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Morpho-physiological and biochemical analysis for soil moisture stress tolerance in chickpea

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Abstract
Plants experience moisture stress when subjected to temperatures that are higher than their ideal range for growth and development. It is a major environmental element that can have a detrimental influence on plant health and agricultural yield. A field experiment was conducted in the rabi season of 2021-22 under irrigated and moisture stress conditions on medium black soil to study the effect on growth and yield variation in chickpea genotypes and to assess the physiological and biochemical variation in chickpea under soil moisture stress and non-stress conditions.
According to the findings, measures such as relative leaf water content, SPAD index, chlorophyll stability index, membrane injury index, proline concentration, and glycine betaine are the most beneficial when choosing genotypes for drought resistance. Under both circumstances, genotypes (Phule G-1415-15-15), (Phule G-1415-13-20), and (Phule G-1424-7-7) had the maximum grain production per plant and harvest index values.
The genotypes Phule G-1415-15-15, Phule G-1415-13-20, and Phule G-1424-7-7 exhibited higher values of number of secondary branches, relative leaf water content, leaf area, SPAD index, chlorophyll stability index, grain yield, harvest index, drought tolerance efficiency, and lower values of membrane injury index and drought susceptible index, indicating drought tolerance behavior, in the current study. These genotypes can be exploited as a source of drought resistance in future breeding programs to generate drought-tolerant genotypes in chickpea.

Keywords: Crop growth and development, genotype, crop phenology, soil moisture stress, stress tolerance

Introduction

Chickpea (*Cicer arietinum* L.), genus Cicer of the Fabaceae family. Chickpea is one of the most important cool-season food legumes produced on marginal soil by impoverished farmers in the world's semi-arid regions. In these places, it is often cultivated under rainfed circumstances, either on residual soil moisture in subtropical environments with summer-dominant rainfall or on current rainfall in Mediterranean-type habitats with winter-dominant rainfall. Terminal drought induces production reductions in non-irrigated chickpea crops in both situations. It is mostly seeded between October and November and harvested between February and April.

In addition to boosting soil fertility, it is a vital source of proteins for the human population. Chickpea protein content ranges between 15 and 30% (Hulse 1994) [9], depending on variety and environmental conditions (Nleya *et al.* 2000) [18]. It is a cheap and healthy source of protein. It also contains 60-65% carbohydrates, 6% fat, and is high in minerals and B vitamins.

Salinity, cold, and drought are the three most critical abiotic stresses to chickpeas. Drought and soil salinity are the most severe abiotic stresses in chickpea. Moisture stress occurs during one or more developmental phases of the crop, depending on soil water availability. Droughts affect chickpeas in two ways: intermittent drought, in which soil moisture is dependent on precipitation but rainfall is unpredictable and inadequate, and terminal drought, in which soil moisture content continuously drops toward the conclusion of the growth season. As a result, during the vegetative and reproductive development periods, plants are subjected to intermittent and terminal drought stresses. Drought stress occurs when the water supply to the roots is cut off or when the transpiration rate increases dramatically. These two characteristics typically coexist in arid and semi-arid settings.

Aside from dry and semi-arid environments, there are other elements that might induce water stress during crop growth and development, lowering yield. Modifications to pigment concentration, osmotic adjustment, photosynthetic activity, and water usage efficiency are examples of these. These processes are required to prevent membrane breakdown and to provide resistance to cellular dehydration and drought. Drought resistance is associated with high relative water content (RWC) and low excised-leaf water loss, and it has been argued that when compared to other water potential metrics under drought stress, these characteristics are more helpful indicators of plant water status.

Water stress always slows down a number of critical plant activities while also modifying a number of morphological and physiological features to assist a plant survive drought. How drought impacts grain yield is determined by the combined response of morphological and physiological processes such as photosynthesis, leaf area expansion, leaf senescence, and biomass production. It also depends on the timing of the stress throughout the development period, as well as the soil and climatic conditions. A decline in photosynthesis is regarded to be a key yield limiting factor during water stress. Moisture stress during the seed filling stage has been shown to have a significant detrimental influence on chickpea output. According to research, a considerable fall in vegetative biomass or above-ground dry matter during drought circumstances has been associated to a decrease in chickpea grain output. Plants can adapt to a drought-prone environment by adopting evasion, avoidance, or tolerance mechanisms. Increasing crop tolerance to water scarcity is the most cost-effective strategy to boost output while reducing agricultural usage of freshwater resources.

As a result, solutions for increasing agricultural productivity, increasing food availability, and reducing crop loss due by soil moisture stress must be developed. So the "Morpho-Physiological and Biochemical Analysis for Soil Moisture Stress Tolerance in Chickpea" study was undertaken.

Materials and Methods

Chickpea (*Cicer arietinum* L.) is a significant rabi season legume that may be grown in a variety of farming settings. Because of its great nutritional content, it is an essential grain legume. It thrives in receding soil moisture conditions, where soil moisture supply is limited. The experiment was set up in a split plot design with three replications for this study. There were 32 treatment combinations with sixteen genotypes that included two field conditions, I_1 irrigated and I_0 moisture stress. Daily visual observations were used to capture phenological data such as days to bloom initiation, days to 50% flowering, and days to physiological maturity. A portable infrared thermometer (Model OS 530 HR) was used to assess canopy temperature. At 50% blooming, the SPAD index was calculated non-destructively using a SPAD 502 chlorophyll meter (Minolta Corp., Ramsey, NJ, USA). Observations were taken between 12:00 p.m. and 2:00 p.m. After harvesting and threshing each plant independently, the grain yield per plant was determined. The data were analyzed using Panse and Sukhatme's (1985) [19] Factorial Completely Randomized Block Design (FCRD).

Climatic conditions

The Rahuri area is located in the semi-arid tropics (scarcity zone), with short and moderate winters. In different years, rainfall is unpredictable and unevenly spread throughout 15-45 days. Annual rainfall ranges from 307 to 619 mm (average rainfall is 525 mm). Maximum and lowest temperatures are averaged at 32.1 °C and 16.6 °C, respectively. The average relative humidity at 7.30 hours (RH-I) is 72%, while it is 37% at 14.00 hrs (RH-II). The average yearly wind speed is 7.95 km/h. The average number of bright sunlight hours per day was 7.79.

Weather during experimental period (2021-22)

The highest temperature varied from 35.7 to 24.7 °C throughout the crop growing season, while the lowest temperature ranged from 21.1 to 12.1 °C. Mean relative humidity at 7.30 hr (RH-I) ranged from 92.7 to 59.00 percent, while at 4.30 hr (RH-II) ranged from 54.4 to 18.00 percent. The total rainfall obtained during crop growth season 2021-22 was 71.00 mm in the two days preceding planting, followed by no rain throughout crop growth period.

Irrigation: Water stress condition: The crop received no irrigation following a pre-sowing irrigation. Irrigated condition: The crop was irrigated on a regular basis at intervals of 25 to 30 days to retain soil moisture near to field capacity.

Fertilizer application: Total dose of 25 kg N/ha, 50 kg P_2O_5/ha and 30 kg K_2O/ha were given at the time of sowing.

Soil moisture observations: Soil samples were collected at 0-15 cm and 15-30 cm depth. Weight of soil samples before and after drying were taken. Soil samples were dried in hot air oven at 60°C till samples were dried completely.

The percentage of moisture content in the soil was calculated by using the formula.

$$\text{Moisture content (\%)} = \frac{\text{Weight of wet soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Morphological studies

Plant height of five randomly selected plants from each plot was recorded in cm by measuring length from the base of the near the ground up to the growing point of the plant and its mean was calculated at harvesting. Total number of secondary branches at harvesting of 5 plants from each plot and replications were recorded and then the average numbers of secondary branches were computed.

Leaf area was recorded at 50% flowering of selected plants. Average leaf area of selected plants was recorded by using Automatic Leaf Area Meter (Model LIE 3000 A). It measures leaf area in cm^2 which was converted into dm^2.

Days to initiation of flowering: The number of days required for initiation of appearance of first flower bud were recorded from date of sowing.

Days to physiological maturity: The number of days required for complete physiological maturity of pod of each variety were recorded.

Relative leaf water content (RLWC): The relative leaf water content (RLWC) was determined according to the modified method of Barr's and Weatherly (1962) [2] at 50% flowering, and it was expressed in per cent. SPAD chlorophyll meter, SPAD index was estimated non-destructively, using a SPAD-502 chlorophyll meter (Minolta

Corp., Ramsey, NJ, USA) at 50% flowering. Chlorophyll stability index, The chlorophyll stability index was computed by using the method given by Dhopte (2002) [4].
Membrane injury index (MII) was calculated at 50% flowering by the procedure given by Blum and Ebercon (1981) [26].
Canopy temperature depression (CTD), measurements were made using a hand-held infrared thermometer (Model OS 530 HR, Omega Engineering Inc. 42 Stamford CT USA). Leaf Proline Content (µ moles g^{-1} fresh weight) in leaf tissues were determined by using the acid ninhydrin reagent as per the method described by Bates *et al.* (1973) [3] at 50% flowering. Glycine betaine content (µ moles g^{-1} fresh weight) in leaves was determined by using the Dragendorff reagent as per the method described by Stumpf (1984) [22].

Grain yield plant^{-1}: The pods harvested from five observation plants were threshed separately and grain yield was recorded and average was worked out.

Number of pods plant^{-1}: At the time of harvesting pods from five observational plants in each plot were collected separately and mean of pods plant^{-1} was worked out and noted.

Harvest index (%) was calculated by using the formula given by Donald (1962) [5] and expressed as per cent.

Drought tolerance efficiency (DTE): Drought tolerance efficiency was calculated as per the formula suggested by Fischer and Wood (1979) [6].

Drought susceptibility index (DSI): The drought susceptibility index was calculated by using formula suggested by Fischer and Maurer (1978) [7].

Results and Discussion

Morphological studies

Plant height (cm) at 90 DAS: The plant height at 90 DAS was considerably decreased under moisture stress condition. Under irrigated condition the plant height ranged from 35.67 to 68.13 (cm), while under moisture stress condition it was ranged from 30.47 to 61.80 (cm). The genotype Phule G-1415-13-20 (68.13, 61.80 and 64.97 cm) recorded significantly highest plant height at 90 DAS under irrigated and moisture stress condition and highest mean among the genotypes, respectively. The genotype TRCH-2 (35.67 cm) and the genotype TRCH-4 (30.47 cm) recorded lowest plant height at 90 DAS under irrigated and moisture stress condition respectively. The height of the plant represents the vegetative stage and perform a specific function of the plant. Due to insufficient moisture content in the field, cell division and cell enlargement in the plant were decreased that's why plant height was reduced under moisture stress. These results are similar to the Shinde *et al.* (2010) [21].

Number of secondary branches at harvesting: From the Table No. 1 it was observed that there were significant differences among the genotypes, field conditions and its interaction effect for number of secondary branches at harvesting.
Number of secondary branches at harvesting significantly decreased under moisture stress condition. Considering mean of all genotypes, Phule G-1424-7-7 (14.72) recorded highest number of secondary branches at harvesting followed by the genotype Phule G-1415-15-15 (13.72). Under irrigated condition highest number of branches at harvesting was recorded in the genotype Phule G-1424-7-7 (17.43) and it was lowest in the genotype Phule G-1403-18-14 (12.30). Number of secondary branches under moisture stress condition was ranged from 8.47 to 12.00, genotype Phule G-1424-7-7 (12.00) showed significantly highest number of secondary branches at harvesting which was at par with Phule G-1415-15-15 (11.10), Phule G-1424-4-2 (10.87), Phule G-1412-19-3 (10.87), Vishwaraj (10.57) and Phule G-1415-13-20 (10.43) and the genotype TRCH-4 (8.47) recorded lowest number of secondary branches.
However, it was noticed that there were more secondary branches under irrigated conditions than under moisture stress conditions, which also led to a higher grain yield. More number of branches resulted in more pods and seeds per plant, which in turn increased yield. These findings are similar to the Mathur *et al.* (2005) [16].

Leaf area at 50% flowering: The data depicted in Table No. 1. showed significant differences among the genotypes and field conditions and its interaction effect also significant for leaf area at 50% flowering. The mean leaf area at 50% flowering among the genotypes was higher in genotype Phule G-1424-7-7 (6.28 dm^2) and lower in the genotype TRCH-4 (3.67 dm^2). Leaf area at 50% flowering ranged from 4.26 to 7.46 dm^2 and 3.08 to 5.26 dm^2, under irrigated and moisture stress conditions, respectively.
Under irrigated condition genotype Phule G-1424-7-7 (7.46 dm^2) recorded maximum leaf area and it was minimum in the genotype TRCH-2 (4.26 dm^2) at 50% flowering. Leaf area at 50% flowering was significantly highest in the genotype Phule G-1415-13-20 (5.26 dm^2) except the genotypes Phule G-1424-7-7 (5.11 dm^2), Phule G-1415-15-15 (5.05 dm^2), Phule G-201216 (4.95 dm^2) and Phule G-1403-18-14 (4.77 dm^2) and the genotype TRCH-2 (3.08 dm^2) showed lowest under moisture stress condition. The observations recorded are in agreement with the findings of Rahman *et al.* (2000) [20].

Phenological studies

Days to initiation of flowering: Phenology is the study of relationship between climatic factors and periodic phenomenon in organism. Patterns of phenological events is variously used for characterization of vegetation type.
In case of days to initiation of flowering, differences were statistically significant in field conditions and genotypes while it was non-significant for interaction effect between them (Table No. 1).
Among the genotypes, Phule G-1412-19-3 (48.83) showed highest mean number of days to flower initiation. Under irrigated condition genotype Phule G-1412-19-3 (52.33) recorded late flower initiation and genotype TRCH-4 (35.67) showed earlier flower initiation. Days to initiation of flowering was comparatively earlier under moisture stress condition than the irrigated condition and the genotype TRCH-2 (32) and the genotype Phule G-1403-18-14 (45.67) showed early and late flower initiation under moisture stress condition, respectively. Under moisture stress condition days to initiation of flowering was less than the irrigated condition, these results was similar to the findings of Malhotra and Saxena (2002) [15].

Days to physiological maturity: The data pertaining to effect of field conditions on days to physiological maturity was statistically significant in the genotypes while it showed non-significant among interaction between them (Table No. 2).

All the genotypes under moisture stress condition mature earlier than the irrigated condition. Genotype TRCH-2 (95 and 89.33) mature earlier than the other genotypes under irrigated moisture stress condition, respectively. While genotype Phule G-1412-19-3 (109.33 and 102.67) recorded highest number of days to maturity under irrigated and moisture stress conditions, respectively. However, among the genotypes, mean days to physiological maturity was lower in the genotype TRCH-2 (92.17) and higher in the genotype Phule G-1412-19-3 (106.00).

Days to physiological maturity are the key phenological characters that influence crop performance, especially under moisture stress condition, therefore these parameters are important while breeding drought-tolerant chickpea cultivars. In the present study it was observed that the early flowering genotypes mature earlier and these results are similar to the Krishnamurthy *et al.* (2011) [13].

Relative leaf water content (%): The differences in relative leaf water content at 50% flowering due to field conditions and genotypes and interaction among them were statistically significant (Table No. 2).

Considering the mean relative leaf water content among the genotypes, it was significantly highest in the genotype Phule G-1424-7-7 (63.99%) and lowest in the genotype TRCH-2 (47.51%). Under irrigated condition relative leaf water content ranged from 50.15 to 68.24 (%) and it was highest in the genotype Phule G-1424-7-7 (68.24%) and lowest in the genotype TRCH-2 (50.15%). However, under moisture stress condition the genotype Phule G-1415-15-15 (61.09%) recorded significantly highest relative leaf water content except the genotype Phule G-1424-7-7 (59.75%) and it was lowest in the genotype Phule G-1403-18-8 (44.06%).

Water is an important biomolecule that plays a key role in the basic life process of plant like photosynthesis. Chickpea crop respond to water deficit in the form of changes in various biochemical and physiological processes. Genotype Phule G-1424-7-7 maintained highest relative leaf water content while lowest by Phule G-1403-18-8. Relative leaf water content is very important as retention of water in the leaf under moisture stress condition is a major indication of drought tolerance. Similar results were reported by Talebi *et al.* (2013) [23].

SPAD index (%) at 50% flowering: The data on SPAD index presented in the Table No. 2 showed significant differences among the genotypes and field conditions and its interaction effect was non-significant.

In case of SPAD index, under irrigated condition it was significantly higher than moisture stress condition. Mean of SPAD index among the genotypes ranged from 40.49 to 57.18 and genotype Phule G-1415-15-15 (57.18%) showed its highest value, and it was least in the genotype Phule G-1415-13-28 (40.49%). The genotype Phule G-1415-15-15 (60.45%) showed the highest SPAD index at 50% flowering and it was the lowest in the genotype Phule G-1415-13-28 (43.07%) under irrigated condition. Under rainfed condition SPAD index was higher in the genotype Phule G-1415-13-20 (54.58%), while it was lowest in the genotype Phule G-1403-18-14 (37.16%).

In the present study moisture stress significantly decreases SPAD index and these findings were similar to the Jangpromma *et al.* (2010) [11].

Chlorophyll stability index: In the present study differences in chlorophyll stability index at 50% flowering due to field conditions and genotypes were statistically significant, while it was non-significant among interaction between the field conditions and genotypes.

The chlorophyll stability index considerably decreased under moisture stress condition. Mean chlorophyll stability index among the genotypes ranged from the 0.248 to 0.370 and genotype Phule G-1415-13-20 (0.370) recorded its higher value. Under irrigated condition chlorophyll stability index was higher in the genotype Phule G-1415-13-20 (0.426) while lower in the genotype TRCH-2 (0.286). Under moisture stress condition genotype Phule G-1424-7-7 (0.316) showed significantly highest chlorophyll stability index at 50% flowering except the genotype Phule G-1415-13-20 (0.313), Phule G-1415-15-15 (0.308), Phule G-1424-4-2 (0.298) and Phule G-14448-1 (0.296) and it was lowest in the genotype TRCH-2 (0.209).

The green plant pigments are thermosensitive, and their degradation occurs when subjected to higher temperature. Genotype Phule G-1415-13-20 recorded highest, and TRCH-2 recorded lowest chlorophyll stability index. Similar findings were reported by Dhopte (2002) [4] indicating that chlorophyll stability index was found to be inversely related with drought tolerance efficiency.

Membrane injury index: From the data it was observed that membrane injury index at 50% flowering influenced by chickpea genotype under irrigated and moisture stress condition were statistically significant among the field conditions, genotypes and interaction between them (Table No. 3).

Mean of membrane injury index among the genotypes ranged from 0.214 to 0.442. Under irrigated condition membrane injury index ranged from 0.154 to 0.393 and the genotype Phule G-1415-13-20 (0.154) recorded significantly lowest membrane injury index at 50% flowering. Under moisture stress condition genotype Phule G-1415-15-15 (0.269) showed significantly lowest membrane injury index while it was highest in the genotype Phule G-201107 (0.491). Gupta *et al.* (2000) [8] reported that drought tolerant genotypes have lower membrane injury index as compared to other genotypes.

Canopy temperature depression: In the present investigation, differences in canopy temperature depression at 50% flowering due to field conditions, genotypes and their interaction were statistically significant (Table No. 3).

The genotype Phule G-1424-7-7 (-0.73 °C) showed highest mean canopy temperature depression among the genotypes at 50% flowering. Under irrigated condition higher canopy temperature depression was observed and which ranged from (-0.54 to -1.33 °C), whereas under moisture stress condition it ranged from (-0.92 to -1.70 °C) and genotype Phule G-1424-7-7 (-0.92 °C) recorded significantly highest canopy temperature depression except the genotype Phule G-1415-13-20 (-1.08 °C) and it was lowest in genotype TRCH-4 (-1.70 °C).

From the above results it was clear that drought tolerant genotypes exhibit higher canopy temperature depression, and which are similar to the findings of Krishnamurthy *et al.* (2015) [14] who reported that canopy temperature depression can be used as rapid tool to select stable and high yielding bread wheat genotypes under heat stress conditions in the field.

Proline content (µ moles g^{-1} fresh weight): The differences in the proline accumulation due to field conditions and genotypes and interaction among them were statistically significant at 50% flowering.

Proline accumulation among the genotypes ranged from 6.21 to 9.73 (µ moles g^{-1} fresh weight) and genotype Phule G-1415-15-15 (9.73 µ moles g^{-1} fresh weight) recorded highest proline content at 50% flowering. Under irrigated condition the genotype Phule G-1403-18-8 (6.53 µ moles g^{-1} fresh weight) recorded highest proline content while, it was lowest in the genotype Phule G-1412-19-3 (4.31 µ moles g^{-1} fresh weight). Under moisture stress condition genotype Phule G-1415-15-15 (14.27 µ moles g^{-1} fresh weight) recorded significantly highest proline content while, lowest by the genotype Phule G-201216 (8.35 µ moles g^{-1} fresh weight).

Genotype Phule G-1415-15-15 (174.03%) recorded maximum% increase in proline content and it was minimum in the genotype Phule G-1403-18-8 (44.57%).

Proline helps in osmotic adjustment, increases the concentration of cell protoplasm to maintain normal membrane function under moisture stress and increases plant adaptability. Proline can be promising signaling molecules to tackle moisture stress in plants. These findings were matched to the Kaushal *et al.* (2011) [12]. Who reported that proline accumulation was more under moisture stress condition and proline induce drought tolerance in chickpea plants by protecting vital enzymes of carbon and anti-oxidative metabolism.

Glycine betaine content (µ moles g^{-1} fresh weight): It was noticed that differences ware statistically significant due to field conditions, genotypes and interaction among them (Table No. 3).

Mean glycine betaine content at 50% flowering among the genotypes was highest in the genotype Phule G-1415-13-20 (9.97 µ moles g^{-1} fresh weight) and lower in the Phule G-201107 (7.02 µ moles g^{-1} fresh weight). Value of glycine betaine content was lower under irrigated condition and ranged from 5.58 to 7.41 (µ moles g^{-1} fresh weight). Under moisture stress condition the genotype Phule G-1415-13-20 (12.30 µ moles g^{-1} fresh weight) showed significantly highest glycine betaine at 50% flowering except the genotype Phule G-1415-15-15 (12.22 µ moles g^{-1} fresh weight) and it was significantly lowest in the genotype Phule G-1403-18-8 (7.52 µ moles g^{-1} fresh weight).

The% increase in glycine betaine content was maximum in the genotype Phule G-1415-15-15 (64.91%) and minimum in the genotype Phule G-1403-18-8 (26.98%).

Results showed that glycine betaine content under moisture stress condition was more than the irrigated condition. These results were similar to the Wu *et al.* (2014) [25].

Post harvest studies

Grain yield per plant (g): The data pertaining to effect of field conditions and genotypes on grain yield per plant were statistically significant and interaction among them was also significant (Table No. 4).

Grain yield per plant was significantly reduced under moisture stress condition. Among the genotypes, Phule G-1415-15-15 (14.93 g) showed highest mean grain yield per plant. Under irrigated condition all the genotypes recorded higher grain yield per plant than moisture stress condition. Genotype Phule G-1415-15-15 (15.96 and 13.89) recorded significantly highest grain yield per plant under irrigated and moisture conditions, respectively and genotype Phule G-1403-18-8 (7.89 and 6.13 g) recorded lowest grain yield per plant under irrigated and moisture conditions, respectively. The genotype Phule G-1415-15-15 (12.96%, 0.60 and 87.03) showed less% reduction, drought susceptibility index and higher drought tolerance efficiency, respectively and the genotype Phule G-1415-13-28 (26.08%, 1.20 and 73.91) showed higher% reduction, drought susceptibility index and lower drought tolerance efficiency, respectively. Genotypes Phule G-1415-15-15, Phule G-1415-13-20 and Phule G-1424-7-7 recorded highest yield and this is due to the production of higher number of pods per plant which was supported by the greater number of secondary branches per plant. The results of present study were in agreement with the result of Islam *et al.* (2008) [10].

Number of pods per plant: From the data it was observed that differences due to filed conditions and genotypes and their interaction effect were statistically significant (Table No. 4).

Number of pods per plant significantly reduced under moisture stress condition. The genotype Vishwaraj (62.55) significantly showed highest mean number of pods per plant, and it was lowest in the genotype TRCH-4 (30.17). The genotype Vishwaraj (68.43 and 56.67) showed highest number of pods per plant under irrigated and moisture stress conditions, respectively. The genotype TRCH-4 (35.00 and 25.33) recorded lowest number of pods per plant under irrigated and moisture stress conditions, respectively.

It was observed that the genotype Phule G-1448-1 (29.11%, 1.55 and 70.88) showed higher% reduction, drought susceptibility index and lower drought tolerance efficiency, respectively. The genotype Phule G-1415-13-20 (11.74%, 0.62 and 88.25) showed less% reduction, drought susceptibility index and higher drought tolerance efficiency, respectively. These results were similar to the Nagar *et al.* (2013) [17].

Harvest index (%)

Differences on harvest index due to field conditions and genotypes were statistically significant and interaction effect also statistically significant (Table No. 5).

Harvest index among the genotypes ranged from the 27.03 to 38.66 (%). Genotype Phule G-1415-15-15 (40.15 and 37.17%) recorded significantly highest harvest index and genotype Phule G-1403-18-8 (28.21 and 25.84%) recorded its lowest value under irrigated and moisture stress conditions, respectively.

The genotype Vishwaraj (4.37%, 0.50 and 95.62) recorded lowest% reduction, drought susceptibility index and highest drought tolerance efficiency and genotype Phule G-1424-4-2 (19.28%, 2.24 and 80.71) recorded highest% reduction, drought susceptibility index and lowest drought tolerance efficiency, respectively. These results were matched with Thomas *et al.* (2010) [24].

Table 1: Morphological Parameters influenced by irrigated and moisture stress condition in chickpea genotypes

		Plant Height @ 90 DAS			Number of secondary branches at harvesting			Leaf area (dm^2) at 50% flowering			Days to initiation of flowering		
Sr. No.	Genotype	I_1	I_0	Mean	I_1	I_0	Mean	I_1	I_0	Mean	I_1	I_0	Mean
1	Phule G-201216	61.67	55.67	58.67	13.33	9.90	11.62	6.09	4.95	5.52	41.33	37.00	39.17
2	Phule G-1424-4-2	65.00	59.73	62.37	15.67	10.87	13.27	6.98	4.25	5.62	49.67	44.67	47.17
3	Phule G-201107	59.93	53.73	56.83	13.77	9.67	11.72	6.19	4.39	5.29	46.33	41.00	43.67
4	Phule G-1403-18-14	55.80	50.67	53.23	12.30	9.13	10.72	6.60	4.77	5.69	51.33	45.67	48.50
5	Phule G-1403-18-8	52.67	46.27	49.47	13.33	9.67	11.50	5.82	3.97	4.90	48.67	44.00	46.33
6	Phule G-1412-19-3	60.07	54.07	57.07	12.77	10.87	11.82	5.77	4.02	4.89	52.33	45.33	48.83
7	TRCH-2	35.67	30.80	33.23	12.47	8.90	10.68	4.26	3.08	3.67	35.67	32.00	33.83
8	Phule G-1415-13-28	60.07	53.73	56.90	14.03	8.90	11.47	5.91	4.51	5.21	49.67	44.67	47.17
9	Phule G-1415-13-20	68.13	61.80	64.97	14.33	10.43	12.38	7.11	5.26	6.18	40.33	35.67	38.00
10	Phule G-1424-7-7	67.27	60.67	63.87	17.43	12.00	14.72	7.46	5.11	6.28	42.00	37.33	39.67
11	Phule G-1415-15-15	61.47	54.93	58.20	16.33	11.10	13.72	6.57	5.05	5.81	41.33	37.00	39.17
12	Phule G-1420-13-6	55.00	48.00	51.50	12.90	9.47	11.18	4.67	3.72	4.19	43.00	37.67	40.33
13	TRCH-4	36.60	30.47	33.53	12.43	8.47	10.45	4.32	3.12	3.72	36.67	32.67	34.67
14	Phule G-1448-1	51.33	44.80	48.07	13.20	9.00	11.10	6.52	4.15	5.34	50.67	45.00	47.83
15	Vijay	41.00	35.00	38.00	13.10	8.57	10.83	6.61	3.67	5.14	40.00	36.33	38.17
16	Vishwaraj	40.47	35.40	37.93	16.67	10.57	13.62	6.25	4.19	5.22	39.33	35.33	37.33
	Mean	54.51	48.47	51.49	14.00	9.84	11.92	6.07	4.26	5.17	44.27	39.46	41.86
		S.E.(m) ±		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**
	Conditions (I)	0.50		1.44	0.08		0.23	0.05		0.14	0.09		0.25
	Genotype (G)	1.05		2.97	0.42		1.19	0.16		0.47	0.47		1.34
	Interaction (I x G)	1.48		NS	0.59		1.69	0.23		0.67	0.67		NS

Table 2: Physiological Parameters influenced by irrigated and moisture stress condition in chickpea genotypes

		Days to physiological maturity			Relative leaf water content			SPAD index (%)			Chlorophyll stability index		
Sr. No.	Genotype	I_1	I_0	Mean	I_1	I_0	Mean	I_1	I_0	Mean	I_1	I_0	Mean
1	Phule G-201216	101.00	94.33	97.67	54.38	48.72	51.55	51.54	43.15	47.35	0.376	0.289	0.333
2	Phule G-1424-4-2	107.33	99.33	103.33	62.78	57.52	60.15	56.21	48.90	52.56	0.361	0.298	0.329
3	Phule G-201107	106.00	97.00	101.50	53.37	46.08	49.72	49.39	41.41	45.40	0.339	0.252	0.296
4	Phule G-1403-18-14	108.33	101.00	104.67	55.37	47.67	51.52	45.23	37.16	41.20	0.298	0.219	0.258
5	Phule G-1403-18-8	106.67	99.33	103.00	51.00	44.06	47.53	52.13	44.09	48.11	0.311	0.263	0.287
6	Phule G-1412-19-3	109.33	102.67	106.00	59.03	51.23	55.13	55.33	47.99	51.66	0.341	0.283	0.312
7	TRCH-2	95.00	89.33	92.17	50.15	44.87	47.51	48.79	43.13	45.96	0.286	0.209	0.248
8	Phule G-1415-13-28	108.00	101.33	104.67	57.06	51.18	54.12	43.07	37.90	40.49	0.312	0.246	0.279
9	Phule G-1415-13-20	100.33	93.67	97.00	60.52	55.29	57.90	59.26	54.58	56.92	0.426	0.313	0.370
10	Phule G-1424-7-7	101.67	94.67	98.17	68.24	59.75	63.99	55.69	48.07	51.88	0.391	0.316	0.353
11	Phule G-1415-15-15	100.67	94.00	97.33	64.97	61.09	63.03	60.45	53.92	57.18	0.393	0.308	0.350
12	Phule G-1420-13-6	103.00	96.33	99.67	59.70	53.69	56.69	52.39	46.73	49.56	0.307	0.254	0.280
13	TRCH-4	96.00	89.67	92.83	54.72	46.03	50.38	48.21	40.91	44.56	0.346	0.278	0.312
14	Phule G-1448-1	108.33	99.33	103.83	53.04	49.91	51.48	53.14	45.70	49.42	0.329	0.296	0.313
15	Vijay	100.00	93.33	96.67	59.73	53.88	56.81	55.20	51.08	53.14	0.357	0.239	0.298
16	Vishwaraj	99.33	92.67	96.00	56.97	50.44	53.70	52.04	44.19	48.12	0.330	0.226	0.278
	Mean	103.19	96.13	99.66	57.56	51.33	54.45	52.38	45.56	48.97	0.344	0.268	0.306
		S.E.(m) ±		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**	**S.E.(m) ±**		**CD @ 5%**
	Conditions (I)	0.37		1.14	0.13		0.38	0.17		0.50	0.002		0.006
	Genotype (G)	0.86		2.45	0.36		1.04	0.60		1.71	0.005		0.016
	Interaction (I x G)	1.22		NS	0.52		1.47	0.85		NS	0.008		0.023

Table 3: Physiological and Biochemical Parameters influenced by irrigated and moisture stress condition in chickpea genotypes

		Membrane injury index			Canopy temperature depression (°C)			Proline content (µ moles g^{-1} fresh weight)				Glycine betaine (µ moles g^{-1} fresh weight)			
Sr. No.	Genotype	I_1	I_0	Mean	I_1	I_0	Mean	I_1	I_0	Mean	% Increase	I_1	I_0	Mean	% Increase
1	Phule G-201216	0.382	0.425	0.403	-1.12	-1.54	-1.33	4.07	8.35	6.21	103.19	6.19	8.38	7.29	35.14
2	Phule G-1424-4-2	0.204	0.319	0.262	-0.89	-1.24	-1.07	5.29	10.88	8.09	105.24	7.17	10.99	9.08	53.03
3	Phule G-201107	0.393	0.491	0.442	-1.05	-1.37	-1.21	4.57	9.39	6.98	105.37	5.88	8.17	7.02	38.42
4	Phule G-1403-18-14	0.264	0.429	0.346	-1.18	-1.49	-1.33	6.17	11.08	8.63	79.09	7.48	9.84	8.66	31.25
5	Phule G-1403-18-8	0.283	0.379	0.331	-1.25	-1.52	-1.39	6.53	9.46	8.00	44.57	5.91	7.52	6.71	26.98
6	Phule G-1412-19-3	0.212	0.425	0319	-1.09	-1.40	-1.24	4.31	10.27	7.29	137.96	5.58	8.51	7.05	52.23
7	TRCH-2	0.198	0.326	0.262	-1.33	-1.63	-1.48	5.46	11.68	8.57	113.62	7.15	10.54	8.84	47.29
8	Phule G-1415-13-28	0.253	0.407	0.330	-1.24	-1.56	-1.40	4.98	12.72	8.85	155.29	6.99	10.71	8.85	52.94
9	Phule G-1415-13-20	0.154	0.314	0.234	-0.70	-1.08	-0.89	5.00	13.49	9.24	169.53	7.63	12.30	9.97	61.20
10	Phule G-1424-7-7	0.192	0.322	0.257	-0.54	-0.92	-0.73	4.91	12.67	8.89	157.85	7.14	11.20	9.17	56.20
11	Phule G-1415-15-15	0.159	0.269	0.214	-0.92	-1.25	-1.08	5.19	14.27	9.73	174.03	7.41	12.22	9.81	64.91
12	Phule G-1420-13-6	0.187	0.362	0.275	-1.05	-1.39	-1.22	6.02	9.92	7.97	64.30	6.12	8.77	7.45	43.30
13	TRCH-4	0.243	0.354	0.299	-1.31	-1.70	-1.51	5.22	11.41	8.32	117.86	6.17	9.04	7.60	46.11
14	Phule G-1448-1	0.302	0.422	0.362	-1.28	-1.62	-1.45	5.42	12.15	8.79	122.68	7.54	10.45	9.00	38.59
15	Vijay	0.193	0.369	0.281	-1.09	-1.40	-1.24	5.75	12.33	9.04	113.39	6.36	8.81	7.58	38.25
16	Vishwaraj	0.266	0.351	0.309	-1.04	-1.47	-1.25	6.05	11.58	8.82	91.12	7.48	11.15	9.32	48.61
	Mean	0.243	0.373	0.308	-1.07	-1.41	-1.24	5.31	11.35	8.33	115.93	6.76	9.91	8.38	45.90
		S.E.(m) ±	**CD @ 5%**		**S.E.(m) ±**	**CD @ 5%**		**S.E.(m) ±**		**CD @ 5%**		**S.E.(m) ±**		**CD @ 5%**	
	Conditions (I)	0.003	0.010		0.02	0.06		0.08		0.24		0.03		0.10	
	Genotype (G)	0.007	0.019		0.04	0.13		0.16		0.45		0.10		0.31	
	Interaction (I x G)	0.010	0.028		0.06	0.18		0.23		0.64		0.15		0.43	

Table 4: Yield and Number of pods per plant influenced by irrigated and moisture stress condition in chickpea genotypes

		Yield per plant (g)						Number of pods per plant					
Sr. No.	Genotype	I_1	I_0	Mean	%Reduction	DSI	DTE	I_1	I_0	Mean	%Reduction	DSI	DTE
1	Phule G-201216	9.87	7.81	8.84	20.87	0.96	79.12	54.57	42.80	48.68	21.56	1.14	78.43
2	Phule G-1424-4-2	13.43	10.91	12.17	18.76	0.86	81.23	59.13	49.00	54.07	17.13	0.91	82.86
3	Phule G-201107	10.24	7.67	8.95	25.09	1.15	74.90	51.70	41.23	46.47	20.25	1.07	79.74
4	Phule G-1403-18-14	11.13	8.31	9.72	25.33	1.17	74.66	47.67	38.33	43.00	19.59	1.04	80.40
5	Phule G-1403-18-8	7.89	6.13	7.01	22.30	1.03	77.69	35.80	29.90	32.85	16.48	0.87	83.52
6	Phule G-1412-19-3	11.76	9.53	10.65	18.96	0.87	81.03	51.87	43.67	47.77	15.80	0.84	84.19
7	TRCH-2	10.31	7.69	9.00	25.41	1.17	74.58	47.70	41.33	44.52	13.35	0.71	86.64
8	Phule G-1415-13-28	12.23	9.04	10.64	26.08	1.20	73.91	51.00	40.80	45.90	20.00	1.06	80.00
9	Phule G-1415-13-20	14.49	12.19	13.34	15.87	0.73	84.12	58.43	51.57	55.00	11.74	0.62	88.25
10	Phule G-1424-7-7	13.86	11.25	12.55	18.83	0.87	81.16	66.13	54.32	60.22	17.85	0.95	82.14
11	Phule G-1415-15-15	15.96	13.89	14.93	12.96	0.60	87.03	62.77	51.13	56.95	18.54	0.98	81.45
12	Phule G-1420-13-6	10.27	7.72	8.99	24.82	1.14	75.17	50.91	39.33	45.12	22.74	1.21	77.25
13	TRCH-4	8.01	6.32	7.17	21.09	0.97	78.90	35.00	25.33	30.17	27.62	1.47	72.37
14	Phule G-1448-1	13.39	10.17	11.78	24.04	1.11	75.95	56.43	40.00	48.22	29.11	1.55	70.88
15	Vijay	13.24	9.95	11.0	24.84	1.15	75.15	64.87	51.47	58.17	20.65	1.10	79.35
16	Vishwaraj	12.49	9.27	10.88	25.78	1.19	74.21	68.43	56.67	62.55	17.18	0.91	82.81
	Mean	11.79	9.24	10.51	21.93	1.01	78.05	53.54	43.49	48.51	19.52	1.02	81.39
		S.E.(m) ±			**CD @ 5%**			**S.E.(m) ±**				**CD @ 5%**	
	Conditions (I)	0.06			0.19			0.12				0.34	
	Genotype (G)	0.14			0.40			1.06				3.02	
	Interaction (I x G)	0.20			0.56			1.51				4.27	

Table 5: Harvest Index influenced by irrigated and moisture stress condition in chickpea genotypes

		Harvest index (%)					
Sr. No.	**Genotype**	**I_1**	**I_0**	**Mean**	**% Reduction**	**DSI**	**DTE**
1	Phule G-201216	30.26	27.76	29.01	8.26	0.96	91.73
2	Phule G-1424-4-2	36.51	29.47	32.99	19.28	2.24	80.71
3	Phule G-201107	32.00	29.22	30.61	8.68	1.01	91.31
4	Phule G-1403-18-14	34.15	31.29	32.72	8.37	0.97	91.62
5	Phule G-1403-18-8	28.21	25.84	27.03	8.40	0.97	91.59
6	Phule G-1412-19-3	35.27	32.51	33.89	7.82	0.91	92.17
7	TRCH-2	33.56	30.32	31.94	9.65	1.12	90.34
8	Phule G-1415-13-28	34.77	31.76	33.27	8.64	1.00	91.34
9	Phule G-1415-13-20	38.02	35.59	36.81	6.39	0.74	93.60
10	Phule G-1424-7-7	37.08	34.84	35.96	6.04	0.70	93.95
11	Phule G-1415-15-15	40.15	37.17	38.66	7.42	0.86	92.57
12	Phule G-1420-13-6	32.88	29.98	31.43	8.81	1.02	91.18
13	TRCH-4	31.70	27.89	29.80	12.01	1.39	87.98
14	Phule G-1448-1	36.14	33.77	34.96	6.55	0.76	93.44
15	Vijay	36.55	33.52	35.04	8.29	0.96	91.70
16	Vishwaraj	35.39	33.84	34.62	4.37	0.50	95.62
	Mean	34.54	31.55	33.04	8.65	1.01	91.34
		S.E.(m) ±			**CD @ 5%**		
	Conditions (I)	0.05			0.15		
	Genotype (G)	0.15			0.42		
	Interaction (I x G)	0.21			0.59		

Conclusion

The field screening of chickpea genotypes by exposing them to moisture stress differentiated their moisture stress potential in various morpho-physiological parameters like secondary branches, relative leaf water content, SPAD index, chlorophyll stability index, membrane injury index and canopy temperature depression.

The accumulation of osmoprotectant *viz*, proline and glycine betaine under moisture stress should be considered for screening as well as selecting the available genotypes in breeding for moisture stress tolerance.

The number of pods per plant, harvest index and seed index contributing grain yield in chickpea were higher under normal condition compared to moisture stress. The genotypes Phule G-1415-15-15, Phule G-1415-13-20 and Phule G-1424-7-7 maintains minimum percent reduction in these character under field moisture stress condition.

In the present investigation, the screening of genotypes, moisture stress condition showed that the genotypes *viz*, Phule G-1415-15-15, Phule G-1415-13-20 and Phule G-1424-7-7 performed best as evident of less reduction in grain yield per plant. Therefore, in chickpea improvement programme these genotypes may be used as a new source of drought tolerance.

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