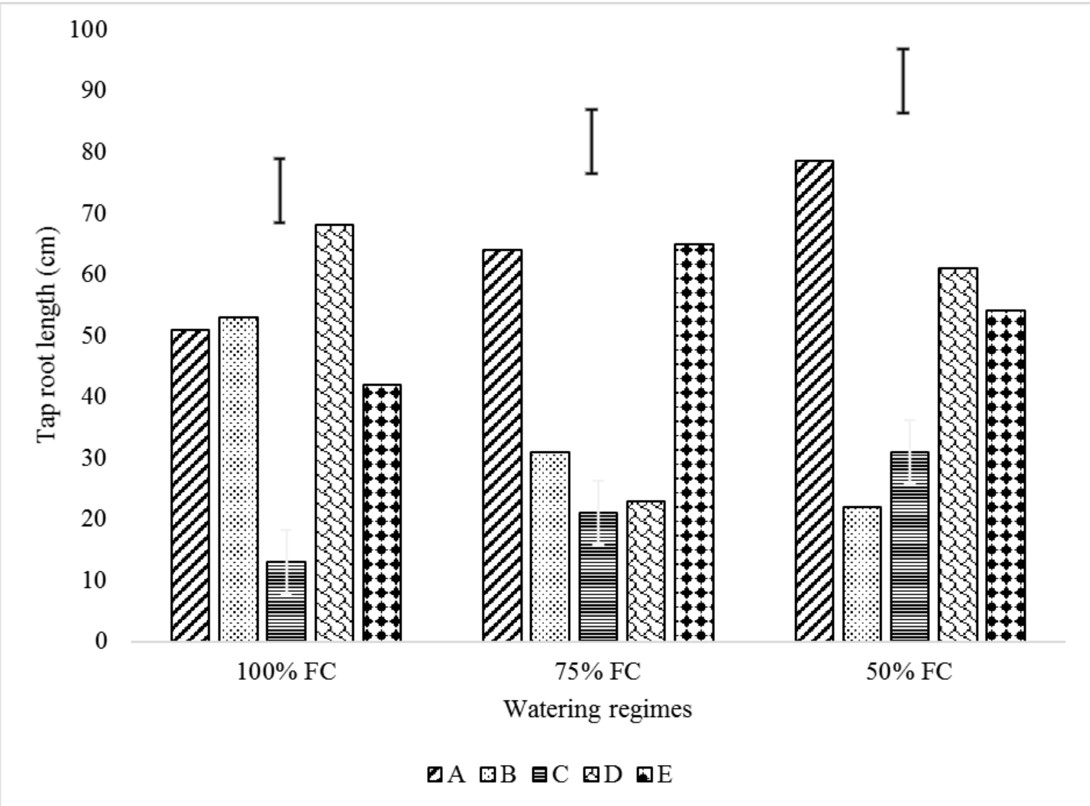

Fig. 1. Effect of watering regimes on tap root length of citrus
Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange and FC = Field capacity

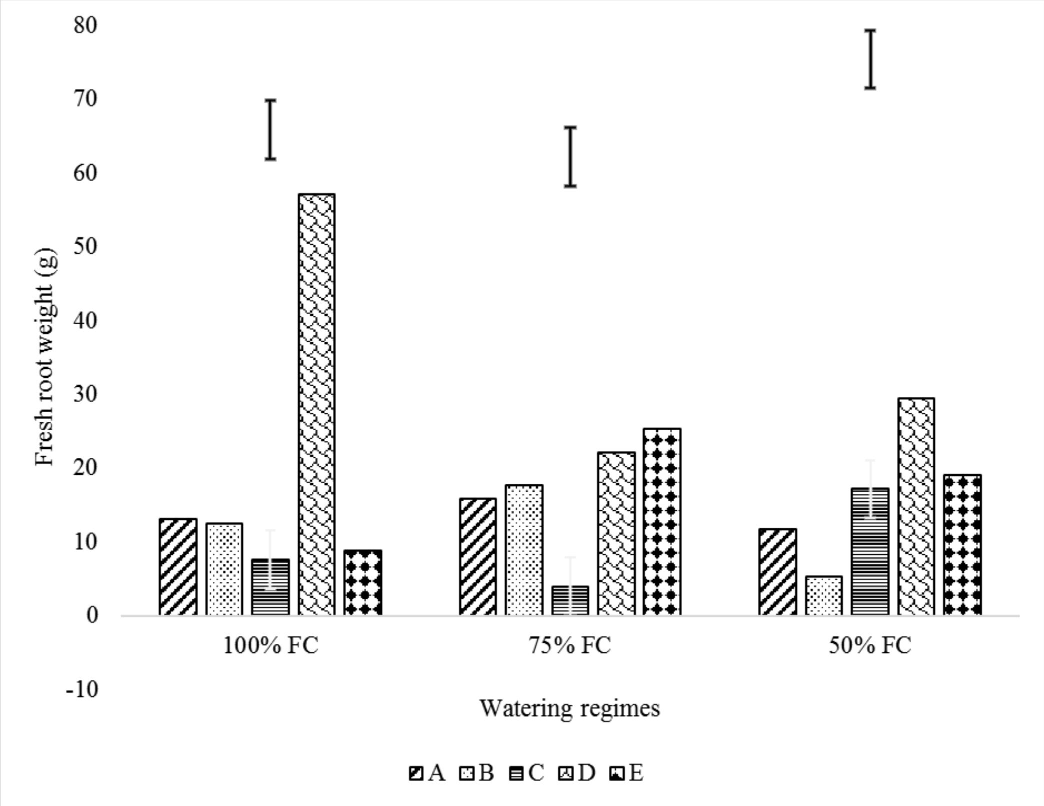

Fig. 2. Effect of watering regimes on fresh root weight of citrus

Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange and FC = Field capacity

3.3 Effect of Watering Regimes on Chlorophyll Content of Citrus Leaves

The leaf chlorophyll contents determination of leaves of citrus species showed that values were close for species while significant differences were found for water treatment (Table 2). Decrease in the chlorophyll content of leaves was observed with decreasing water treatment for the species for high, intermediate and low watering regime (100% FC > 75% FC > 50% FC).

Although lemon (species D) had the highest content of chlorophyll 'a' under 100% FC watering regime, bitter orange however has the highest content of chlorophyll 'b' and total chlorophyll contents. At 75% FC, among citrus species, lemon still retained highest content of chlorophyll 'a' compare with values for other species. Under watering at 50% FC, chlorophyll 'a' and 'b' contents of citrus declined compared with values under 100 and 75% FC.

The degree of stability of chlorophyll pigment in the citrus provenances under differing watering conditions was measured as the ratio of chlorophyll 'a' to chlorophyll 'b' (Chl a/b ratio) The *Chl a/b* ratios increased with decreasing water application. The highest ratio was found for lemon closely followed by sweet and bitter orange while the lowest ration was obtained for grapefruit.

3.4 Effect of Watering Regimes on Stomata Architecture of Citrus

Figs. 3, 4 and 5 showed results obtained from the determination of the stomata architecture of citrus leaves as affected by the three watering regimes; 100, 75 and 50% FC. Stomata architecture determined include; stomata density, stomata index, stomata size, aperture area and stomata structure (guard cell length and width, stomata length and width). Reduction in sizes of stomata due to reduction in water application was observed among the citrus species. Some of the stomatal traits showed significant differences among the species of citrus.

There were no significant differences observed in the guard cell lengths in the species under the three watering regimes as well as when compared among the species.

Table 2. Chlorophyll 'a' and 'b' content of leaves of citrus provenances as affected by watering regime

Watering regimes	Citrus species	Chlorophylla (µg/g)	Chlorophyll b (µg/g)	Total chlorophyll (µg/g)
100% FC	A	18.58u	14.79s	33.37t
	B	21.15r	39.84q	60.99q
	C	19.06t	14.97t	34.03s
	D	23.83q	12.31u	36.14r
	E	20.41s	16.34r	36.75r
75% FC	A	18.20s	13.96s	32.16r
	B	18.55s	15.89r	34.44q
	C	19.06r	13.44s	32.5r
	D	21.02q	9.41t	30.43s
	E	19.77r	16.13q	35.9q
50% FC	A	17.49r	10.77s	28.26s
	B	16.86s	12.17q	29.03r
	C	18.52q	12.50q	31.02q
	D	14.16t	7.41t	21.57t
	E	17.91r	11.42r	29.33r
	WR	*	*	*
	CiT	*	*	*
	WR x CiT	*	*	*

Values along the column bearing same letters are not significantly different (α= 0.05 level of significance). Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange, FC = Field capacity, WR = Watering regime and CiT = Citrus provenances

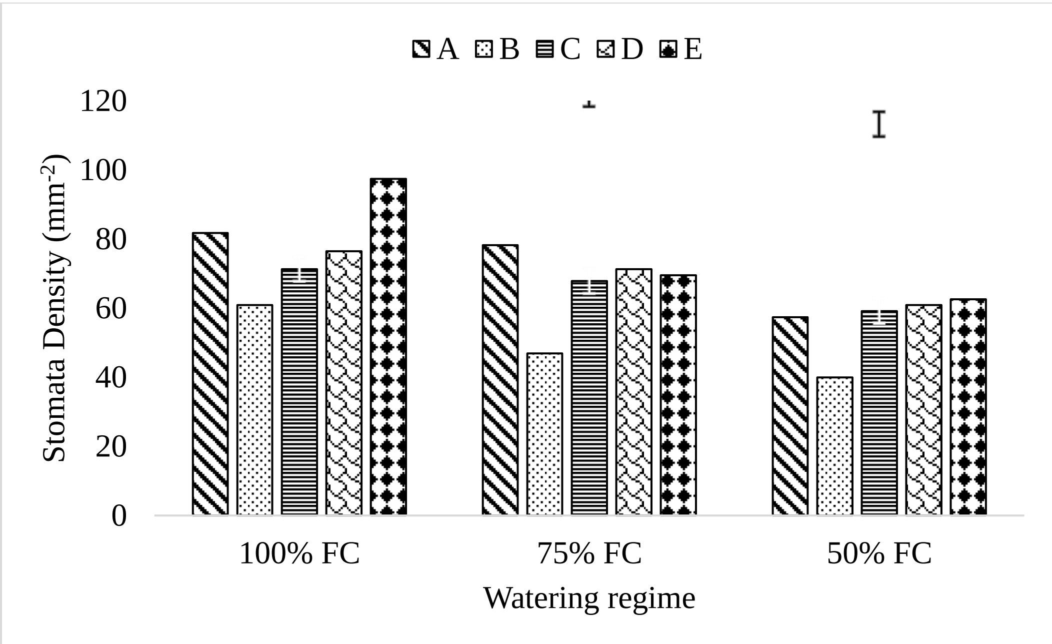

Fig. 3. Stomata density of leaves of citrus as affected by watering regimes
Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange and FC = Field capacity

3.5 Effects of Watering Regimes on Proline Content of Citrus

The citrus species differently accumulated proline in response to watering regimes (Fig. 6). Grapefruit under 100 and 75% FC have the close values for proline which is lower than the content under 50% FC (highest proline content). But for bitter orange and tangelo, increases in proline concentration in leaves were found with decreasing water application. Lemon however has the similar contents of proline for all watering regimes. This is different for sweet orange as its highest content of lowest proline was observed under 75 and 100% FC. The figure also compared proline contents among citrus species. Grapefruit under both 100 and 75% FC has the lowest content of proline while sweet orange under 75% FC has the highest content of proline followed by sweet orange under 50% FC.

3.6 Effects of Watering Regimes on Membrane Lipid Peroxidation (Malonaldehyde) of Citrus

Fig. 7 showed values for malonaldehyde contents (MDA) of the citrus leaves. When compared species responses to watering regimes, grapefruit has the highest content of MDA under 100% FC but has the lowest content under 75% FC. Bitter orange has the highest content under 50% FC which is not too greater than its content under FC and 75% FC (lowest content). Tangelo has its highest MDA content under 75% FC but its lowest content under FC which is not too lesser than its content under 50% FC. Lemon has the highest content of MDA under 75% FC and lowest under 50% FC. It was observed that its content under 75% FC is not too higher than under FC. For sweet orange, it has its highest MDA content under 50% FC and lowest under FC. Among citrus species it was observed that sweet orange has highest content of MDA under 75% FC watering and the lowest content of MDA under 50% FC.

3.7 Effects of Watering Regimes on Superoxide Dismutase (SOD) Activity of Citrus

The superoxide dismutase (SOD) content as affected by citrus species and watering regime is presented in Fig. 8. Thjere were non-significant differences in the SOD content of the leaves of the citrus species subjected to the watering regimes. Grapefruit has its highest SOD content under 75% FC and lowest under 50% FC. Bitter orange has its highest under 75% FC but lowest under 100% FC. Tangelo has close but highest values of SOD content under both 100 and 50% FC and the lowest at 75% FC. Lemon has its highest under 100% FC and lowest under 75% FC. Sweet orange has same but highest SOD content under 50 and 75% FC and lowest under 100% FC. Sweet orange has the highest SOD content which was under its 50 and 75% FC but grapefruit has the lowest content of SOD which was under its 50% FC watering regime.

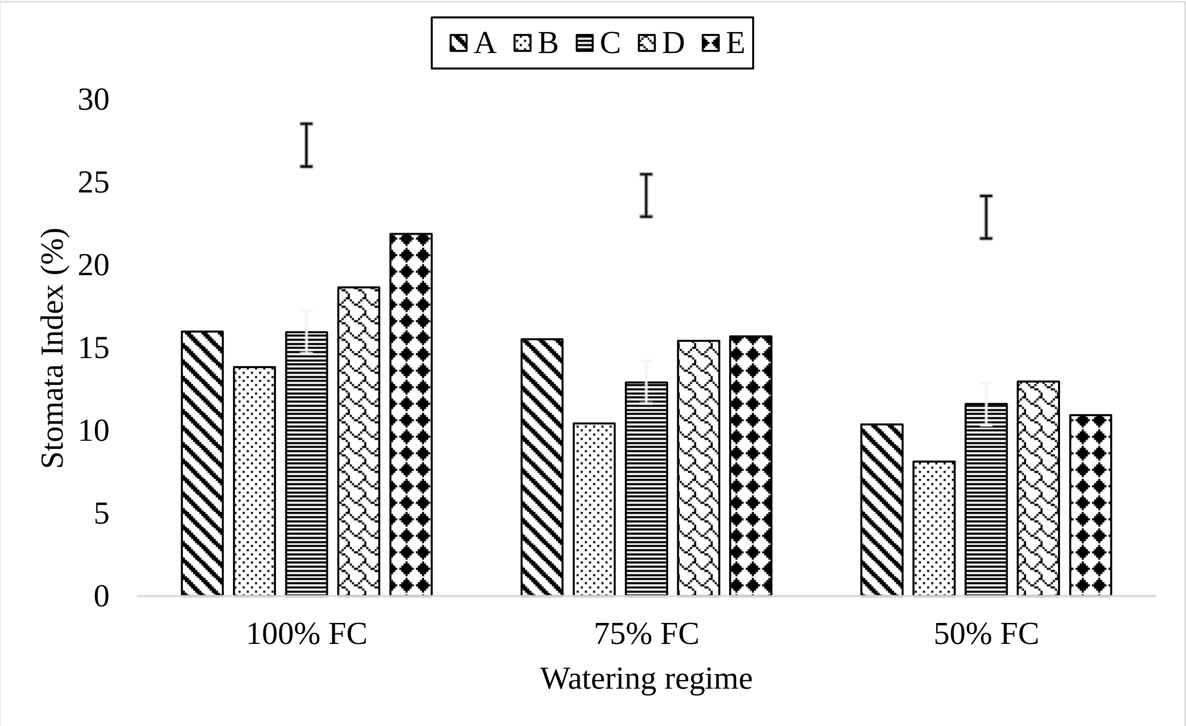

Fig. 4. Stomata index of leaves of citrus as affected by watering regimes
Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange

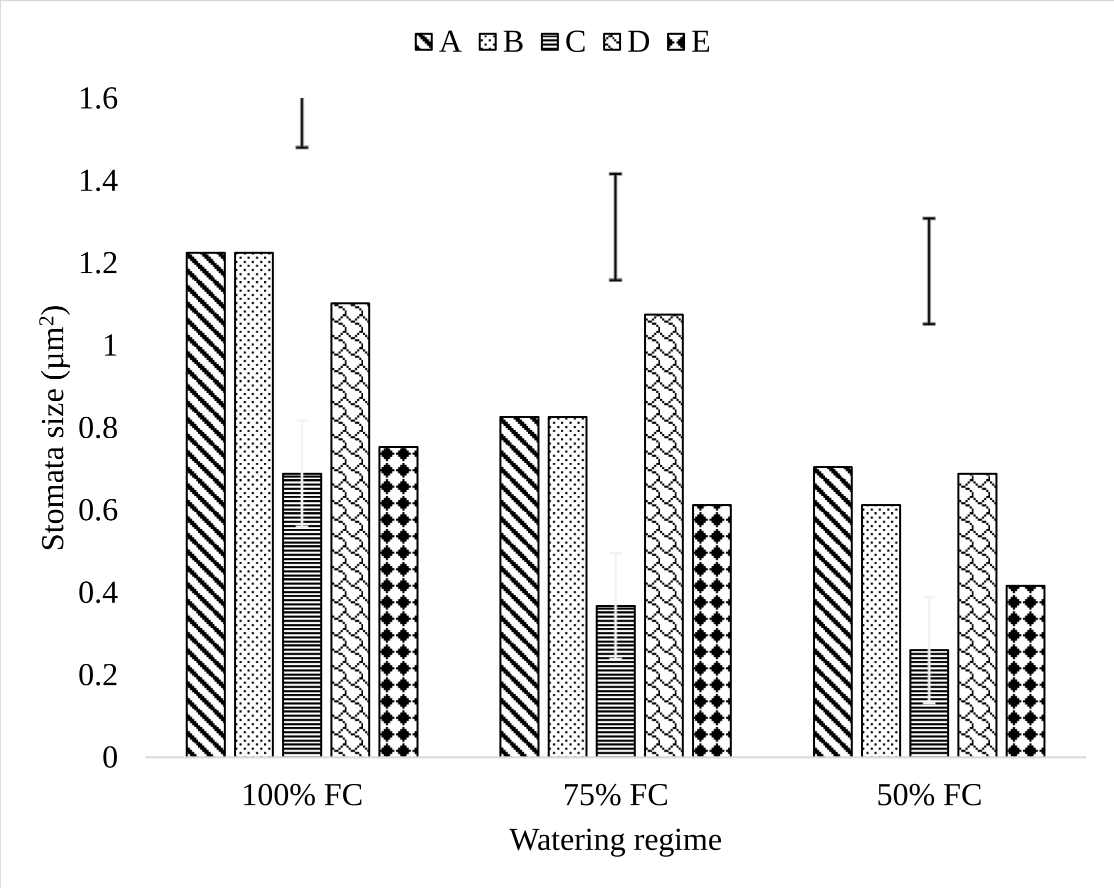

Fig. 5. Stomata size of leaves of citrus as affected by watering regimes

Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange and FC = Field capacity

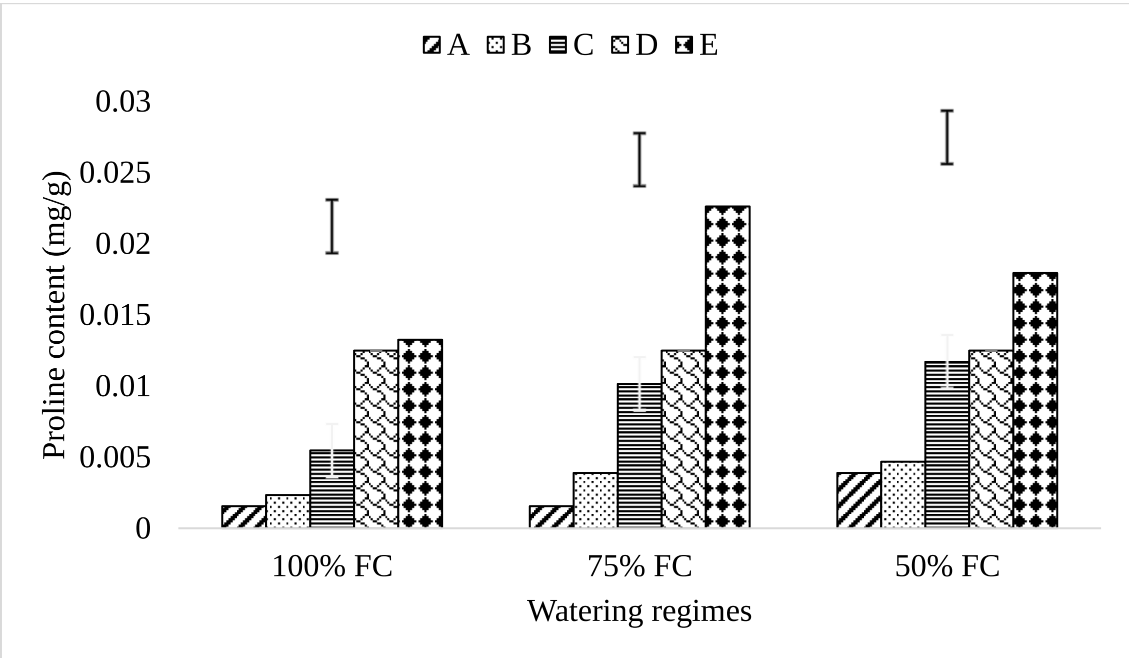

Fig. 6. Proline content of citrus leaves as affected by watering regimes

Where A= Grapefruit, B= Bitter orange, C= Tangelo, D= Lemon, E= Sweet orange and FC = Field capacity

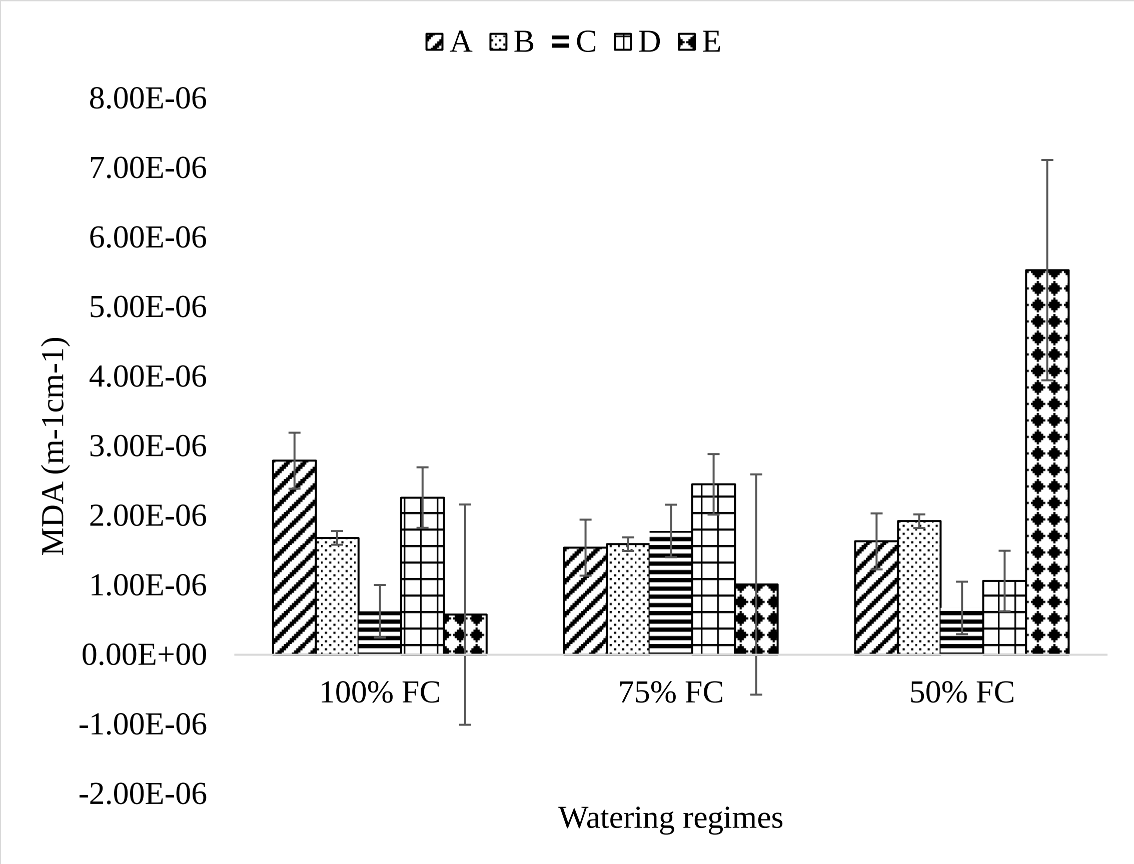

Fig. 7. Bar graph showing malonaldehyde contents (MDA) of the citrus leaves

3.8 Effects of Watering Regimes on Catalase Activity (CAT) of Citrus

Catalase activity (CAT) of citrus in relation to watering regimes is presented on Fig. 9. Among the citrus species grapefruit has its highest CAT activity under 50% FC and lowest under FC. Same goes for bitter orange but tangelo has its highest CAT activity under 100% FC which is not sigbificant over values for 75 and 50% FC watering. Lemon has its highest CAT activity under 50 and 75% FC but lowest under 100% FC. Sweet orange has its highest CAT activity under 50% FC and lowest under 75% FC. When compared among species, it was observed that sweet orange has the highest content of CAT activity at 50% FC but grapefruit has the lowest CAT activity at 100% FC

3.9 Effects of Watering Regimes on Contents of Phenolic Compounds of Citrus

Fig. 9 showed the results for the phenolic acids content of citrus leaves subjected to watering regimes. Grapefruit has its highest phenolic content under 75% FC and lowest under 100% FC. Bitter orange has its highest under 75% FC and lowest under 100% FC. Tangelo has its highest under 50% FC and lowest under 100% FC. Lemon has its highest under 100% FC and the lowest under both 75 and 50% FC (which were same). Sweet orange has its highest under 50% FC and lowest under 100% FC. When all the species were compared among one another as presented in Fig. 10, it was observed that sweet orange has the highest phenolic content which is under 50% 100% FC but grapefruit was observed to have the lowest phenolic content which was under 100% FC watering treatment.

4. DISCUSSION

4.1 Response of Growth Traits of Citrus to Watering Regimes

In this study, reduction in the height of citrus plants and number of leaves under the low watering condition (50% FC) can be attributed to limited water availability in the rootzone for growth compare with height under high status of soil water under 75 and 100 % FC condition. This observation is consistent with the report of Elemike et al. [10] that decrease in soil water negatively affects its growth in addition to inhibition of nutrient uptake. There were however no significant differences among the heights of bitter orange under the three watering regimes, between the heights of sweet orange and grapefruit under FC and 75% FC watering regimes, and heights of lemon under 75 and 50% FC. This may mean that these species were able to cope with changes in watering regimes especially for bitter orange. The high capacity of citrus to tolerate unfavourable climatic conditions was reported by Shafqat et al. [11]. This high-tolerance capacity is however different for different species which explains why the heights of plants were significantly different under the three watering regimes. These same reasons are explainable for the insignificant differences observed in the number of leaves of citrus under the tree watering regimes (100, 75 and 50% FC).

4.2 Response of Root Traits of Citrus to Watering Regime

The result of this study showed variation in the root traits within and among species, bitter orange showed decrease in the tap root length with decreasing watering (FC > 75% FC > 50% FC) which is in line with the report of Khalil et al. [12] on wheat. However, grapefruit and tangelo showed increasing tap root length with reducing water application (50% FC > 75% FC > FC), this observation was similar with report of Silva et al. [13] on citrus. Sousa et al. [14] reported that water stress impaired root growth of plants. Results of the present study were consistent with the earlier findings on soil moisture deficits effects on root development. Lemon has the highest root biomass under FC when compared among the species, it also has the greatest root biomass when compared under 50% FC watering regimes among all species. Its great root biomass due to its root system conferred it advantage to support accelerated plant growth during the early crop-growth stage and extraction of water that might be loss to evaporation from shallow soil layers. Under water stress conditions, a plant with well-developed root system can enhance its drought tolerance and improve the use of it resources to increase yield and crop quality [15]. Zhang et al. [16] reported that crops with optimized root system architecture can strengthen their root number and depth to take up deeper soil water from the soil and improve their water stress tolerance.

4.3 Response of Physiological Traits of Citrus to Watering Regime

Chlorophyll content of citrus leaves reduced with reducing water application. Kimm et al. [17] reported that plant leaves undergo decrease in chlorophyll content under drought stress, decreased chlorophyll contents may results on deterioration of chloroplast structure due to oxidative stress. The 100% FC watering produced the highest chlorophyll contents (both chlorophyll a and chlorophyll b) among species followed by 75% FC while the low watering regime (50% FC) has the lowest content of leave chlorophyll for all the species. According to Bano et al. [18], the oxidative damage of chloroplast lipids and proteins or the degradation of the pigment protein complexes by chlorophyllase enzyme could cause chlorophyll loss. This study showed that stomata conductance of all the citrus species reduced with reducing water treatment (FC > 75% FC > 50% FC). Reports from early researches showed increase in stomatal density and decrease in cell size under water stress, this indicates that plant adaptation to water deficit could occur [19]. This study showed a decrease in stomata density with decreasing water application which is in contrary with some of the reports stated above but is however in consistent with the report of Li et al. [20]. The number of stomata, stomata size, stomata index, aperture area, stomata length and width as well as guard cell length and width decreased with decreasing water application (FC > 75% FC > 50% FC) for all the five species of citrus, this is consistent with the reports of Verma et al., [21]. The difference in stomata sizes observed among the species can be linked with the report of Bertolini et al. [22] that different effects of abiotic factors on the size of stomata may depend on plant species/varieties. Lemon still has the highest stomata architecture under low watering (50% FC) when compared among the species, which gives it better chances to tolerate water deficit at the nursery stage.

4.4 Response of Biochemical Traits of Citrus to Watering Regime

One of the early reactions of plant to water stress is that it adjusts the intercellular osmotic potential through the accumulation of some organic compatible osmolytes such as sugars betaines and proline [23,24]. Proline accumulation in plants increases in response to water deficit [25]. It was reported by Chun et al. [26] that the main strategy of plants to avoid detrimental effect of

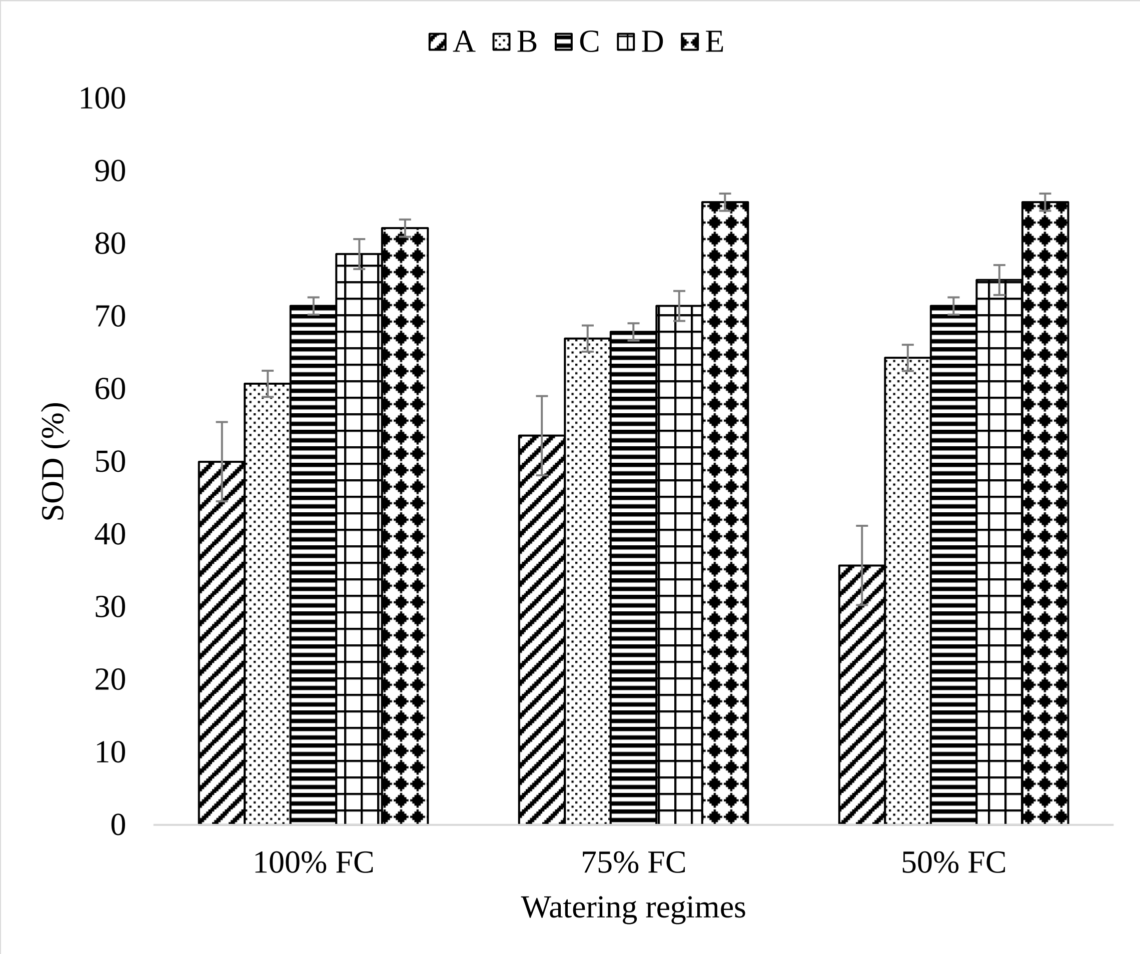

Fig. 8. Effects of watering regimes on superoxide dismutase (SOD) activity of citrus

water is the involvement of proline in the tolerance mechanisms against oxidative stress in plants. Gonçalves et al. [27] also reported that one of the most common strategies of drought tolerance in citrus is the accumulation of amino acids such as proline, which makes proline content usable as a biochemical marker of water stress in citrus as suggested by Zaher-Ara et al. [28]. This study showed that there was continuous increase in the proline accumulated by the species with decreasing water regime especially for grapefruit, bitter orange and tangelo. This was in consistent with the report of Olayemi et al. [5] on cacao. Lemon however accumulated the same content of proline under the three watering regimes, which means as at the time of proline content determination, this could be explained that its proline content for the 75 and 50% FC might have decreased to the basal level when the species (lemon) no longer see water stress as a limiting factor, since stress-induced proline content is reversible as reported by Raza et al. [29]. This is also complemented by the report that proline content is remobilized after some rehydration and degraded to release energy and nitrogen for the cell growth [30]. In the case of proline content of sweet orange which follows the trend of increasing proline content with decreasing water application except that it has higher content of proline under mild watering regime (75% FC) than under low watering regime (50% FC), this could be attributed to the proline accumulating far in excess of the demands of protein synthesis under mild watering (75% FC) as reported by Meena et al. [31].

Plant tolerance to environmental stresses is in relation with higher levels of antioxidant enzymes activities under the particular environmental stress [32]. Meaning that these antioxidants such as catalase (CAT), superoxide dismutase (SOD) and guaiacol peroxidase (GPx) are expected to increase with increasing rate of stress (50% FC > 75% FC > FC as in the case of this study). Lemon showed high content of CAT, SOD and

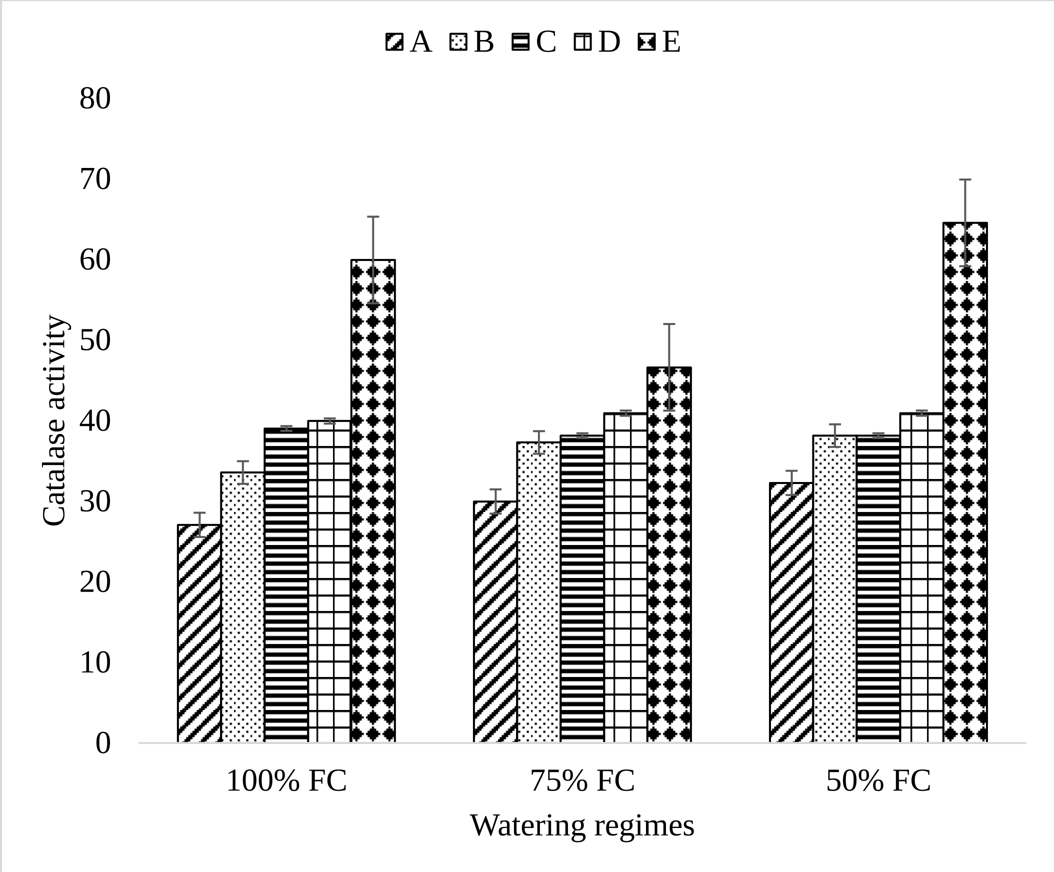

Fig. 9. Effects of watering regimes on catalase activity (CAT) of citrus

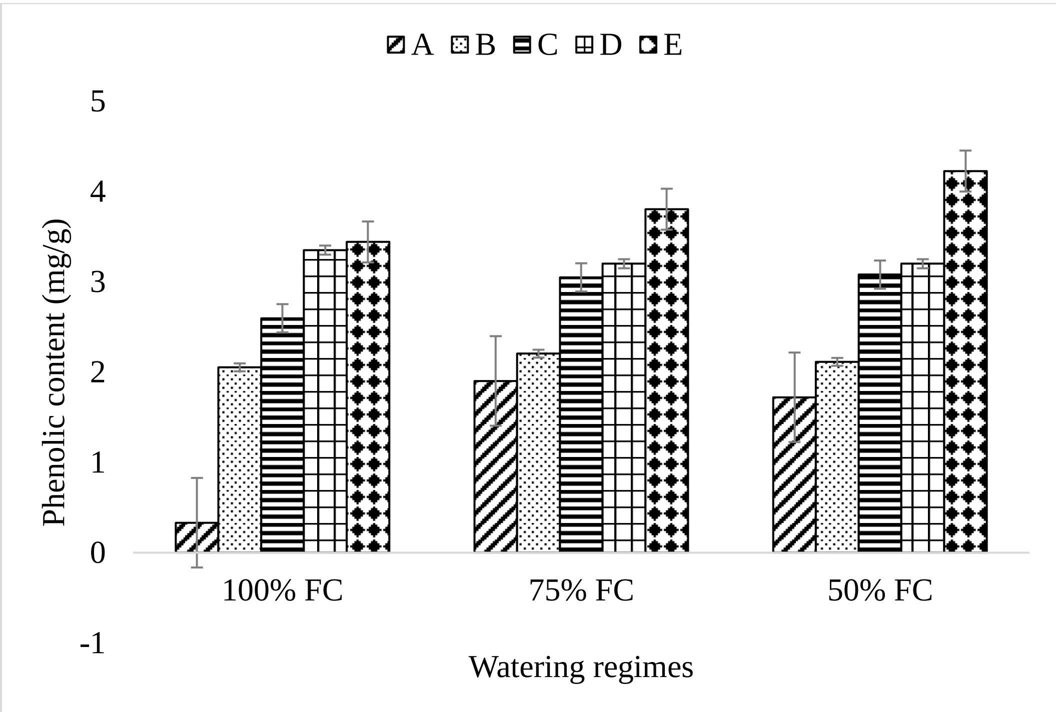

Fig. 10. Phenolic acids content of citrus leaves subjected to watering regimes

GPx under stress (50% FC) which may have contributed to its relatively high stress tolerance. Although sweet orange has the highest content of SOD and CAT under 50% FC compared with other species, it also has the highest content of SOD and CAT as well as GPx under 100 and 75% FC watering situation which might mean that SOD and CAT might not be suitable markers for the effect of water stress in sweet orange. Most of the five species of citrus considered under this study did not produce increases in SOD, CAT and GPx content under 50% FC (low watering regime) compared with the 75 and 100% FC watering treatments. This may mean that these antioxidants are not suitable as markers for water stress in the citrus species considered or the level of water stress treatment (50% FC) was not detrimental to citrus at the nursery which show high tolerance of citrus to water stress. It might however be attributed to the fact that citrus species evaluated deployed the antioxidants (GPx specifically) for combating water stress [33]. High CAT activity is species specific, sweet orange having the most activity at 50% FC followed by lemon, which explains the differences in CAT activities of the species as consistent with the report of Liu et al. [34] on rice.

5. CONCLUSIONS

Watering regimes (100, 75 and 50 % FC watering) affected the growth, physiological attributes and biochemical constituents of five citrus provenances evaluated in the nursery.

Watering at 100, 75 and 50% FC affected the growth traits, physiological attributes and biochemical constituents of the seedlings of the citrus provenances.

Watering at 75 and 50% FC enhanced the accumulation of proline, malondialdehyde (MDA) and activities of enzymatic antioxidants in citrus seedlings compare with 100% FC watering.

Watering at 50% FC enhanced the activities of superoxide dismutase (SOD), catalase (CAT) and guaiacol peroxidase (GPx) while 75 % FC watering up regulated only the activities of CAT and GPx.

Differences were observed among the citrus provenances for growth traits, stomata architecture, osmolytes and enzymatic activities when subjected to watering regimes treatment.

Lemon was identified as the most tolerant to soil water deficit, followed by bitter orange, grapefruit and then sweet orange. Tangelo was the least moisture stress-tolerant of the five species.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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