Characterization of Yield, Physiological and Biochemical Responses in Chickpea Genotypes Under Contrasting Water Availability

Abstract

Thirty chickpea genotypes were evaluated under irrigated and rainfed condition separately Randomized Block Design (RBD) with three replications to study yield, physiological and biochemical response for drought tolerance. Analysis of variance observed significant difference among studied genotypes in irrigated and rainfed condition for all the characters studied. Genetic variation exists in diverse chickpea genotypes for bio-physiological, morphological and yield attributing characters which can be explored for genetic improvement. As expected, water stress adversely affected the physiological, biochemical and yield responses of all the chickpea genotypes evaluated. The performance of genotypes Phule G-16318 and Phule G-1420-13-6 was observed to be stable for most of the characters such as chlorophyll content, membrane stability index, relative water content, photosynthesis rate, proline content under moisture stress condition. Similarly, both the genotypes with minimal reductions in seed yield, 100 seed weight, pod number and biomass plant^{-1} under rainfed condition, can serve as donors for drought tolerance in chickpea improvement programs.

Keywords: Drought, chickpea, irrigated, rainfed and soil moisture.

Introduction

Chickpea (*Cicer arietinum* L.) is a self-pollinating legume with eight basic chromosomes and a diploid genome (2n = 16) consisting of 738 Mb of genome size (Varshney *et al*. 2013). It is a popular crop among the farming community, especially in Africa and Asian countries due to less quantity of anti-nutritional factors in its seeds, as compare to other pulses and oilseeds. Chickpea crop has a prime importance at the global level as it improves soil fertility due to nitrogen fixation ability (50-60 kgha^{-1} N) especially in dry and rain fed region. Due to its nitrogen fixation capacity, it can be used in intercropping as well as in crop rotation contributing to climate resilient agriculture. This crop plays a dual role by not only fixing atmospheric nitrogen to support its own growth, thereby reducing its reliance on external nitrogen sources, but also by enhancing the availability of nitrogen for subsequent crops in the rotation (Merga and Haji, 2019).

Although India is a leading producer of chickpea, its productivity is very less. This is mainly due to biotic and abiotic stresses. Abiotic stresses such as drought, heat stress, salinity, frost, water logging and high temperature are major stresses which are responsible to reduce the chickpea yield.

The development of breeding lines that can acclimatize to wider environmental stresses with better yield is prime objective of any breeding programme. There are different abiotic stresses which affect chickpea yield to a great extent such as drought, heat, salinity and cold. Among them, drought stress is a major problem in rain-fed areas, which is second major factor for yield reduction after disease attack (Jha *et al*. 2016). Including chickpeas almost all the crops are affected by soil moisture stress. About 85% of the world's chickpea is grown under rain-fed conditions on residual soil moisture after harvest of *kharif* crops, which generally experiences terminal drought. Moisture deficiency affects the crop in many ways such as on seed germination, establishment of crop, photosynthesis and grain filling process. Hence, terminal drought is one of the major constraint which limits the productivity and yield stability of chickpea (Kashiwagi *et al*. 2006).

The impact of drought on chickpea yield is profound, as it hampers plant growth, flowering, and pod development. Critical growth stages are particularly vulnerable to water stress, leading to a reduction in both pod number and size, ultimately resulting in decreased yield. Furthermore, the physiological stress induced by drought can cause seeds to be smaller, thereby lowering the overall productivity of the crop. It is necessary to learn the various physiological process which helps to tackle the drought related problems. Along with this, it is need of hour to screen our available germplasm and cultivated lines for different biophysiological characters of drought related studies. It may help to identify potential donors which could be incorporated in future breeding programmes to bred improved varieties for drought tolerance. Therefore, the study was undertaken to evaluate promising chickpea genotypes for drought tolerance against biophysiological characters.

Materials and Methods

Thirty genotypes of chickpea were evaluated under irrigated and rainfed condition separately in Randomized Block Design (RBD) with three replications at Post Graduate Institute Research Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri in *Rabi* 2022-23. The fertilizer dose was applied before sowing @ 25:50:30 and 12.5:25:30, N: P: K kg/ha for irrigated and rainfed conditions, respectively. The sowing was carried out by dibbling method with spacing of 30 × 10 cm with plot size of 4.00 × 2.70 m^2. Each plot contains 6 rows. In each plot three genotypes were represented by two rows each. One irrigation was given to rainfed condition at the time of sowing, for better germination whereas, additional irrigations were given to irrigated conditions as per requirement of crop. Gap filling was carried out, 10 days after sowing to maintain optimum plant population. Observations were recorded on soil moisture status yield and yield contributing traits such as pods $plant^{-1}$, 100 seed weight and biomass $plant^{-1}$. Soil moisture were estimated by neutron moisture meter at the time of sowing and 50% flowering.

Chlorophyll content (SPAD index) was estimated non-destructively, using SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, NJ, USA) at 50% flowering. Membrane stability index was calculated at 50% flowering by the following procedure given by Blum and Ebercon, (1981). The relative water content (RWC) was determined according to the modified method of Barrs and Weatherly (1962) at 50% flowering.

$$\text{Relative water content (\%)} = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid weight - Dry weight}} \times 100$$

The observations on net photosynthetic rate (P_n) and transpiration rate (E) were recorded at 50% flowering with the help of portable Infrared Gas Analyzer (IRGA; Model Portable Photosynthesis System LI 6400, LI-COR Inc., Lincon, Nebraska, USA). Proline content in leaf tissues was determined using the acid ninhydrin reagent as per the method described by Bates *et al.* (1973).

Results and Discussion

A. Analysis of variance

The figures in table 1 represent analysis of variance for thirty chickpea genotypes evaluated under irrigated and rainfed conditions for ten characters. Significant difference was observed in irrigated and rainfed condition among all the genotypes for all the characters studied.

B. Soil moisture status

The information in table 2 depicts soil moisture status at different stages of crop growth. At the time of sowing, in irrigated condition moisture content was 35.40% at 0-15 cm depth, whereas it was 36.10% at 15-30 cm depth. Afterwards, at 50% flowering moisture content was 34.10% at 0-15 cm depth, and 34.40% at 15-30 cm depth. By harvesting stage, it was decreased up to 27.73% at 0-15 cm depth and 25.90% at 15-30 cm depth. Under rainfed condition, at the time of sowing, it was 35.35%, 36.00% at 0-15 and 15-30 cm depth respectively. There was considerable decrease in moisture content at flowering stage and afterwards. At 0-15 and 15-30 cm depth, moisture content was 29.20% and 29.50% respectively at 50% flowering stage. Furthermore, at harvesting stage it was 20.20% and 20.25% at 0-15 and 15-30 cm respectively.

Under water stress situation, the moisture content consistently decreased until the crop was harvested. Krishnamurthy *et al*. (2010) in their studies of chickpea drought tolerance experiment reported that, soil moisture content deceased from flowering to maturity. Similar findings were recorded by Ulemale *et al*. (2013) and Yaqoob *et al*. (2013). Pang *et al*. (2017) stated that soil moisture content decreased in all the layers of soil. Furthermore, Korbu *et al*. (2022) reported that soil moisture content was very less at time of harvesting and affected all the agro morphological traits.

C. **Effect of water stress on different character studied in thirty chickpea genotypes evaluated under rainfed and irrigated condition**

a. Yield and yield contributing characters

1. No. of pods plant^{-1}

There was significant effect of soil moisture stress on pods plant^{-1} (Table 3). On an average, chickpea genotypes grown under irrigated condition had 41.44 pods plant^{-1} compared to those grown under rainfed conditions which had 28.53 pods plant^{-1}. The genotype Phule G-16318 had maximum number of pods plant^{-1} (63.26) followed by Phule G-191304 (57.89), Vijay (54.80), Phule G-1420-13-6 (53.66) and Phule G-1327-10-12 (50.94) in well-watered condition Whereas, genotype ICC 6472 (23.59) had minimum pods plant^{-1}. In rainfed condition, moreover same trend was observed as genotype Phule G-16318 had maximum pods plant^{-1} (47.33) followed by Vijay (42.03), Phule G-191304 (40.97) and Phule G-1420-13-6 (38.87).

The percent reduction lied between 23.31 to 53.78. Genotype Vijay exhibited minimum percent reduction (23.31) whereas, genotype ICC 3538 (53.78) had maximum percent reduction.

Due to water stress no. of pods plant^{-1} were significantly reduced under rainfed condition. It may be due to, under rainfed conditions, water shortages reduce the rate of photosynthesis, which can hinder fertilization and cause flowers to shed (Jan *et al*. 2020). Under drought stress, chickpeas produce fewer flowers and pods because many are aborted and shed. This leads to fewer pods plant^{-1} (Rokhzadi, 2014) and lower overall productivity (Sachdeva *et al*. 2022). Drought stress reduces normal pollen growth, increasing the number of empty pods. This results in lower yields due to more empty pods and smaller seeds (Waqas *et al*. 2019). Similar findings like our results, were also reported by Sharma *et al*. (2015), Dalvi *et al*. (2016), Gunes *et al*. (2018) and Sachdeva *et al*. (2022).

2. 100 seed weight (g)

There were significant differences in 100 seed weight (g) of irrigated and that of rainfed chickpea genotypes (Table 3). All chickpea genotypes grown under irrigated conditions were found to record a significantly high 100 seed weight (22.71 g) compared to those grown under rainfed conditions (20.53 g). Genotype Phule G-16318 (29 g) recorded highest 100 seed weight followed by ICC 4958, Phule G-191304 and Phule G-1420-13-6 (28.33 g) in irrigated condition.

In rainfed condition, maximum 100 seed weight was recorded for the genotype Phule G-16318 (26.17 g), followed by Phule G-191304 (25.67 g) and Phule G-1415-13-28 (24.90 g). However, lowest 100 seed weight was observed for the genotype ICC 3650 (16 g, 14.33 g) in irrigated and rainfed condition respectively.

For 100 seed weight (g) reduction percentages ranged from 4.23 to 13.56. The genotype Phule G-17314 showed the minimum amount of reduction (4.23%). Conversely, the genotype with the highest significant reduction was ICC 6636 (13.56%).

Water stress significantly decreased the 100 seed weight of chickpea genotypes which were grown under rainfed condition as reported for chickpea (Sachdeva *et al*. 2022). Due to rainfed condition pollen growth became affected which results in empty pods and smaller seed size as compare to irrigated condition (Waqas *et al*. 2019). Similar findings were also reported in chickpea by Ulemale *et al*. (2013), Sharma *et al*. (2015), Gunes *et al*. (2018), Mekonnen, (2020) and Korbu *et al*. (2022).

3. Seed yield plant^{-1}

The data in the table 3 relates to seed yield plant^{-1} as affected by irrigated and rainfed conditions. On an average, seed yield plant^{-1} recorded under irrigated conditions (9.84 g) was significantly higher than the same measured under rainfed condition (6.64 g). The genotype Phule

G-16318 recorded highest seed yield plant^{-1} (13.31 g) followed by Phule G-1424-7-7 (12.81 g), Phule G-1221-2-6 (12.55 g), Phule G-19304 (12.43 g) and Phule G-1420-13-6 (12.10 g). Significantly lowest seed yield plant^{-1} was observed in the genotype ICC 4129 (7.32 g) in irrigated situation. In rainfed condition, genotype Phule G-16318 recorded highest seed yield plant^{-1} (10.91 g) followed by genotypes Phule G-1424-7-7 (9.10 g), Phule G-1221-2-6 (9.07 g) and Phule G-1420-13-6 (9.01 g). Whereas, genotype ICC 6485 recorded lowest seed yield plant^{-1} (4.28 g).

Reduction percentage for seed yield plant^{-1} ranged between 18.05 to 52.73. In given genotypes screened, the genotype Phule G-16318 observed minimum reduction (18.05%) whereas, genotype ICC 6488 recorded maximum reduction in yield (52.73%).

Water stress caused a significant reduction in seed yield plant^{-1} across all genotypes compared to the controls, similar to findings reported for chickpea by Sachdeva *et al*. (2022). Similar results were also reported by Mafakheri *et al*. (2010), Ulemale *et al.* (2013), Talebi *et al*. (2013), Sharma *et al*. (2015), Kumar *et al*. (2018), Jan *et al*. (2020), Mekonnen, (2020) and Korbu *et al*. (2022).

4. Biomass plant^{-1}

The information in table 3 pertains to biomass plant^{-1} (g) under both rainfed and irrigated conditions. When compared to genotypes grown under rainfed conditions (20.63 g), all genotypes of chickpeas grown under irrigation had a significantly higher biomass plant^{-1} (26.20). In irrigated and rainfed condition respectively, among the genotypes maximum biomass plant^{-1} was recorded in Phule G-1121-2-6 (33.09 g, 27.44 g) followed by Phule G-16318 (32.25 g, 27.31 g), Phule G-1424-7-7 (31.57 g, 26.70 g) and Phule G-191304 (30.76 g, 25.84 g). Under irrigated conditions, genotype ICC 3650 recorded the lowest biomass plant^{-1} (21 g), while genotype ICC 4850 recorded the lowest biomass plant^{-1} (15.22 g) under rainfed conditions.

The reduction percentage for biomass plant^{-1} differed between 11.36 to 38.93. Across the studied genotypes, significantly lower reduction percentage was recorded in the genotype Phule G-1327-10-12 (11.36%), whereas higher reduction was observed in the genotype ICC 6488 (38.93%).

The reduction in biomass in water-stressed plants may be due to decreased CO_2 accumulation in the biochemical reactions of photosynthesis, leading to lower carbohydrate production (Hopkins and Huner, 2009; Pots *et al*. 2008). Similar findings were recorded by Sharma *et al*. (2015), Gunes *et al*. (2018), Kumar *et al*. (2018), Mekonnen, (2020), Jan *et al*. (2020), Korbu *et al*. (2022) and Sachdeva *et al.* (2022).

b. Physiological characters

1. Chlorophyll content

The information on chlorophyll content influenced by irrigated and rainfed condition at 50% flowering are presented in table 4. Chickpea genotype grown under irrigated condition (43.34) recorded significantly maximum chlorophyll content as compared to those grown under rainfed condition (34.22). Across the genotype, under irrigated condition genotype Phule G-191304 (48.62) recorded highest chlorophyll content followed by Vijay (48.62), Phule G-16318 (48.44), BGM-10216 (48.31) and Phule G-1314-3-27 (47.98). Whereas, in same situation lowest chlorophyll content was observed in genotype Phule G-1415-13-28 (37.95). In rainfed condition, among the genotypes Phule G-16318 (41.33) recorded highest chlorophyll content followed by genotypes Vijay (40.16), Phule G-1314-3-27 (39.85), Phule G-19304 (39.21), and Phule G-1415-15-15 (38.59). Genotype ICC 6472 (29.26) had lowest chlorophyll content in rainfed condition.

The range of the reduction percentage for the content of chlorophyll was 14.68 to 25.77. The genotype ICC 6636 (25.77%) showed the maximum reduction in chlorophyll content, while the genotype Phule G-16318 (14.68%) had the least reduction as a result of water stress.

The present study found a decrease in total chlorophyll content due to rainfed condition. Ulemale *et al*. (2013) and Awari *et al*. (2017) observed that varying moisture levels led to a reduction in total chlorophyll content in chickpeas. This reduction in chlorophyll content is typical under drought stress, as chlorophyll pigment oxidation occurs (Kato and Shimizu, 1985; Javadi *et al*. 2017). Similar findings in the chickpea crop were also reported by Dalvi *et al*. (2016) and Singh *et al*. (2021).

2. Membrane stability index (%)

The data on MSI of chickpea genotypes influenced by irrigated and moisture stress condition at 50% flowering are presented in table 4. Due to moisture stress there was considerable decrease in membrane stability in rainfed condition (59.25%) as compare to irrigated condition (69.99%). In well-watered condition, maximum MSI was observed for the genotype Phule G-

16318 (81.49%), followed by Phule G-191304 (79.52%), Phule G-201216 (78.76%), Phule G-1420-13-6 (78.56%) and ICC 4958 (78.26%). However, lowest MSI was observed for the genotype ICC 3538 (49.96%). In rainfed condition, genotype Phule G-16318 (77.11%) found to be better for MSI followed by Phule G-191304 (74.08%), Phule G-201216 (73.88%), Phule G-1420-13-6 (72.55%) and Vijay (72.01%). Genotype ICC 4850 (39.41%) was poor for MSI in water stress condition.

The reduction percentage for MSI lied between 5.37 to 31.49. The genotype Phule G-16318 (5.37%) had minimum reduction while genotype ICC 6687 (31.49%) had maximum reduction.

The genotypes grown under water limited condition recorded low membrane stability index than in irrigated one. According to Blum and Ebercon, (1981) and Sachdeva *et al*. (2022), membrane stability index (MSI) is a crucial indicator of a plant's tolerance to drought, reflecting the integrity of cell membranes under stress. Drought conditions often cause membrane damage through increased reactive oxygen species, leading to higher electrolyte leakage and a lower MSI. Plants with higher MSI values maintain better membrane stability, indicating greater drought resistance. Similar results were also obtained by Ulemale *et al*. (2013), Meena *et al*. (2014) and Sachdeva *et al*. (2022).

3. Relative water content (%)

The data in the table 4 relates to RWC (%) of thirty chickpea genotypes at 50% flowering as affected by irrigated and rainfed conditions. On an average, RWC recorded under irrigated conditions (72.69%) was significantly higher than the same measured under rainfed condition (61.93%). The genotype Phule G-16318 (81.02%) recorded highest RWC followed by Phule G-201216 (81.85%), Phule G-191304 (81.02%), Phule G-1131-4 (80.96%) and Phule G-1420-13-6 (80.78%) in irrigated condition. Although, minimum RWC was recorded for the genotype ICC 6472 (60.67%) under same situation. In rainfed condition, maximum RWC was recorded for the genotype Phule G-16318 (78.15%) followed by Phule G-201216 (75.57%), Phule G-1131-4 (75.18%), Phule G-1420-13-6 (75.03%) and Phule G-191304 (74.39%). In same situation, minimum RLWC was recorded in the genotype ICC 6687 (47.54%).

The reduction percentage for RWC varied between 5.87 to 26.18. The genotype Phule G-16318 (5.87%) had minimum reduction while genotype ICC 3538 (26.18%) had maximum reduction for RWC.

Leaf water content of chickpea genotypes screened under irrigated condition was high with respect to those genotypes grown under rainfed condition. During drought conditions, plants with higher RLWC can maintain better physiological functions and survive longer periods of water scarcity as reported by Gonzalez and Gonzalez-Vila, (2001). Similar findings concurrent with our research were reported by Ulemale *et al*. (2013), Talebi *et al*. (2013), Meena *et al*. (2014), Sharma *et al*. (2015), Awari *et al*. (2017), Kumar *et al*. (2018), Singh *et al*. (2021) and Sachdeva *et al*. (2022).

4. Rate of photosynthesis

It was seen that, decrease in soil moisture can drastically affect rate of photosynthesis in studied genotypes as indicated in the table 4.

Across the genotype studied, in irrigated condition genotype JG-11 (17.42 µmol of CO_2 m^{-2} s^{-1}) had highest photosynthesis rate followed by genotype Phule G-16318 (17.33 µmol of CO_2 m^{-2} s^{-1}), Phule G-191304 (17.29 µmol of CO_2 m^{-2} s^{-1}), BGM 10216 (17.11 µmol of CO_2 m^{-2} s^{-1}) and Phule G-201216 (16.57 µmol of CO_2 m^{-2} s^{-1}). In rainfed condition genotype Phule G-16318 (15.00 µmol of CO_2 m^{-2} s^{-1}) performed better for photosynthesis followed by ICC 4958 (14.46 µmol of CO_2 m^{-2} s^{-1}), BGM 10216 (14.34 mol of CO_2 m^{-2} s^{-1}), JG-11 (13.88 µmol of CO_2 m^{-2} s^{-1}) Phule G-1420-3-6 (13.37 µmol of CO_2 $m^{-2}s^{-1}$). Genotype ICC 4129 recorded lowest photosynthesis rate in irrigated and rainfed (11.16 µmol of CO_2 m^{-2} s^{-1}, 7.24 µmol of CO_2 m^{-2} s^{-1}) conditions respectively.

The reduction percentage for photosynthesis rate lied between 12.17 to 39.67. The genotype Vijay (12.17%) had minimum reduction in photosynthesis, however genotype ICC 6636 (39.67%) had maximum reduction in photosynthesis rate due to water stress condition.

As anticipated, the photosynthetic rate in all chickpea genotypes significantly declined with soil moisture depletion. This aligns with the findings of Seifikalhor *et al*. (2022), who reported a reduction in photosynthetic efficiency across all chickpea genotypes as moisture levels decreased. Several factors contribute to the reduction of the photosynthetic rate under drought stress

Similarly, decrease in photosynthesis rate due to water stress were also reported by Mafakheri *et al*. (2010), Dalvi *et al*. (2016) and Awari *et al*. (2017).

5. Transpiration rate

It was observed that the depletion in soil moisture can substantially affect the transpiration rate in all the chickpea genotypes as indicated in table 5. Altogether, the transpiration rate was significantly highest in chickpea genotypes grown under irrigated condition (5.18 mmol of H_2O m^{-2} s^{-1}) as compare to rainfed condition (3.78 mmol of H_2O m^{-2} s^{-1}). Genotype Vijay (6.30 mmol of H_2O m^{-2} s^{-1}) recorded highest transpiration rate followed by genotypes Phule G-16318 (5.97 mmol of H_2O m^{-2} s^{-1}), ICC 4958 (5.93 mmol of H_2O m^{-2} s^{-1}), BGM 10216 (5.87 mmol of H_2O m^{-2} s^{-1}) and Phule G-191304 (5.85 mmol of H_2O m^{-2} s^{-1}) in irrigated condition. In rainfed condition, genotype Phule G-16318 (4.85 mmol of H_2O m^{-2} s^{-1}) recorded highest transpiration rate followed by ICC 4958 (4.73 mmol of H_2O m^{-2} s^{-1}), JG-11 (4.69 mmol of H_2O m^{-2} s^{-1}) and ICC 6687 (4.66 mmol of H_2O m^{-2} s^{-1}). Whereas minimum transpiration rate was observed in the genotype Phule G-1415-15-15 (3.62 mmol of H_2O m^{-2} s^{-1}, 2.73 mmol of H_2O m^{-2} s^{-1}) in irrigated and rainfed condition respectively.

There was wide variation in reduction percentage for transpiration rate as it lied between 18.72 to 37.12. The genotype Phule G-16318 (18.72%) affected less due to water stress as compare to genotype ICC 4850 (37.12%).

Transpiration rate decreases due to water stress condition as, plants respond by closing their stomata to conserve water, which limits the loss of water vapor to the atmosphere. This mechanism helps to minimize water loss but also restricts the plant's ability to cool itself and perform photosynthesis efficiently as reported by Mafakheri *et al*. (2010). Reduction in transpiration rate due to moisture stress condition were also reported by Dalvi *et al*. (2016) and Awari *et al*. (2017).

c. Biochemical characters

1. Proline content

The data in the (Table 5) relates to chickpea proline content (μmoles g^{-1} tissue) at 50% flowering stage as affected by irrigated and rainfed conditions. All chickpea genotypes grown under rainfed condition had a 2.31 folds greater proline content (7.98 μmoles g^{-1}) compared to irrigated condition (3.45 µmoles g^{-1}). Within the genotype studied, in irrigated condition maximum proline content was observed in the genotype Phule G-1131-4 (4.52 µmoles g^{-1}), followed by ICC 6687 (4.26 µmoles g^{-1}), Phule G-191304 (4.15 µmoles g^{-1}), ICC 4958 (4.01 µmoles g^{-1}) and Vijay (3.78 µmoles g^{-1}). Genotype ICC 6485 (2.95 µmoles g^{-1}) had lowest proline content in well-watered condition.

Due to water stress there was increase in proline content in rainfed condition as genotype Phule G-19304 (9.20 µmoles g^{-1}) recorded maximum proline content followed by Phule G-1420-13-6 (9.18 µmoles g^{-1}), Phule G-1131-4 (9.13 µmoles g^{-1}), Phule G-1121-2-6 (8.75 µmoles g^{-1}) and ICC 6687 (8.63 µmoles g^{-1}). Although lowest proline content was recorded in the genotype Phule G-1403-18-14 (6.14 µmoles g^{-1}).

There was a greater variation in the percent increase in proline content due to water stress, ranging from 102.05% to 188.36%. The genotype Phule G-1420-13-6 showed the maximum increase in proline content due to water stress at 188.36%, whereas the genotype Phule G-1131-4 had the minimum increase at 102.05%.

In the current study, drought stress remarkably elevated the proline content in all chickpea genotypes when compared to well water conditions. In the same aspects, Hussain *et al*. (2020) noted that water stress considerably increased the proline content in chickpeas. Similar to our findings, the researchers Awari *et al*. (2017), Singh *et al*. (2021), Karim *et al*. (2022) and Ghosh *et al*. (2023) also reported that proline content in chickpea increase during drought condition.

Conclusion

The study successfully identified significant genetic variation among the 30 chickpea genotypes under both irrigated and rainfed conditions, confirming the diversity in bio-physiological, morphological, and yield-attributing traits. The results demonstrated that water stress had a negative impact on the physiological, biochemical, and yield responses of all genotypes. However, genotypes Phule G-16318 and Phule G-1420-13-6 exhibited stable performance under drought conditions, with minimal reductions in key yield parameters such as seed yield, 100-seed weight, pod number, and biomass per plant. These genotypes show promise as potential donors for enhancing drought tolerance in chickpea breeding programs. The findings underscore the importance of selecting and utilizing genetically diverse chickpea genotypes to improve drought resilience, which is crucial for sustaining productivity in water-limited environments.

References

Awari, V.R., Dalvi, U.S., Lokhande, P.K., Pawar, V.Y., Mate, S.N., Naik, R.M. and Mhase, L.B. 2017. Physiological and biochemical basis for moisture stress tolerance in chickpea under pot study. *International Journal of Current Microbiology and Applied Sciences* **6**(5): 1247-1259.

Barrs, H. D. and Weatherley, P. E. 1962. A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Sciences* **15**(3): 413-428.

Bates, L. S., Waldren, R. A. and Teare, I. D. 1973. Rapid determination of free proline for water-stress studies. *Plant and Soil* **39**: 205-207.

Blum, A., and Ebercon, A. 1981. Cell membrane stability as a measure of drought and heat tolerance in wheat. *Crop Science* **21**(1): 43-47.

Dalvi, U. S., Naik, R. M., and Awari, V. R. 2016. Morpho-physiological responses of chickpea (*Cicer arietinum* L.) genotypes under drought stress. *International Journal of Science, Environment and Technology* **5**(3): 997-1007.

Ghosh, S., Sharma, V. K., Arya, M., Sahni, S., and Singh, S. K. 2023. Screening of chickpea genotypes based on morphological and biochemical attributes and drought tolerant indices. *The Pharma Innovation Journal* **12**(8): 113-120.

Gonzalez L and Gonzalez-Vila M. 2001. Determination of Relative Water Content. (In) Handbook of Plant Ecophysiology Techniques. 207–12. Roger M J R (Ed). *Springer*, Netherlands.

Gunes, A., Inal, A. and Adak, M.S. 2018. Effect of drought stress on sensitivities and yields of chickpea (*Cicer arietinum* L.) cultivars. *Yuzuncu Yil University Journal of Agricultural Sciences* **28**: 180-189.

Hopkins, W. G. and Huner, N. P. A. 2009. Introduction to Plant Physiology. 4th edition, John Wiley and Sons, Inc., Hoboken, 503p.

Hussain, I., Rasheed, R., Ashraf, M.A., Mohsin, M., Shah, S.M.A., Rashid, D.A., Akram, M., Nisar, J. and Riaz, M. 2020. Foliar applied acetylsalicylic acid induced growth and key-biochemical changes in chickpea (*Cicer arietinum* L.) under drought stress. *Dose*

Response **18**(4) 15-19.

Jan, M., Haq, T.U., Sattar, H., Butt, M., Khaliq, A., Arif, M. and Rauf, A. 2020. Evaluation and screening of promising drought tolerant chickpea (*Cicer arietinum* L.) genotypes based on physiological and biochemical attributes under drought conditions. *Pakistan Journal of Agricultural Research* **33**(3): 662.

Javadi, T., Rohollahi, D., Ghaderi, N. and Nazari, F. 2017. Mitigating the adverse effects of drought stress on the morpho-physiological traits and anti-oxidative enzyme activities of *Prunus avium* through β-amino butyric acid drenching. *Scientia Horticulturae* **218**: 156-163.

Jha, U. C., Basu, P., Shil, S., and Singh, N. P. 2016. Evaluation of drought tolerance selection indices in chickpea genotypes. *International Journal of Bio-resource and Stress Management* **7**(6): 1244-1248.

Kashiwagi, J., Krishnamurthy, L., Crouch, J. H., and Serraj, R. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L.) under terminal drought stress. *Field Crops Research* **95**(2-3): 171-181.

Kato, M. and Shimizu, S. 1985. Chlorophyll metabolism in higher plants VI. Involvement of peroxidase in chlorophyll degradation. *Plant and Cell Physiology* **26**(7): 1291-1301.

Korbu, L., Fikre, A., Tesfaye, K., Funga, A., Bekele, D., and Ojiewo, C. O. 2022. Response of chickpea to varying moisture stress conditions in Ethiopia. *Agrosystems, Geosciences and Environment* **5**(1): 20234.

Kumar, T., Bharadwaj, C., Tiwari, N., Satyavathi, C. T., Patil, B., Sarker, A. and Alam, A. 2018. Morphological characterization and grouping of chickpea (*Cicer arietinum*) genotypes for drought tolerance. *The Indian Journal of Agricultural Sciences* **88**(11): 1740-1745.

Mafakheri, A., Siosemardeh, A. F., Bahramnejad, B., Struik, P. C., and Sohrabi, Y. 2010. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian Journal of Crop Science* **4**(8): 580-585.

Meena, N.L., Ali, K., Dehmukh, P.S. and Tyagi, A. 2014. Effect of heat stress on physio-biochemical characteristics of chickpea (*Cicer arietinum*) genotypes. *Indian Journal of Agricultural Sciences* **84**(3): 401-6.

Mekonnen, L. 2020. Effects of water stress applied at different phenological phases of chickpea (*Cicer arietinum* L.). *International Journal of Agricultural Research, Innovation and Technology* **10**(1): 13-21.

Merga, B. and Haji, J. 2019. Economic importance of chickpea: Production, value, and world trade. *Cogent Food and Agriculture* **5**(1): 1615718.

Pots, D.L., Stanley. H., Goulden. W. and Suding, K.N. 2008. The impact of invasion and subsequent removal of an exotic Thistle, *Cynara cardunculus*, on CO_2 and H_2O vapor exchange in a Coastal California Grassland. *Biological Invasions* **10**: 1073-1084.

Rokhzadi, A. 2014. Response of chickpea (*Cicer arietinum* L.) to exogenous salicylic acid and ascorbic acid under vegetative and reproductive drought stress conditions. *Journal of Applied Botany and Food Quality* **87**: 22-24.

Sachdeva, S., Bharadwaj, C., Patil, B. S., Pal, M., Roorkiwal, M. and Varshney, R. K. 2022. Agronomic performance of chickpea affected by drought stress at different growth stages. *Agronomy* **12**(5): 995.

Seifikalhor, M., Niknam, V., Aliniaeifard, S., Didaran, F., Tsaniklidis, G., Fanourakis, D. and Li, T. 2022. The regulatory role of γ-Aminobutyric acid in chickpea plants depends on drought tolerance and water scarcity level. *Scientific Reports* **12**(1): 1-17.

Sharma, K. D., Boora, K. S., and Kumar, N. 2015. Plant water status, canopy temperature and chlorophyll fluorescence in relation to yield improvement in chickpea (*Cicer arietinum* L.) under soil moisture stress environments. *Journal of Agro Meteorology* **17**(1):11-16.

Singh, L., Kohli, D., Gaikwad, K., Kansal, R., Dahuja, A., Paul, V., Bharadwaj, C. and Jain, P.K. 2021. Effect of drought stress on morphological, biochemical, physiological traits and expression analysis of microRNAs in drought-tolerant and sensitive genotypes of chickpea. *Indian Journal of Genetics and Plant Breeding* **81**(02): 266-276.

Talebi, R., Ensafi, M.H., Baghebani, N., Karami, E., and Mohammadi, K. 2013. Physiological responses of chickpea (*Cicer arietinum*) genotypes to drought stress. *Environmental and Experimental Biology* **11**: 9-15.

Ulemale, C. S., Mate, S. N., and Deshmukh, D. V. 2013. Physiological indices for drought tolerance in chickpea (*Cicer arietinum* L.). *World Journal of Agricultural Sciences* **9**(2):123-131.

Varshney, R.K., Song, C., Saxena, R.K., Azam, S., Yu, S., Sharpe, A.G., Cannon, S., Baek, J., Rosen, B.D., Tar'an, B. and Millan, T. 2013. Draft genome sequence of chickpea (*Cicer arietinum*) provides a resource for trait improvement. *Nature Biotechnology* **31**(3): 240-246.

Waqas, M., Azhar, M. T., Rana, I. A., Arif, A. and Atif, R. M. 2019. Drought stress in chickpea: Physiological, breeding and omics perspectives. In Recent Approaches in Omics for Plant Resilience to Climate Change. pp. 189-227.

Table 1. Analysis of variance for thirty genotypes under irrigated and rainfed condition for different characters in chickpea.

Sr. No.	Name of character	Irrigated Mean sum of squares		Rainfed Mean sum of squares	
		Treatment	Error	Treatment	Error
	Degrees of freedom	29	58	29	58
1	Number of pods plant^{-1}	348.14**	7.80	265.87**	12.81
2	100 seed weight	30.20**	0.23	36.92**	0.52
3	Seed yield plant^{-1}	10.33**	0.59	10.13**	0.11
4	Biomass plant^{-1}	38.03**	2.65	46.84**	0.74
5	Chlorophyll content	34.98**	0.32	38.98**	0.34
6	Membrane stability index	235.26**	0.32	395.29**	1.91
7	Relative water content	115.64**	26.34	304.69**	8.14
8	Rate of photosynthesis	7.38**	0.30	11.02**	0.13
9	Transpiration rate	1.27**	0.02	1.24**	0.008
10	Proline content	0.42**	0.03	1.64**	0.06

* Significance at 5% level, ** Significance at 1% level

Table 2. Soil moisture content at different soil depths and stages of crop growth.

Sr. No.	Soil depth (cm)	Stage of crop	Soil moisture content (%)

			Irrigated	**Rainfed**
1	0-15	Sowing	35.40	35.35
2	15-30	Sowing	36.10	36.00
3	0-15	50% flowering	34.10	29.20
4	15-30	50% flowering	34.40	29.50
5	0-15	Harvesting	25.73	20.20
6	15-30	Harvesting	25.90	20.25

Table 3. Yield and yield contributing characters in chickpea genotypes evaluated under irrigated and rainfed conditions.

Sr. No.	Traits / Genotypes	Pods/plant			100 seed weight			Seed yield plant^{-1}			Biomass plant^{-1}		
		I_1	I_0	↓%	I_1	I_0	↓%	I_1	I_0	↓%	I_1	I_0	↓%
1	BGM-10216	49.91	34.69	30.50	23.50	21.71	7.63	11.28	8.15	27.70	28.60	22.83	20.20
2	JG-11	50.07	35.88	28.34	23.17	21.80	5.90	10.18	6.90	32.24	26.31	20.44	22.30
3	Vijay	54.80	42.03	23.31	22.33	20.50	8.21	10.68	8.00	25.06	26.40	22.37	15.26
4	ICC 4958	49.22	35.54	27.79	28.33	26.17	7.65	10.27	7.65	25.48	27.21	22.58	17.00
5	Phule G-1327-10-12	50.94	37.05	27.27	26.67	24.63	7.63	11.60	8.35	28.02	28.98	25.69	11.36
6	Phule G-1131-4	48.66	35.00	28.08	26.00	23.70	8.85	12.02	8.43	29.82	30.27	24.25	19.91
7	Phule G-1221-2-6	49.88	36.90	26.02	21.50	19.67	8.53	12.55	9.07	27.73	33.09	27.44	17.06
8	Phule G-1424-7-7	50.78	35.33	30.44	20.50	19.00	7.32	12.81	9.10	28.98	31.57	26.70	15.42
9	Phule G-17314	48.27	32.80	32.04	23.67	22.67	4.23	9.92	7.59	23.43	28.67	23.57	17.77
10	Phule G-16318	63.26	47.33	25.18	29.00	26.17	9.77	13.31	10.91	18.05	32.25	27.31	15.32
11	Phule G-1403-18-14	46.89	32.85	29.94	24.00	22.00	8.33	9.18	5.67	38.29	25.00	17.96	28.18
12	Phule G-1415-13-28	38.84	29.32	24.53	27.00	24.90	7.78	11.24	7.36	34.48	27.90	22.05	20.96
13	Phule G-191304	57.89	40.97	29.23	28.33	25.67	9.41	12.43	8.38	32.57	30.76	25.84	15.99
14	Phule G-1424-4-2	38.97	25.28	35.14	21.17	19.33	8.66	9.04	6.20	31.42	25.63	20.33	20.67
15	Phule G-1314-3-27	37.23	25.12	32.53	25.67	23.17	9.74	8.82	5.60	36.48	24.87	18.24	26.67
16	Phule G-1415-15-15	34.44	25.35	26.39	18.67	16.33	12.50	9.90	7.07	28.62	25.74	22.22	13.65
17	Phule G-1420-13-6	53.66	38.87	27.56	28.33	25.67	9.41	12.10	9.01	25.51	29.96	25.21	15.85
18	ICCV 21111	30.93	19.65	36.47	25.67	22.30	13.12	8.85	5.30	40.13	24.62	17.34	29.58
19	Phule G-201216	46.67	35.22	24.53	25.00	22.50	10.00	11.40	8.16	28.46	29.06	22.90	21.19
20	ICC 6636	38.89	28.11	27.71	19.67	17.00	13.56	8.25	4.53	45.04	23.07	15.60	32.40
21	ICC 3650	38.67	25.22	34.77	16.00	14.33	10.42	7.70	4.87	36.76	21.00	16.17	23.01
22	ICC 4129	23.62	13.70	42.00	18.67	16.17	13.39	7.32	4.40	39.92	21.10	16.10	23.71
23	ICC 6472	23.59	17.12	27.40	21.00	18.50	11.90	8.22	5.21	36.58	22.80	16.93	25.76
24	ICC 6385	34.89	23.78	31.85	19.00	17.00	10.53	7.61	5.28	30.57	22.76	19.34	15.04
25	ICC 6485	27.45	15.56	43.32	17.33	15.47	10.77	7.51	4.28	43.05	21.86	15.92	27.19
26	ICC 4850	26.45	13.18	50.16	19.67	17.67	10.17	7.62	4.54	40.41	21.79	15.22	30.12
27	ICC 3538	36.00	16.64	53.78	20.67	18.00	12.90	7.86	4.41	43.87	22.40	16.49	26.39
28	ICC 6399	29.95	18.76	37.36	20.67	18.40	10.97	8.42	5.17	38.55	24.60	17.61	28.42

Table 3 contd …..

29	ICC 6488	33.00	22.02	33.28	21.67	18.92	12.69	9.52	4.50	52.73	26.45	16.15	38.93
30	ICC 6687	29.51	16.68	43.47	18.67	16.67	10.71	7.85	5.37	31.62	21.32	18.30	14.19
	Mean	41.44	28.53	31.15	22.71	20.53	9.60	9.84	6.64	32.52	26.20	20.63	21.26
	SEm(±)	1.61	2.06		0.27	0.41		0.44	0.19		0.94	0.49	
	CD (5%)	4.79	6.14		0.82	1.24		1.32	0.58		2.79	1.48	

I_1: Irrigated condition, I_0: Rainfed condition, ↓%: Percent reduction

Table 4. Physiological characters in chickpea genotypes evaluated under irrigated and rainfed conditions.

Sr. No.	**Traits / Genotypes**	**Chlorophyll content**			**MSI**			**RWC**			**ROP**		
		I_1	**I_0**	**↓%**	**I_1**	**I_0**	**↓%**	**I_1**	**I_0**	**↓%**	**I_1**	**I_0**	**↓%**
1	BGM-10216	48.31	38.18	20.97	78.17	71.26	8.85	75.67	68.91	8.93	17.11	14.34	16.19
2	JG-11	45.99	36.24	21.20	77.74	70.43	9.40	71.57	65.02	9.16	17.42	13.88	20.29
3	Vijay	48.62	40.16	17.39	77.95	72.01	7.62	78.87	73.78	6.45	15.28	12.79	16.28
4	ICC 4958	46.25	37.29	19.38	78.26	71.44	8.72	80.00	73.84	7.70	16.46	14.46	12.17
5	Phule G-1327-10-12	46.29	36.86	20.36	76.17	67.83	10.95	73.78	65.09	11.78	15.49	11.90	23.19
6	Phule G-1131-4	44.88	34.95	22.13	75.72	68.73	9.23	80.96	75.18	7.14	12.24	8.86	27.66
7	Phule G-1221-2-6	41.37	31.09	24.86	76.75	69.63	9.27	79.52	73.24	7.90	13.48	11.12	17.51
8	Phule G-1424-7-7	40.05	31.04	22.50	68.95	60.32	12.52	75.97	69.80	8.12	14.39	10.31	28.35
9	Phule G-17314	39.16	30.12	23.08	66.78	56.77	14.98	70.54	56.02	20.58	14.28	10.57	25.96
10	Phule G-16318	48.44	41.33	14.68	81.49	77.11	5.37	83.02	78.15	5.87	17.33	15.00	13.43
11	Phule G-1403-18-14	39.34	31.35	20.31	60.97	49.39	19.00	66.94	55.06	17.75	16.33	11.65	28.67
12	Phule G-1415-13-28	37.95	30.59	19.38	73.38	59.89	18.38	68.24	52.24	23.45	15.96	12.10	24.20
13	Phule G-191304	48.62	39.21	19.34	79.52	74.08	6.84	81.02	74.39	8.18	17.29	13.24	23.42
14	Phule G-1424-4-2	47.23	38.45	18.60	76.54	64.19	16.13	73.58	55.90	24.02	15.34	11.57	24.61
15	Phule G-1314-3-27	47.98	39.85	16.95	74.27	60.75	18.20	78.90	69.13	12.38	15.63	11.60	25.80
16	Phule G-1415-15-15	45.86	38.59	15.85	76.06	65.15	14.34	68.84	59.56	13.48	14.28	11.90	16.67
17	Phule G-1420-13-6	41.76	35.24	15.62	78.56	72.55	7.65	80.78	75.03	7.12	16.30	13.37	17.94
18	ICCV 21111	39.64	30.35	23.44	56.33	49.42	12.28	66.73	59.83	10.33	14.67	9.22	37.19
19	Phule G-201216	43.24	34.50	20.22	78.76	73.88	6.20	81.85	75.57	7.68	16.57	13.33	19.52
20	ICC 6636	41.21	30.59	25.77	70.63	52.41	25.80	70.85	59.11	16.57	15.20	9.17	39.67

Table 4 contd ……..

21	ICC 3650	39.80	30.78	22.66	62.73	51.22	18.36	69.13	53.98	21.91	13.17	8.18	37.86
22	ICC 4129	43.00	33.20	22.79	66.70	50.74	23.93	64.86	48.99	24.46	11.26	7.24	35.69
23	ICC 6472	38.73	29.26	24.47	66.98	49.35	26.33	60.67	48.12	20.69	14.31	11.00	23.13
24	ICC 6385	45.59	34.63	24.03	71.90	52.43	27.08	66.62	49.84	25.19	16.31	11.15	31.67
25	ICC 6485	44.49	33.12	25.56	55.88	44.28	20.75	68.46	51.28	25.09	14.24	10.40	26.93
26	ICC 4850	42.31	31.64	25.22	51.97	39.41	24.17	66.94	50.20	25.01	13.97	10.19	27.04
27	ICC 3538	41.51	31.38	24.41	49.96	39.74	20.44	69.41	51.24	26.18	12.34	9.17	25.66
28	ICC 6399	39.73	31.29	21.24	63.73	50.85	20.21	68.52	57.18	16.55	14.20	10.26	27.75
29	ICC 6488	41.35	32.15	22.25	65.82	50.42	23.40	74.70	64.95	13.04	13.32	10.70	19.67
30	ICC 6687	41.72	33.26	20.28	61.16	41.90	31.49	64.05	47.54	25.79	15.59	10.79	30.81
	Mean	43.34	34.22	21.04	69.99	59.25	15.35	72.69	61.93	14.80	14.99	11.31	24.55
	SEm(±)	0.33	0.33		0.33	0.79		2.96	1.64		0.31	0.21	
	CD (5%)	0.98	1.00		0.98	2.37		8.80	4.89		0.94	0.62	

I_1: Irrigated condition, I_0: Rainfed condition, ↓%: Percent reduction, MSI: Membrane stability index, RWC: Relative water content, ROP: Rate of photosynthesis

Table 5. Physiochemical characters in chickpea genotypes evaluated under irrigated and rainfed conditions.

Sr. No.	Traits / Genotypes	Transpiration rate			Proline content		
		I_1	**I_0**	**↓%**	**I_1**	**I_0**	**↓%**
1	BGM-10216	5.87	4.64	20.97	3.33	8.52	155.68
2	JG-11	5.83	4.69	19.66	3.38	7.12	110.86
3	Vijay	6.30	4.47	29.10	3.78	8.61	127.48
4	ICC 4958	5.93	4.73	20.22	4.01	8.37	108.92
5	Phule G-1327-10-12	5.44	3.85	29.18	3.20	7.28	127.14
6	Phule G-1131-4	5.32	4.03	24.26	4.52	9.13	102.05
7	Phule G-1221-2-6	5.30	3.82	27.99	3.20	8.75	173.87
8	Phule G-1424-7-7	5.27	3.83	27.26	3.26	7.43	128.09
9	Phule G-17314	4.31	3.17	26.53	3.38	8.30	145.42

Table 5 contd…..

10	Phule G-16318	5.97	4.85	18.72	3.08	7.89	156.55
11	Phule G-1403-18-14	5.38	4.21	21.64	2.95	6.14	108.08
12	Phule G-1415-13-28	4.89	3.90	20.19	3.26	8.12	148.96
13	Phule G-191304	5.85	4.62	20.97	4.15	9.20	121.87
14	Phule G-1424-4-2	5.38	3.94	26.81	3.47	7.42	113.91
15	Phule G-1314-3-27	5.47	3.83	29.96	3.75	8.45	125.13
16	Phule G-1415-15-15	3.62	2.73	24.42	3.27	8.40	156.62
17	Phule G-1420-13-6	4.53	3.44	23.99	3.18	9.18	188.36
18	ICCV 21111	5.24	3.50	33.25	3.42	7.16	109.32
19	Phule G-201216	5.42	4.34	19.82	3.58	8.52	138.12
20	ICC 6636	4.18	3.17	24.30	3.63	7.71	112.15
21	ICC 3650	5.39	3.43	36.30	3.62	8.12	124.46
22	ICC 4129	4.43	2.90	34.49	3.32	8.08	143.76
23	ICC 6472	5.25	3.31	37.06	3.50	8.60	145.66
24	ICC 6385	4.43	2.79	36.97	3.38	7.52	122.27
25	ICC 6485	4.19	2.90	30.73	2.95	6.87	132.79
26	ICC 4850	5.51	3.47	37.12	3.38	7.59	124.91
27	ICC 3538	5.42	3.67	32.25	3.24	7.64	135.54
28	ICC 6399	4.29	2.87	33.23	3.10	7.70	148.08
29	ICC 6488	5.27	3.81	27.59	3.13	7.07	125.60
30	ICC 6687	5.76	4.66	19.14	4.26	8.63	102.42
	Mean	5.18	3.78	27.03	3.45	7.98	131.30
	SEm(±)	0.09	0.05		0.10	0.15	
	CD (5%)	0.27	0.16		0.30	0.44	

I_1: Irrigated condition, I_0: Rainfed condition