



Evaluation of Morpho-physio Parameters of *Corchorus olitorius* Accessions under Water Deficit Conditions

Senewa Bobby Pholoma ^{a*}, Goitseone Malambane ^a,
Gulelat Haki ^b and Seoleseng Tshwenyane ^a

^a Crop and Soil Sciences Department, Botswana University of Agriculture and Natural Resources, Botswana.

^b Food Science and Technology Department, Botswana University of Agriculture and Natural Resources, Botswana.

Authors' contributions

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

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ABSTRACT

It has been well established that water deficit stress greatly affects the physiological process of most crops thus subsequently affecting yield as it disturbs the photosynthesis process. So it important to continuously evaluate potential future crops on the performance under limited moisture conditions to document their physiological response. This study aimed to analyse morpho-physiological parameters of six *Corchorus olitorius* (Jew's mallow) accessions grown under water deficit stress in Botswana. A greenhouse pot study was conducted during 2022-2023 and 2023-

*Corresponding author: E-mail: senewapholoma@yahoo.com;

2024 seasons. The six accessions were subjected to 30% FC as water deficit stress and 80% FC as control. The yield and yield components, physiological parameter including SPAD content, proline, stomatal conductance and leaf relative water content of six selected *Corchorus olitorius* accessions were assessed during two consecutive seasons. There was a significant difference in all the studied accessions yield and their components under the water deficit stress and control treatment with decreased mean values under the 30% FC. Bafia and TOT6684 accessions recorded higher fresh weight, dry weight, leaf area, root weight, under both water deficit stress and control treatments suggesting that they are high yielding accessions while MSB072 mostly recorded lower values for the same traits thus it could be characterised as low yielding accession. Interestingly, these two high yielding accessions had the fewest number of branches, resulting in a negative correlation between the yield and number of branches. SUD3 accession, recorded the highest root length despite low yielding, possibly because it transmitted more assimilates into developing long roots to seek for water. Bafia and TOT6684 recordings in all the variables under both treatments therefore suggested that, they are high yielding accessions while MSB072 is low yielding accession. These high yielding accessions during water deficit stress suggest that *Corchorus olitorius* might be having some tolerance mechanisms that sustain physiological growth during stress.

Keywords: *Corchorus olitorius*; indigenous leafy vegetable; moisture deficit stress; fresh weight; leaf area; stomatal conductance.

1. INTRODUCTION

Water deficit stress is of major importance as it affects crop performance, especially when it occurs at critical point during the growing season. When it coincides with high air temperatures which increase plant evapotranspiration, it then results in stomatal closure leading to reduced photosynthetic activity and subsequently lower yields (Chatterjee & Solankey, 2015). Plant responses to abiotic stresses are species specific and may cause reversible or irreversible changes in plant physiology and metabolism (Bhattacharyya et al., 2020). These responses may also depend on phenological stage, stress intensity and duration, as well as the tissue or organ involved in the response mechanism or subjected to stress (Seymen, 2021). Leafy vegetables are susceptible to water deficit, their yield and quality is usually significantly reduced (Ufoegbune et al., 2016). In the case of water inadequacy occurring early in crop development, yields are often reduced as maturity may be delayed. Even though total yields are not affected when it occurs later in the growing season, quality is often reduced (Ufoegbune et al., 2016). The notion that the indigenous leafy vegetables grow in the wild and in adverse environments could mean that they have various mechanisms to tolerate drought stress.

The effect of drought stress on physiological parameters and vegetables quality was examined in numerous studies and it was observed that plant do develop defense

mechanisms against drought, which vary depending upon the species the drought intensity and duration (Zhu et al., 2020). Several physiological parameters are associated with water availability and can be considered indices of drought stress, such as osmotic adjustment (OA). The reactions of plants to water deficit differ significantly at numerous organizational levels depending upon its stage of growth, plant species, intensity and duration of stress. However, the characteristics of drought tolerance of indigenous leafy vegetables like *Corchorus olitorius* are not fully well known. It was reported that the application of 40% of field capacity water level (as severe water deficit) in *Corchorus olitorius* significantly negatively affected the majority of agro-morphological, physiological and reproductive traits (Jakoub et al., 2016). The Jew's mallow forage yield, plant growth traits, photosynthetic and transpiration rate, stomatal conductance, relative water content (RWC) and chlorophyll a and b contents were significantly decreased in plants subjected to water deficit. Plants submitted to 40% FC accumulated higher concentration of proline than the water treated plants, by (Dhar et al., 2018). This plant had high capacity of adjustment in terms of accumulating proline following water deficit stress. This augmentation of osmo-regulation maintains the water retention under drought conditions. These data confirmed that proline is an important amino acid for osmotic adjustment in Jew's mallow plant subjected to water deficit. To fully understand the tolerance mechanisms of this important indigenous vegetable it is important to

continuously evaluate different genotypes from different regions to identify the tolerant ones that can be adopted and be used in the climate change times to compliment food security. Therefore, this study was undertaken to evaluate selected *Corchorus olitorius* accessions yield attributes and physiological parameters in response to water deficit stress. The results will incorporate new information and also elucidate some previous findings leading to easier adoption of the plant as a leafy vegetable that the horticulture industry can infuse into their climate smart plants.

2. MATERIALS AND METHODS

2.1 Experimental Sites and Pot Preparation

A pot experiment was carried out in a greenhouse at the Botswana University of Agriculture and Natural Resources (BUAN), Faculty of Agriculture, Department of Crop and Soil Sciences, Botswana. The experiments were conducted from 2022-2023 as season 1 and repeated in 2023-2024 as season 2. The potted soil was collected from the University Garden site and sieved off some plant residues that may interfere with seed germination and emergence, then added to the pots, and each pot was weighed at 10 kg.

2.2 Plant Material and Planting

Six (6) *Corchorus olitorius* accessions selected from previous study (Pholoma et al., 2024) were used in this study. Seeds underwent dormancy relief by soaking in hot water at 90 °C for 5 minutes (Denton et al., 2013). Out of the six (6) accessions studied; four (4) were obtained from the World Vegetable Centre, Tanzania (Bafia, TOT6684, SUD3 and Big Local leave) and two (2) from NARDI, Botswana (MSB072 and Delele1). Four seeds were planted in each pot and thinned to two seedlings after 2 weeks. Immediately after planting, watering was done whenever there was a need until the fourth week, when watering was done according to the water regime treatments.

2.3 Experimental Design

The experiment was set up in a two Factorial Randomized Complete Block Design (RCBD) with accessions and water regimes as the two factors and all with three replications. There were six accessions and two watering regimes (30% field capacity as water deficit stress and the control at 80% field capacity). Blocking in the

greenhouse was done against temperature because it was cooler closer to the wet wall while the temperature increased towards the extractor fans.

2.4 Watering Regime

Under the watering regime treatment, the plants were subjected to water stress whereby they were allowed to dry down without reaching permanent wilting point with 30% field capacity (875ml) as water deficit stress treatment and control at 80% field capacity (2000ml). This watering regime treatment was applied when seedlings were four weeks old. The plants were re-watered after every data collection (10 days) and drying cycles were repeated until reproductive development (flowering commences when drying cycles will end). Thinning was done to have two plants left in each pot for data collection.

2.5 Data Collection

Dependent variables studied were physiological parameters and yield and yield attributes. Measured variables were observed from seedling stage until the reproductive growth stage fortnightly. The following data were observed:

Physiological parameters: SPAD measured using handheld portable MultispeQ V 2.0 device on a healthy fully expanded leaves at flowering.

Leaf relative water content: immediately after picking the leaves at flowering, they were enclosed in a plastic bag to minimize water loss during transferring them to the laboratory from the greenhouse. The top most fully expanded healthy leaf was used. Each harvested leaf was weighed to determine the fresh weight. To obtain the turgid weight, leaves were soaked in distilled water for 24 hours at room temperature and blotted dry using paper towel then turgid weight was measured. The leaf dry weight was determined after oven drying the leaves at 60°C for 48 hours. The RWC was calculated as per the formula below:

$$\text{RWC (\%)} = \frac{[(\text{FW}-\text{DW})/(\text{TW}-\text{DW})] * 100}$$

Where FW is initial fresh weight, TW is turgid weight and DW is dry weight.

Stomatal conductance was determined on plants at flowering using a portable leaf porometer (SC1, Decagon Device, Inc., Pullman, USA) (data was collected at flowering). Proline content was measured once during the first harvest in accordance with Bates et al. (1973).

Yield and yield components measured were: number of leaves where cumulative total number of leaves per plant was obtained by counting the number of harvested leaves on fortnightly basis; fresh weight where the mass of freshly harvested leaves was weighed using a balance scale and averaged to get the leaf yield (data was collected after every 10 days); dry weight; the weighed fresh leaves were then oven-dried for 48 hours at 60°C thereafter weighed using a balance scale (22Adam Nimbus NBL; Max 3600g d= 0.01g). The leaves were harvested fortnightly in the mornings before the transpiration rate increased. Leaf area was determined at the 13th week using leaf area meter where harvested leaves were quantified over the meter. Plant height observed at the 13th week was collected using measuring tape placed against the plant from the ground surface up to the growing tip. The number of branches per plant were counted at the end of the experiment. The gently uprooted roots at flowering were washed off the soil particles and their length measured using a ruler. The washed roots were air dried for 30 minutes, thereafter weighed using a balance scale to observe the weight of fresh roots (data was collected at termination).

2.6 Statistical Analysis

The yield and yield components, physiological, and biochemical data collected were subjected to analysis of variance (ANOVA) using the R-software version 4.2.2 and the agricol package version 1.3. Treatment means were separated using the Least Significant Difference (LSD) at $P = 0.05$.

3. RESULTS

The proline content was significantly increased ($P < 0.05$) in all the accessions following the water deficit stress at 30% FC while the control treatment at 80% FC significantly decreased ($P < 0.05$) in the proline content in all the accessions under study during first season. Under both the water regimes, Bafia and Delele1 had a similar response, thus no significant difference between the two accessions in each water regime treatment. MSB072 recorded the highest proline content mean value of 0.183 $\mu\text{moles/g DW}$ under the control treatment at 80% FC while three accessions, Bafia, TOT6684 and Delele1 recorded the lowest mean values of 0.123 $\mu\text{moles/g dry weight basis}$, 0.123 $\mu\text{moles/g DW}$ and 0.133 $\mu\text{moles/g DW}$, respectively (Fig. 1.A). Under the water deficit stress treatment at 30% FC, MSB072 recorded the highest proline

content mean value of 0.383 $\mu\text{moles/g DW}$ followed by Bafia and Delele1 at 0.303 $\mu\text{moles/g DW}$ and 0.306 $\mu\text{moles/g DW}$, respectively. However, for these two accessions proline content mean values were not significantly ($P \geq 0.05$) different. During the second season, there was a significant difference following the water regimes in which the water deficit stress recorded a significantly highest mean value of 0.31 $\mu\text{moles/g DW}$ while the control treatment recorded 0.13 $\mu\text{moles/g DW}$ (Fig. 1.B). Furthermore, a significant difference was observed on the accessions under study during this year, where MSB072 and Local leave recorded the highest mean value of 0.258 and 0.23 $\mu\text{moles/g DW}$ respectively while TOT6684 recorded the lowest mean value of 0.175 $\mu\text{moles/g DW}$ proline content (Fig. 1.C). This suggests that under water deficit treatment, MSB072 has ability to produce more of the secondary metabolites while TOT6684 recorded the lowest.

Water deficit stress (30% FC) had a significant effect on Jew's mallow SPAD content across all the accessions under study where it significantly decreased ($P < 0.05$). The highest mean values of 27.17 and 27.4 were recorded by TOT6684 and Bafia respectively, although were not significantly different (Fig. 2.A). The lowest mean values of 22.82 and 22.97 were observed on Delele1 and MSB072 respectively and were not significantly different. During 2023-2024 season, it was observed that, the water regime significantly affected the SPAD of *Corchorus olitorius* where it was observed that the water deficit stress recorded 23.92 while the control treatment recorded 33.51 (Fig. 2.B). Water deficit significantly decreased the SPAD content.

The highest stomatal conductance value of 308.78 mmols and 287.44 mmols were recorded on Bafia and Delele1 and were significantly different under the water deficit stress treatment. MSB072, TOT6684, Local leave and SUD3 recorded the lowest mean values although were not significantly different (Fig. 3.A). Further on, during 2023-2024 season, a similar stomatal conductance trend was observed under both the water regime in the studied accessions where Bafia and Delele1 continued to record a significantly high stomatal conductance of 295 and 277.67 mmols while TOT6684 recorded the lowest mean value of 171.33 mmols under water deficit stress treatment (Fig 3.B). Under the control treatment, MSB072 recorded a significantly highest mean value of 1309.33 followed by TOT6684 at 1008.33 mmols, while

Delele1 recorded the lowest value of 741.33mmols.

Plant height, leaf number, fresh leaves mass, dry leaves mass and leaf area were used to estimate the yield of the six *Corchorus olitorius* accessions under the two different water regimes treatments (Table 1. during two experimental seasons). There was a similar trend in the number of leaves and fresh leaf weight during all the seasons, however, during 2022-2023 season the interaction of water regime and accession was significantly different for both the dry leaf weight, leaf area and plant height. In the second season, there was no significant interaction, but only water regime had a significant difference in plant height, while for the leaf area and dry leaf weight were significantly affected by the water regime and accessions under study without the interaction. In all the root variables measured, there was a significant effect on the water regime and accession interaction during season 1.

In all the accessions, all the measured variables were higher in control (80% field capacity) treatments as compared to those measured under water deficit stress (30% field capacity) treatment. There was a significant difference in all parameters for the studied accessions under the water deficit stress and control treatment during first season. The plant height, fresh leaves weight, dry leaves weight, leaf area, number of leaves, root length, root fresh weight and dry root weight showed significant reduction ($P < 0.05$) following the water deficit treatment in all the accessions under study compared to the control treatment. The recorded values of 144.67cm on Delele1 followed by SUD3 at 137.67 cm under water deficit stress were recorded as the highest plant height while the shortest plant height was recorded on Local leave at 101.67 cm during 2022-2023 season. Under the control (80% FC), the highest number of leaves were recorded on TOT6684 and Delele1 with values 340 and 311 respectively and the values were significantly different while MSB072 recorded significantly lowest value of 206 during 2022-2023 season (Table 2). At 30% FC, significant difference on TOT6684 and Delele1 recorded the highest values at 265 and 250 respectively while MSB072 continued to record the lowest at 160 even in the water deficit stress. Interestingly, a similar trend was observed under water deficit stress treatment during second season where Delele1, TOT6684 recorded the highest number of leaves of 135.99 while MSB072 recorded the lowest mean of 125.01 (Table 2). A significant ($P < 0.05$) decline in the fresh leaves mass was

observed in all the accessions following the water deficit stress (30% FC) during 2022-2023 and 2023-2024 seasons. A significantly different value on Bafia and TOT6684 was observed, recording the highest at 255 g/plant and 231.55 g/plant respectively under the control treatment, while MSB072 recorded the lowest value of 76.95 g/plant fresh leaves mass (Table 2). Similar trend was observed under the water deficit stress treatment where Bafia and TOT6684 recorded the highest values of 143 g/plant and 139.75 g/plant respectively, even though the values were not significantly different under this treatment. However, MSB072 continued to record the lowest value of 48.70 g/plant following the water deficit stress. During 2023-2024 season, a similar trend to season 2022/2023 was observed under both the water regimes. The mean values of the leaf area on Bafia were the highest under both the water deficit stress and control treatment recording 131.63 cm² (30% FC) and 147.74 cm² (80% FC) respectively (Table 2). These values were significantly different. MSB072 recorded the lowest leaf area value under both the water deficit stress and the control treatment. The leaf area of 40.16 cm² was observed under the 80% FC while the 30% FC recorded 33.54 cm². MSB072 was an underperforming accession under both the control and water deficit stress treatment in all the yield and yield components observed during all seasons.

Water deficit stress had a significant decrease ($P < 0.05$) effect on *Corchorus olitorius* accessions studied root length, fresh root weight and dry roots weight (Table 3). The mean values of these roots' variables decreased with the 30% FC treatment in all the accessions where increased mean values were observed under the control treatment at 80% FC. Bafia and SUD3 accessions recorded significantly high root length mean values of 25 cm and 21.1 cm respectively under the control treatment, while MSB072 recorded the lowest mean value of 13 cm during 2022-2023 season. Bafia accession continued to record the highest root length mean value of 16.5cm under the water deficit stress treatment while MSB072 recorded the lowest value of 10.67 cm. Bafia, SUD3 and TOT6684 recorded the highest fresh roots weight mean values of 15.96 g/plant, 11.7 g/plant and 12.93 g/plant respectively at 80% FC, while MSB072 recorded the lowest mean value of 4.0 g/plant during 2022-2023 season (Table 3). Interestingly, a similar trend under the water deficit stress on root length was observed under the fresh root

weight, where the highest mean value of 10.27 g/plant was recorded on Bafia while the lowest mean value of 2.7 g/plant was observed on MSB072. During 2023-2024 season, TOT6684 and Bafia recorded a significantly highest mean values of the dry root weight of 6.09 g/plant and 3.57 g/plant respectively, while Local accession recorded the lowest value of 1.064g/plant (Table 3) under control treatment. TOT6684 and Bafia accessions continued to record the significant

highest mean values of 2.05 g/plant and 1.81 g/plant respectively while Delele1 recorded the lowest mean value of 0.79 g/plant under water deficit stress. Generally, Bafia and TOT6684 gave the highest roots mean values despite the watering regime in all the studied accessions, which might as well justify the highest yield and yield components by these two accessions. Meanwhile, MSB072 accession performed lowest in all the yield characters observed.

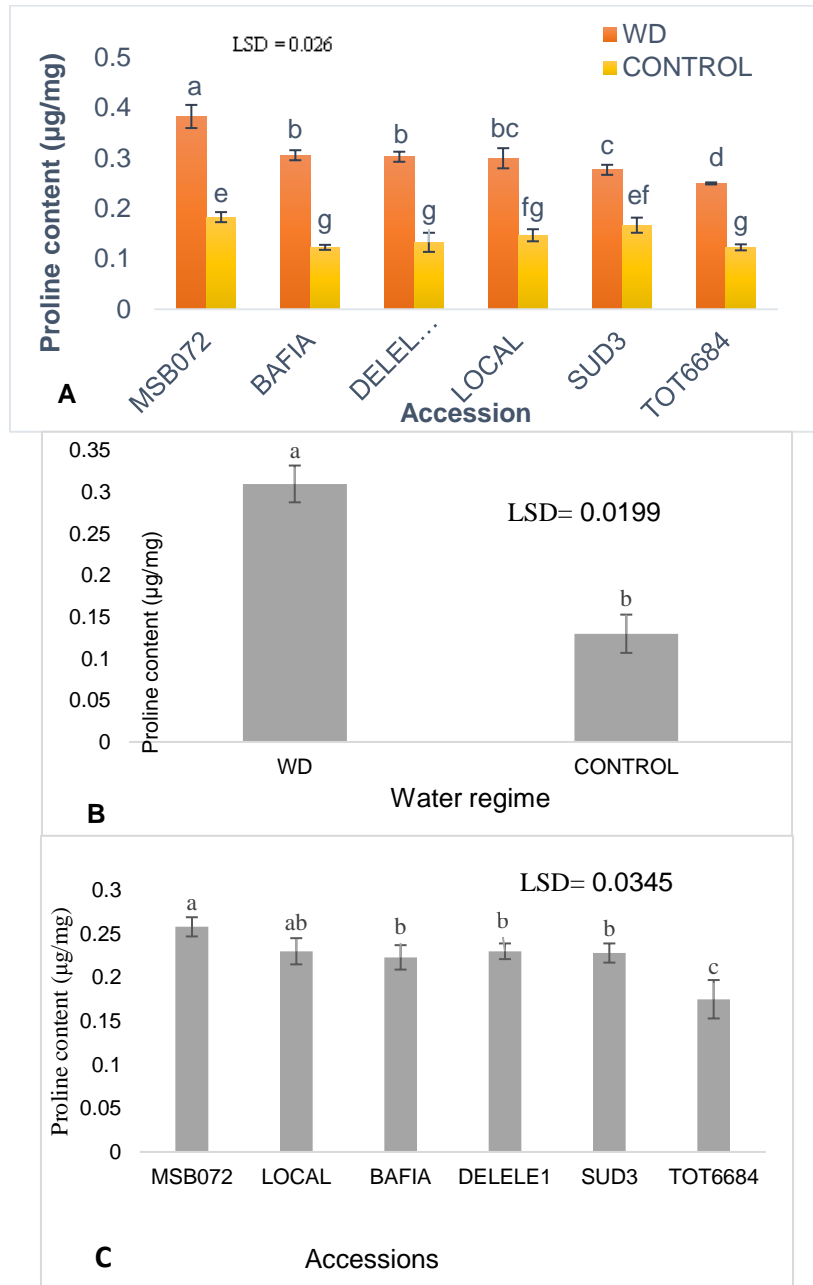


Fig. 1. Effects of water regimes on proline content of the *Corchorus olitorius* accessions (A). During 2022-2023 season. (B). during 2023-2024 season. (C). Response of *Corchorus olitorius* accessions proline content during 2023-2024 season. Values followed by dissimilar letter are significantly different at $P = 0.05$.

Table 1. Anova for yield and yield components for two seasons (2022-2023 and 2023-2024)

Treatment	Plant height		Leaf number		Fresh leaf weight		Dry leaf weight		Leaf area		Root length		Root fresh weight		Root dry weight	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
WR	1360 ***	70.82* **	680.15 ***	35.99* **	673.31 ***	32.18* **	168.82 ***	16.60 **	322.22 ***	6.14* ***	137.05 ***	12.76* **	241.50 ***	12.02 **	48.30 ***	42.10* **
ACSN	547.81 ***	2.34ns	392.20 ***	6.61**	287.27 ***	13.27* **	57.07 ***	4.90**	552.76 ***	2.90*	37.86 ***	2.05ns	139.25 ***	2.68*	21.03 ***	8.26**
WR*ACSN N	6.58 **	0.51ns	12.49 ***	5.07*	57.75 ***	2.82*	10.57 ***	0.96n s	15.01 ***	0.46n s	6.46 **	0.46ns	10.55 ***	0.69n s	5.0 ***	2.92*
CV	1.38	17.65	2.43	12.09	6.05	24.48	10.71	42.25	5.03	42.58	8.17	64.02	9.46	18.03	21.96	39.14
RMSE	1.82	15.65	1.15	9.98	1.71	8.55	0.89	2.85	3.66	19.97	1.26	3.76	0.74	1.88	0.51	0.88

WR (water regime), ACSN (accession), WR*ACSN (Interaction of water and accession, S1 (2022-2023 season), S2 (2023-2024 season). *** ($P < 0.0001$); ** ($P < 0.001$); * ($P < 0.05$); ns (not significantly different). Values in the column are the F-values

Table 2. Yield and yield components of six *Corchorus olitorius* accessions under control (C) and water deficit (WD) stress condition during 2022-2023

Accession	Treatments	Plant height (cm)	Leaf number	FLW (g)	DLW (g)	Leaf area (cm ²)
SUD3	Control	163.33 ^a ±0.58	265 ^c ±1.00	202.95 ^c ±2.04	56.75 ^b ±0.95	88.37 ^c ±1.59
	Water deficit	139.67 ^d ±1.53	215 ^g ±1.00	105.1 ^e ±1.37	34.4 ^{efg} ±1.84	54.28 ^f ±1.81
DELELE1	Control	163.00 ^a ±4.36	311.65 ^b ±0.58	134.4 ^d ±1.94	42.45 ^{cd} ±0.43	80.39 ^d ±0.07
	Water deficit	144.67 ^c ±2.51	250 ^d ±1.00	104.95 ^e ±1.12	31.1 ^{fg} ±0.22	45.81 ^g ±1.63
BAFIA	Control	148.33 ^b ±1.53	221.65 ^{ef} ±1.15	255.8 ^a ±1.41	62.65 ^b ±0.78	147.74 ^a ±1.31
	Water deficit	119.00 ^h ±1.73	183.35 ⁱ ±1.53	143.0 ^d ±0.72	43.3 ^c ±0.84	131.63 ^b ±2.64
MSB072	Control	134.67 ^e ±1.16	206.65 ^{gh} ±1.53	76.95 ^f ±0.036	31.45 ^{fg} ±0.52	40.16 ^g ±1.89
	Water deficit	114 ⁱ ±1.00	160 ^j ±1.00	48.70 ^g ±1.53	17.1 ^h ±0.53	33.54 ^h ±1.06
TOT6684	Control	127.67 ^f ±1.53	340 ^a ±1.00	231.45 ^b ±2.11	81.75 ^a ±0.99	77.07 ^d ±2.00
	Water deficit	107.00 ^j ±1.00	265 ^c ±2.00	139.75 ^d ±2.26	40.4 ^{cde} ±1.75	63.64 ^e ±1.85
LOCAL leave	Control	123.33 ^g ±1.53	228.35 ^e ±0.58	109.8 ^e ±2.80	34.95 ^{def} ±1.82	68.71 ^e ±1.11
	Water deficit	101.67 ^k ±2.08	200 ^h ±1.00	85.4 ^f ±3.06	27.05 ^g ±0.56	42.14 ^g ±11.35
	LSD	3.08	1.95	2.9	1.52	6.19

FLW (fresh leaf weight), DLW (dry leaf weight). Values followed by dissimilar letter are significantly different at $P = 0.05$

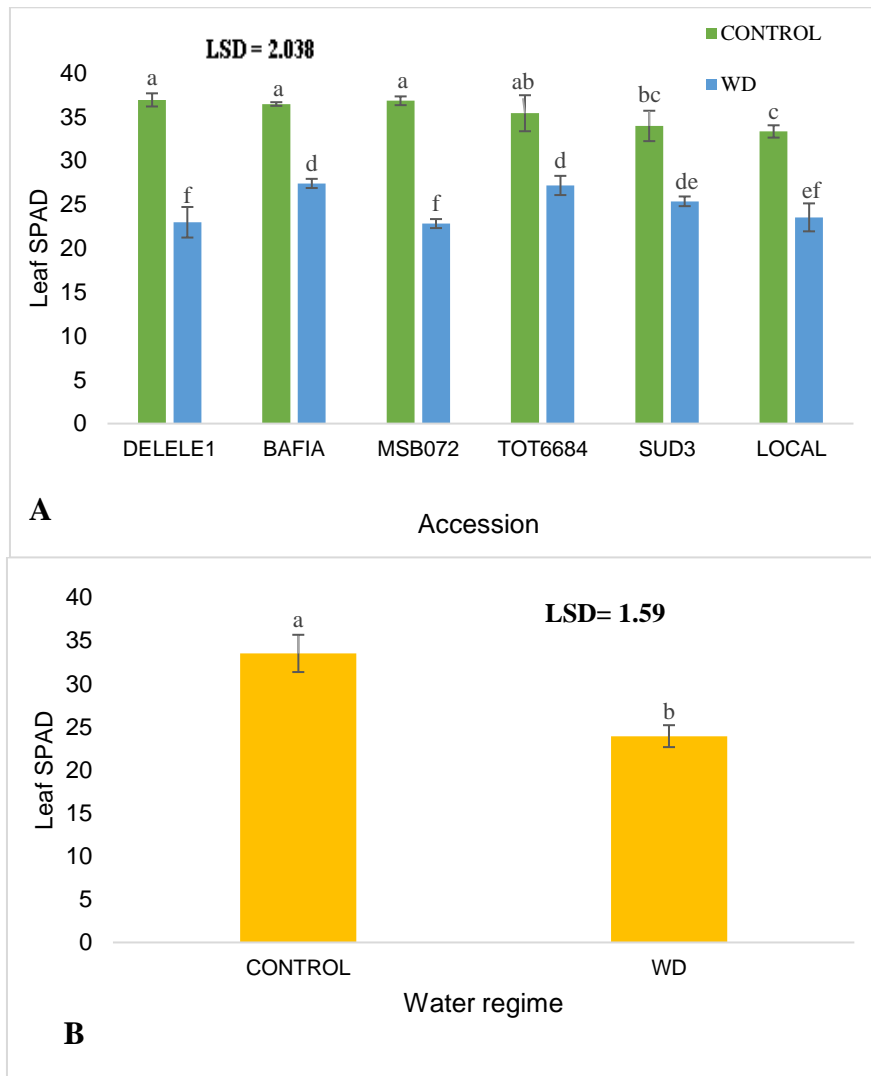
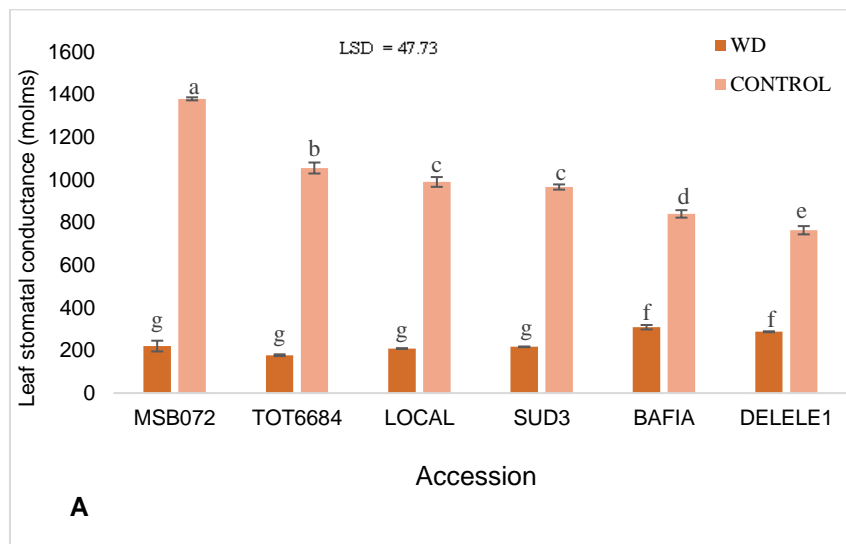


Fig. 2. Effects of water regime on Leaf SPAD content on *Corchorus olitorius* accessions (A). during 2022-2023 season. (B). during 2023-2024 season. Values followed by dissimilar letter are significantly different at $P = 0.05$



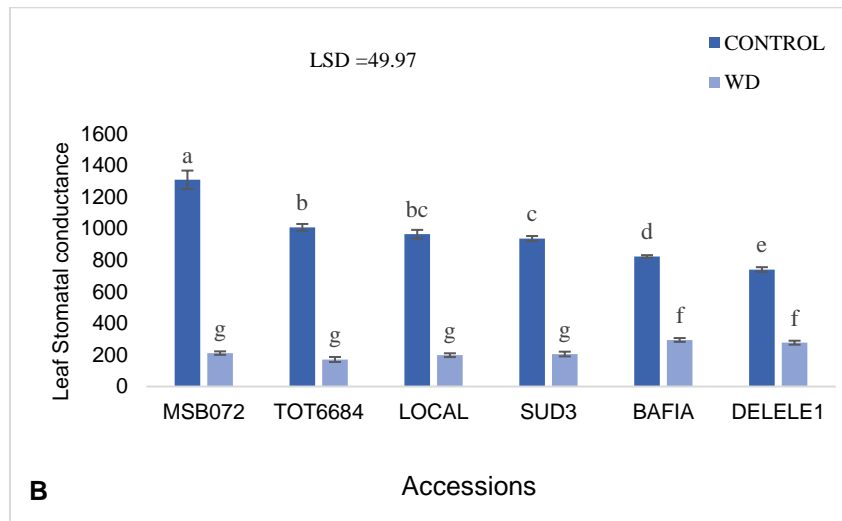


Fig. 3. Response of Stomatal conductance of *Corchorus olitorius* accessions under control and water deficit stress condition (A). during 2022-2023 season. (B). during 2023-2024 season. Values followed by dissimilar letter are significantly different at $P = 0.05$

Table 3. Effects of water regime and *Corchorus olitorius* accessions on leaf number and fresh weight. 2023-2024

Accessions	Treatment	Leaf number	Fresh leaf WGT
TOT6684	Control	222±9.17 ^a	190.47±6.47 ^a
	Water deficit	135.99±11.06 ^{de}	90.51±14.06 ^{bc}
BAFIA	Control	185.04±8.08 ^b	198.66±26.99 ^a
	Water deficit	135.99±5.77 ^{de}	118.29±15.71 ^b
LOCAL	Control	168.99±1.15 ^{bc}	120.63±10.09 ^b
	Water deficit	126±7.94 ^e	79.65±13.17 ^{bc}
SUD3	Control	156.99±15.04 ^{bcd}	117.33±20.03 ^b
	Water deficit	119.01±19.50 ^e	78.24±16.67 ^{bc}
DELELE1	Control	140.01±11.50 ^{cde}	67.8±5.42 ^c
	Water deficit	135±6 ^{de}	61.71±3.95 ^c
MSB072	Control	129±7.81 ^{de}	78.9±16.94 ^{bc}
	Water deficit	125.01±11.59 ^e	54.57±4.77 ^c
LSD		10.14	14.47

Values followed by dissimilar letter are significantly different at $P = 0.05$

Table 4. Effects of water regime and *Corchorus olitorius* accessions on the root variables

2022-2023 season			2023-2024 season		
Accession	Treatments	Root length (cm)	Fresh RW (g)	Dry RW (g)	DRW (g)
BAFIA	Control	25 ^a	15.96 ^a	3.53 ^{bc}	3.57 ^b
	Water deficit	16.5 ^c	10.27 ^c	2.8 ^{cd}	1.8 ^{de}
SUD3	Control	21.17 ^b	11.7 ^b	4.47 ^a	3.44 ^{bc}
	Water deficit	13.5 ^e	5.9 ^e	2.13 ^{def}	1.01 ^e
TOT6684	Control	16.33 ^c	12.93 ^b	4.23 ^{ab}	6.09 ^a
	Water deficit	13.83 ^{de}	7.7 ^d	1.87 ^{efg}	2.05 ^{cde}
LOCAL	Control	16.17 ^c	7.37 ^d	2.27 ^{de}	1.64 ^{de}
	Water deficit	12.43 ^{efg}	4.62 ^f	1.37 ^{fg}	1.07 ^e
DELELE1	Control	15.83 ^{cd}	6.63 ^{de}	1.77 ^{efg}	1.81 ^{de}
	Water deficit	11.0 ^{fg}	4.32 ^f	1.2 ^g	0.79 ^e
MSB072	Control	13.0 ^{ef}	4.0 ^f	1.23 ^g	2.60 ^{bcd}
	Water deficit	10.67 ^g	2.7 ^g	1.03 ^g	1.06 ^e

Values followed by dissimilar letters are significantly different at $P = 0.05$

4. DISCUSSION

Water deficit stress treatment (30% FC) significantly reduced ($P = 0.05$) plant height, leaf number, leaf area, fresh and dry leaves weight as compared to plants in the control treatment at 80% FC for all the studied accessions. These results agreed with reports of Yakoub et al., (2016) who found that, under water deficit at 40% of field capacity significant decline was found in all vegetative traits, the reduction rates were more than 50% for some traits like leaf size, leaf production and plant height. Similarly, Ewetola and Fasanmi (2015), found that 75% FC produced significantly ($P = 0.05$) taller plants while 25% FC gave the shorter plant in height, number of leaves, and the biomass yield. It was concluded that 75% FC was the best for growth and biomass yield of Jew's mallow similar to the study at 80% FC. Reduced leaf area, leaf number, plant height and fresh leaves weight in the current study further on agree with some investigations in which it was shown that water deficit mostly reduced leaf growth and subsequently the leaf areas in *Corchorus olitorius* (Odunnaike, 2011). Shiwachi et al. (2008) reported that plant growth in acute moisture stress (AMS) as 40-30% is generally difficult for most of leaf development. The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence under water stress. Stunted plant height and reduced leaf number under moisture stress conditions were reported by (Prodhan et al., 2001; Shiwachi et al., 2008; Fasinmirin & Olufayo, 2009; Ghosh et al., 2013; Maseko et al., 2019; Saleem et al., 2020; Bashandy & El-Shaieny, 2021). Reduction in plant height concurred with the findings from other researchers who reported reduced plant height in African leafy vegetables such as wild mustard and wild melon under moisture stress (Mbatha & Modi, 2010; Zulu & Modi, 2010). This suggests moisture deficit stress to be one of major factors that strongly influence crop growth (Slabbert et al., 2012). The reduced leaf number in moisture-deficient conditions may possibly have been a result of reduced leaf initiation, a mechanism employed by plants to curtail transpiration by reducing the leaf surface area (Luvaha et al., 2008). The current results are in harmony with findings by Fawusi, et al. (1984); Ayodele & Fawusi, (1989); Ayodele & Fawusi, 1990; Fasinmirin & Olufayo, (2009) who reported that *Corchorus olitorius* plants grown under drought stress were found to be shorter than plants that received full irrigation. Also, they found that the

stem length, total fresh foliage yield, plant weight, leaves weight and number of leaves per plant were reduced significantly under water deficit conditions. These results may be because *Corchorus olitorius* landraces responded diversely to different environments, suggesting the screening of cultivars under different environments as the most effective method for selecting tolerant genotypes (El-Shaieny, 2017). Root growth and elongation is a known plant response to water deficit for plant health. Like other phenotypic characters measured, the measured roots variables significantly decreased in water deficit stress in the current study, contrary to Yakoub et al., (2016) findings that the root system was developed under moderate water deficit (0.73 g/plant) treatments compared to control (0.29 g/plant). Under drought conditions, as the surface soil dries up, the roots extend to deeper moist soils to extract more available water from the soil (Malik et al., 1979; Martin & Thorstenson, 1988). However, the Jew's mallow accessions in this current experiment did not follow this trend and this could be because plants root development was limited by the potting. In water deficit stress conditions, plants' metabolism and physiological processes are greatly hampered resulting in reduced net photosynthesis and growth ultimately leading to reduction in growth parameters (Demir et al., 2013). Decline in cell enlargements, leaf senescence and abscissions due to water stress could as well be a possible reason for reduced growth parameters. This response is reflected in the reduced leaf area of the crop and a decrease in photosynthetic activity.

Proline is an important organic osmolyte accumulated in response to water deficit stress and performs a profound ameliorating function in plants under stress (Andre et al., 2010). Biosynthesis and control of proline levels has also been utilized as the central survival strategy in water stressed *Corchorus olitorius* plants (Das et al., 2016). The current study has shown a significant increase in proline content of all the accessions under the water deficit stress treatment (30% FC) compared to the control treatment (80% FC). These results are supported by Yakoub et al., (2016) who found that *Corchorus olitorius* had high capacity of adjustment in terms of accumulating proline especially when the treatment (40% FC) was applied. The proline increased to reach 2.07 mg/g (8 times higher than control). This data confirmed that proline is an important amino acid for osmotic adjustment in Jew's mallow subjected

to water deficit. These results agreed with Berka & Aid, (2009) who indicate the ability of this species to use these compatible solutes for osmotic adjustment and to grow under heavy soil moisture stress condition. Similarly, Bashandy & El-Shaieny, (2021) reported that, water deficit stress caused a significant increase in proline amount in all landraces. While severe and moderate water deficit increased proline content in the leaves, may be due to the ability of plants to maintain normal physiological functions and to adapt to unfavorable environments. In the current study, the stomatal conductance of the accessions under study significantly decreased in water deficit stress conditions compared to the control treatment. This was supported by Sucre & Suárez, (2011) who explained that the water deficit induced an important reduction of photosynthetic gaseous exchange. In addition, the plants stomatal conductance was significantly changed when the water deficit was applied on Jew's mallow plants which showed a tolerant reaction to the drought. The most inhibition of stomatal conductance was observed with the treatment 40% FC. Similarly, Dhar et al., (2018), reported that the stomatal conductance significantly decreased in *Corchorus olitorius* genotypes following water deficit stress by withholding water for ten days in comparison to control. SPAD mean values significantly declined in all the accessions under the water deficit stress treatment relative to control treatment which reported high mean values. The results agree with Maseko et al. (2019) who reported that the results of chlorophyll content index in *Corchorus olitorius* increased with increase in moisture content from 30% EvapoTranspiration to 60% Evapotranspiration. In crops such as okra and sunflower plants, reduced chlorophyll content because of moisture stress has been reported (Ashraf et al., 1994; Kiani et al., 2008). Similar findings were reported by Bashandy & El-Shaieny, (2021), on the relative amount of chlorophyll content results that showed that the highest value (84.86) was detected in L2 landrace at 95% FC, but at 60% FC, both L2 and L6 landraces shared the highest value. Clearly, the relative amount of chlorophyll content decreased with the increasing drought stress levels. SPAD value decreased due to water deficit stress because drought stress damaged photosynthetic pigments due to oxidation of pigments and reduced photosynthesis rate. The net photosynthetic, the transpiration rates and the contents of chlorophyll significantly decreased in plants subjected to water deficit (Rahman et al., 2021). Severe drought stress

has been reported to inhibit photosynthesis through altering the components and contents of the chlorophyll by damaging/distorting the photosynthetic apparatus (IturbeOrmaetxe et al., 1998; Ommen et al., 1999). Photosynthetic pigments (chlorophylls and carotenoids) play a photo-protective role since they eliminate reactive oxygen species, disperse excess energy in the form of heat or suppress lipid peroxidation (Hussain et al., 2019). A reduction of chlorophyll under drought stress conditions is due to an overproduction of reactive oxygen species in the thylakoids (Mibei et al., 2017).

5. CONCLUSION AND RECOMMENDATIONS

In all the accessions, the measured yield and yield components (plant height, number of leaves, fresh leaf weight, dry leaf weight, leaf area, number of branches, root length, root fresh weight, roots dry weight) were higher in 80% Field capacity as control compared to the limited application of 30% Field capacity as water deficit stress treatment. This decline may be suggesting that despite the plant being able to tolerate the dry spells, its yield traits are negatively affected and not able to perform to its potential. Bafia and TOT6684 recordings in all the variables under both treatments suggested that they are high yielding accessions while MSB072 is low yielding accession. The results of the study suggested that not only the environment and accession but even their interaction also significantly influenced the variations in one of the physiological parameters measured. Thus, it is important to consider both factors when selecting the accessions for continued research or cultivation as a vegetable. It is further recommended that more local accessions should be screened in order to identify plants that have a better tolerance mechanisms and can give good yields under environmental stressors.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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