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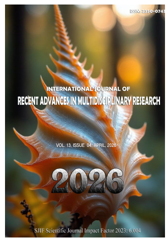

RESEARCH ARTICLE

EFFECT OF WATER STRESS ON GROWTH, YIELD, WATER USE EFFICIENCY, AND DROUGHT TOLERANCE OF THREE CHICKPEA VARIETIES IN NEW HALFA, EASTERN SUDAN

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ABSTRACT

A field experiment was conducted during the winter season (2023/2024) at the experimental farm of the Faculty of Agriculture and Natural Resources, University of Kassala, Sudan, to study the effects of water stress and variety on growth and yield of chickpea. The experiment was arranged in a split-plot design within a randomized complete block design (RCBD). The main plots were assigned to water stress treatments: irrigation every 8 days (W1), 12 days (W2), and 16 days (W3). Subplots were assigned to three chickpea varieties: Gezira (Gz), Atmour (At), and Baladi (B). The studied traits included plant height, dry weight, number of branches per plant, percentage of empty seeds, 100-seed weight, seed yield per hectare, and harvest index. In addition, relative water content (RWC), water use efficiency (WUE), and drought susceptibility index (DSI) were calculated. The results showed that water stress had a significant effect on plant height, dry weight, and days to 50% flowering and physiological maturity. Irrigation every 16 days (W3) significantly reduced these traits, while increasing water use efficiency and relative water content. Significant differences were observed among chickpea varieties in dry weight and days to physiological maturity. The Gezira and Atmour varieties matured 3 days later than the Baladi variety. The Atmour variety recorded the lowest values of RWC and WUE. Severe water stress (W3) significantly reduced seed yield, 100-seed weight, number of branches, and harvest index, while increasing the percentage of empty seeds, particularly in the Atmour variety. The yield reduction reached 38% in the Gezira variety under W3 compared to W1.The Baladi variety recorded the lowest drought susceptibility index (DSI) and stress intensity (SI), indicating better adaptation to water stress conditions in New Halfa. In contrast, the Gezira variety produced the highest yield under well-watered conditions (W1) but was highly affected by water stress. The Gezira variety is suitable under adequate irrigation, while the Baladi variety is more suitable for drought-prone conditions in New Halfa.

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INTRODUCTION

Chickpea (*Cicerarietinum* L.) is a cool-season annual legume belonging to the family Leguminosae. It is widely cultivated worldwide and ranks as the third most important pulse crop globally (Sabri *et al*., 2023). Chickpea is grown in more than 60 countries, covering approximately 120 thousand hectares. Major producing countries include India, Pakistan, Turkey, Iran, Mexico, and Australia (Muruiki *et al*., 2018).Chickpea is an important source of protein and carbohydrates for human nutrition, making it a highly valuable food crop. In addition, it contributes to soil fertility through biological nitrogen fixation via symbiosis with root nodule bacteria (Gan *et al*., 2010; Sabri *et al*., 2022).Water stress is one of the major environmental constraints affecting chickpea production. Several studies have reported that water stress significantly reduces plant dry weight, leaf number, and plant height (Randhawa *et al*., 2014). Moreover, significant variations in growth parameters among chickpea varieties under water stress conditions have been documented (Sachdeva *et al*., 2022).The reproductive stage (flowering, pod formation, and physiological maturity) is considered the most sensitive stage to water deficit in chickpea (Sachdeva *et al*., 2022). Adequate irrigation during flowering and pod development is essential for achieving optimum yield (Randhawa *et al*., 2016). Water stress has also been shown to significantly affect the number of days to flowering and physiological maturity among chickpea varieties (Taleei and Shaaban, 2016). Plants respond to water stress through several physiological and biochemical mechanisms, including changes in water use efficiency (WUE), osmotic adjustment, and photosynthetic activity.

These processes play a key role in maintaining cell integrity and enabling plants to tolerate drought conditions (Jensen, 1996; Tas and Tas, 2007). Relative water content (RWC) is widely used as an indicator of plant water status, and higher RWC is generally associated with improved drought tolerance (Keles and Oncel, 2004). A significant relationship between RWC and drought susceptibility index (DSI) has also been reported, suggesting that these parameters can be used for selecting drought-tolerant genotypes (Talebi *et al*., 2013).Grain yield in legumes is highly sensitive to water stress, particularly during flowering and grain filling stages. Reduced irrigation frequency has been shown to decrease the number of branches, 100-seed weight, and number of pods, resulting in yield reductions of 40–50% compared to well-watered conditions (Randhawa *et al*., 2014). Water stress also reduces seed number and seed weight, with significant variation among chickpea varieties (Muruiki *et al*., 2018; Taleei and Shaaban, 2016). Key yield components such as number of pods and seeds per pod are particularly affected by water stress (Davies *et al*., 2000). In addition, harvest index is significantly influenced by water deficit conditions (Taleei and Shaaban, 2016). Previous studies have demonstrated wide variation among chickpea varieties in their response to water stress (Talebi *et al*., 2013). The drought susceptibility index (DSI) is considered an important indicator for evaluating varietal tolerance, as it measures the relative reduction in performance under stress compared to non-stress conditions (Sachdeva *et al*., 2022). The significant correlation between DSI and RWC further supports their use in screening for drought-tolerant varieties (Talebi *et al*., 2013).In New Halfa region (eastern Sudan), chickpea production faces several challenges, including low productivity of local varieties, susceptibility to pests and diseases, and environmental stresses, particularly water stress. Improving chickpea performance under water-limited conditions has become essential both locally and globally to sustain productivity. Therefore, this study was conducted to evaluate the growth performance, yield, and drought tolerance of three chickpea varieties under water stress conditions, and to examine the relationships between growth traits, yield components, and associated physiological characteristics.

MATERIALS AND METHODS

A field experiment was conducted during the winter season of 2024 at the demonstration farm of the Faculty of Agriculture and Natural Resources, University of Kassala, located in New Halfa, Eastern Sudan.The area is characterized by heavy clay alkaline soils and a semi-arid climate. Rainfall occurs between June and September, with an annual range of 250–500 mm (New Halfa Meteorological Station, 2024).

The experiment was arranged in a split-plot design within a randomized complete block design (RCBD) with three replications.

- **Main plots:** Water stress treatments
  - W1: Irrigation every 8 days
  - W2: Irrigation every 12 days
  - W3: Irrigation every 16 days
- **Subplots:** Chickpea varieties
  - Baladi (B)
  - Atmour (At)
  - Gezira (Gz)

All agronomic practices were carried out according to the recommendations of the Sudanese Agricultural Research Corporation.Water stress treatments were applied 35 days after sowing and continued until harvest.

Data Collection: At flowering stage, five plants were randomly selected from the two الوسط rows of each experimental unit for measuring growth and yield parameters.

Growth Parameters

- **Plant height (cm):** Measured using a measuring tape, and the average of five plants was calculated.
- **Dry weight (g):** Five plants were oven-dried and weighed using a sensitive balance, and the average was recorded.
- **Relative Water Content (RWC):** Five leaves were collected, cut, and weighed fresh. Leaves were then soaked in distilled water overnight to obtain turgid weight, dried with filter paper, and weighed. Finally, they were oven-dried at 80°C for 24 hours to obtain dry weight.

RWC=TW−DWFW−DW×100

Where:

FW = Fresh weight, TW = Turgid weight, DW = Dry weight

- **Days to 50% flowering and physiological maturity:** Number of days from sowing until 50% flowering and until 90% of plants reached physiological maturity.

Yield and Yield Components

At 90% physiological maturity (when plants showed yellowing of leaves, stems, and pods), the selected plants were harvested and the following data were recorded:

- Number of branches per plant
- Number of pods per plant
- Number of seeds per pod
- Seed weight per plant
- 100-seed weight
- Seed yield (kg/ha): Calculated based on harvested yield per experimental unit
- Harvest Index (HI):

HI=Seed YieldBiological Yield×100HI = \frac{Seed\ Yield}{Biological\ Yield} \times 100HI=Biological YieldSeed Yield×100

Drought Indices

- **Drought Susceptibility Index (DSI):** DSI=1−(Ys/Yp)1−(Ys‾/Yp‾)DSI = \frac{1 - (Y_s / Y_p)}{1 - (\overline{Y_s} / \overline{Y_p})} DSI=1− (Ys/Yp)1−(Ys /Yp)

Where:

- YsY_sYs: Yield of a genotype under stress
- YpY_pYp: Yield under non-stress

- Ys‾\overline{Y_s}Ys: Mean yield of all genotypes under stress
- Yp‾\overline{Y_p}Yp: Mean yield under non-stress
- **Stress Intensity (SI):** SI = 1 − (mean yield under stress / mean yield under non-stress)
- **Stress Susceptibility Index (SSI):** SSI=Yp×Ys (Yp)2SSI = \frac{Y_p \times Y_s}{(Y_p)^2} SSI=(Yp) 2Yp×Ys
- **Tolerance Index (TOL):** TOL = Yp−YsY_p - Y_sYp −Ys Lower values of DSI and TOL indicate better drought tolerance.

Statistical Analysis: Data were analyzed using Statistix 10 software according to the split-plot design under RCBD.

- Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at a 5% level of significance.
- Correlation analysis was conducted between growth traits and yield components at a significance level of 5%.

RESULTS AND DISCUSSION

Growth Parameters: Analysis of variance revealed that water stress had a significant effect on plant height and dry weight, while varietal differences significantly affected dry weight.The tallest plants were recorded under irrigation every 8 days (W1), which was significantly superior to irrigation at 12 days (W2) and 16 days (W3). Although the interaction between water stress and variety was not significant, the highest plant heights (7.75 and 8.37 cm) were observed in the combinations W1Gz and W1B for Gezira and Baladi varieties, respectively (Table 1). The superior performance of the Gezira variety in plant height may be attributed to genetic differences among varieties. The increase in plant height under frequent irrigation (W1) can be explained by adequate moisture availability, which enhances cell division and elongation. In contrast, water deficit (W3) reduced plant height and dry weight, likely due to leaf senescence and abscission. These findings are consistent with those reported by Randhawa*et al*. (2014).Water stress and varietal differences significantly affected phenological traits, including days to 50% flowering and physiological maturity. Irrigation at longer intervals (W3) reduced the number of days to flowering and maturity compared to W1 and W2. The Gezira (Gz) and Atmour (At) varieties flowered approximately two days later than the Baladi (B) variety, while Gezira showed delayed physiological maturity by 2–3 days compared to the other varieties (Table 1). Relative Water Content and Water Use Efficiency. Water stress and varietal differences significantly influenced relative water content (RWC) and water use efficiency (WUE).The highest RWC (77.06%) was recorded under W3 (irrigation every 16 days), while the lowest (64.53%) was observed under W1 (Table 2). Among varieties, Atmour recorded the lowest RWC (68.42%) compared to Gezira and Baladi.

Table 1. Effect of water stress and variety on vegetative growth and phenological traits of chickpea

Treatments	Plant height	Plant DM weight gm	Days to 50% flowering	Days to 90% flowering
W1	7.88	107.68	55.75	98.53
W2	5.21	92.15	53.50	95.83
W3	4.37	87.07	52.17	92.67
LSD0.05	1.06	13.96	1.1	2.79
Gz	6.13	97.57	54.75	97.50
At	5.75	89.61	54.17	95.25
B	5.58	99.57	52.50	94.58
LSD0.05	-	7.99	1.25	2.05
W1 Gz	8.37	116.86	56.75	101.5
W2 At	7.5	95.66	54.75	98
W3 B	7.75	110.53	55.75	97
W2 Gz	5.87	94.61	53.75	96.75
W2 At	5	87.7	52.75	95.5
W2 B	4.75	94.13	54	95.25
W3 Gz	4.12	81.69	53.75	94.25
W3 At	4.25	85.45	50	93.25
W3 B	4.75	94.06	52.75	90.5
LSD0.05	-	-	-	-

Table 2. Effect of water stress and variety on relative water content (RWC) and water use efficiency (WUE)

المعاملاتTreatments	RWC	WUE
W1	64.53	3.89
W2	71.88	4.70
W3	79.06	7.99
$LSD._{0.05}$	9.61	0.38
Gz	71.88	5.70
At	68.42	5.16
B	75.18	5.73
$LSD_{0.05}$	5.26	0.46
W1 Gz	65.63	4.58
W2 At	65.26	3.53
W3 B	62.7	3.77
W2 Gz	71.64	5.01
W2 At	66.74	4.3
W2 B	77.26	4.87
W3 Gz	78.36	7.53
W3 At	73.26	7.63
W3 B	85.56	8.83
$LSD_{0.05}$	-	0.74

Table 3. Effect of water stress and variety on yield components and harvest index of chickpea

Treatments	Empty pods No	100 seed weight	HI %	No of branches/plant	Yield(kg/ha)
W1	10.53	25.76	41.82	4.91	1091.0
W2	15.53	21.61	37.20	4.41	922.4
W3	19.62	19.64	32.31	3.58	879.7
LSD0.05	2.24	2.24	4.36	0.79	97.85
Gz	9.99	23.71	39.64	5.33	1020.5
At	19.67	22.07	35.93	4.17	896.4
B	16.02	21.23	35.75	3.42	976.8
LSD0.05	1.79	1.61	3.35	0.46	88.3
W1 Gz	9.00	27.95	47.57	6.50	1283.3
W2 At	11.63	24.13	39.19	4.75	990.0
W3 B	10.75	25.19	39.13	3.50	1001.7
W2 Gz	10.23	23.52	38.68	5.50	950.0
W2 At	18.43	20.36	37.53	4.00	859.9
W2 B	17.95	20.95	34.94	3.75	839.3
W3 Gz	10.75	19.65	32.22	4.00	828.3
W3 At	28.97	19.20	31.07	3.75	839.3
W3 B	19.13	20.06	33.63	3.00	971.6
LSD0.05	3.37	-	-	-	158.24

Table 4. Drought indices of chickpea varieties

Variety	*DSI*	*TOL*	*SI*
Gz	0.44	455.08	0.35
At	0.19	150.67	0.15
B	0.03	30.0	0.02

Table 5. Correlation coefficients among growth traits, yield, and related parameters

	EMPTY SEEDS	100WT	DWT	PNTHGHT	FL50%	MATURTY	RWC	HI	WUE	YIELD
100WT	$-.57^{**}$									
DWT	$-.39^{*}$	$.48^{**}$								
PNTHGHT	$-.49^{**}$	$.71^{**}$	$.69^{**}$							
FLOW0	$-.65^{**}$	$.65^{**}$	.46**	$.72^{**}$						
MATRTY	$-.60^{**}$	$.59^{**}$	$.55^{**}$	$.58^{**}$	$.66^{**}$					
RWC	.27	$.47^{**}$	.29	$.567^{**}$	$.48^{**}$	$.50^{**}$				
HI	$-.53^{**}$	$.55^{**}$	$.61^{**}$	$.58^{**}$	$.53^{**}$	64^{**}	$.37^{*}$			
WUE	$.47^{**}$	$-.56^{**}$	$-.38^{*}$	$-.53^{**}$	$-.45^{**}$	$-.55^{**}$	$.59^{**}$	$.57^{**}$		
YIELD	$-.39^{*}$	$.59^{**}$	$.60^{**}$	$.59^{**}$	$.61^{**}$	$.64^{**}$	-.307	$.58^{**}$	-.14	
DSI	$.45^{**}$	.23	.11	.95	.16	.28	.15	.29	.15	.15

The highest RWC value (85.56%) was observed in the interaction W3B (Baladi under severe stress).These results agree with Keles and Oncel (2004), who reported that higher RWC is associated with improved drought tolerance and reduced water loss.Water use efficiency (WUE) was also significantly affected by water stress. The highest WUE (7.99) was recorded under W3. Although no significant differences were observed between Gezira and Baladi, the Baladi variety showed the highest WUE (8.83) under W3 conditions (Table 2). These findings are consistent with Tas and Tas (2007).

Yield and Yield Components: Water stress, variety, and their interaction significantly affected yield and its components.Water stress (W3) significantly reduced 100-seed weight (19.64 g) compared to W1 (25.76 g). The Gezira variety recorded the highest 100-seed weight compared to Atmour and Baladi (Table 3).In contrast, water stress increased the percentage of empty pods. The highest percentage (19.02%) was recorded under W3, while the lowest (10.53%) was observed under W1. The Atmour variety recorded the highest proportion of empty pods (19.67%), reaching 28.97% under W3, whereas the Gezira variety had the lowest percentage, especially under W1 conditions.The number of branches was highest in the Gezira variety under W1, while the lowest number (3.0 branches) was recorded in the Baladi variety under W3 (Table 3).Seed yield was significantly reduced by water stress. Under W3, yield decreased by approximately 24% compared to W1. The Gezira variety showed a substantial reduction from 1283.3 kg/ha under W1 to 928.3 kg/ha under W3 (a decrease of 38.24%).

Harvest index was also affected by water stress. The lowest value (31.07) was recorded for Atmour under W3, while the highest (47.57) was recorded for Gezira under W1.The reduction in yield and its components under water stress can be attributed to reduced dry matter accumulation and its translocation to seeds, particularly during flowering and grain filling stages. Increased flower and pod abortion under stress conditions also contributes to yield reduction. These findings are in agreement with Randhawa *et al*. (2014) and Ong (1983).

Drought Indices and Varietal Performance. The Drought Susceptibility Index (DSI) revealed clear differences among varieties.The Gezira variety recorded the highest DSI value (0.44), indicating high sensitivity to drought, while the Baladi variety recorded the lowest value (0.03), indicating strong drought tolerance. Similarly, the tolerance index (TOL) was lowest in Baladi (30) and highest in Gezira (455).Baladi also recorded the lowest stress intensity (SI = 0.02), confirming its superior adaptation to water stress compared to Gezira and Atmour (Table 4).These results agree with Talebi *et al*. (2013), who reported significant variation among chickpea varieties in drought tolerance. The low reduction in yield observed in

Baladi (from 1001 to 971.67 kg/ha) further supports its adaptability to drought conditions in New Halfa.

Correlation Analysis: Correlation analysis showed significant positive relationships between plant height and dry weight with yield components, including:

- 100-seed weight
- Harvest index
- Seed yield

Positive correlations were also observed with phenological traits. In contrast, negative correlations were found between these traits and:

- Percentage of empty seeds
- Relative water content (RWC)
- Water use efficiency (WUE)

The positive relationships between yield and growth traits indicate that these characteristics play an important role in enhancing productivity.

General Discussion and Implications: The results clearly demonstrate that the Gezira variety performs best under optimal irrigation (every 8 days), producing the highest yield. However, it is highly sensitive to water stress.In contrast, the Baladi variety showed greater stability and tolerance under drought conditions, making it more suitable for water-limited environments such as New Halfa.Further studies should be conducted using a larger number of varieties and different crops. Gezira variety is recommended under adequate irrigation conditions. Baladi variety is recommended under water stress conditions

CONCLUSION

Water stress significantly affected the growth, yield, and physiological traits of chickpea varieties. Increasing irrigation intervals (up to 16 days) led to reductions in plant height, dry weight, yield components, and overall seed productivity, while increasing water use efficiency and relative water content.mong the tested varieties, the Gezira (Gz) variety produced the highest yield under optimal irrigation conditions (every 8 days), but it was highly sensitive to water stress. In contrast, the Baladi (B) variety showed superior drought tolerance, as indicated by lower DSI, TOL, and stress intensity values, along with minimal yield reduction under stress conditions.Therefore, the Gezira variety is recommended for cultivation under adequate irrigation, whereas the Baladi variety is more suitable for drought-prone conditions such as New Halfa.

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