**Morpho-Physiological Characterization and Yield Performance of Chickpea Genotypes Under Moisture Stress Conditions**

# Abstract

The present study was conducted at the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.) to evaluate twelve chickpea genotypes under normal and late sown conditions. The objective was to analyze their morpho-physiological traits and yield performance under moisture stress and non-stress environments. A split plot complete block design was used for evaluating seed yield, morphological traits, and physiological responses. Results revealed that moisture stress significantly reduced plant height, days to maturity, reproductive duration, and pod number, while relative water content and test weight remained largely unaffected. Genotypes K-850, ICC 4958, and IC-305536 showed superior drought tolerance and yield under stress, making them promising candidates for cultivation in drought-prone and delayed sowing regions.

**Keywords:** Chickpea, drought stress, genotype evaluation, morpho-physiological traits, yield components, late sowing.

# Introduction

“Cicer arietinum L., is popularly known as chickpea, the third most important grain legume in the world after dry beans and dry peas, that brings about a formidable solution to the alarming problems of protein scarcity of the world. Globally, chickpea is cultivated on about 10.4 m ha adding 8.04 m tonnes of seeds to the global food basket with an average productivity of 773 kg/ha. India predominates the global chickpea supply, as it has the distinction of being the largest producer and consumer in the world and accounts for over 66 per cent of the global output. India grows chickpea on about 6.86 m ha, producing 5.35 m tonnes of grains, representing 32 and 42 per cent of the national pulse acreage and production, respectively with productivity of 780 kg/ha. Though Indian average productivity is on par with world’s average productivity, it is less compared to the other countries, like North and Central America (1211 kg/ha) and Canada (1368 kg/ha). Most of the promising chickpea tested in the national network have shown potential yield of 2000 to 2500 kg/ha; whereas, the national average still languishes at 750 to 850 kg/ha. Karnataka grows chickpea on about 319 lakh ha producing 181 lakh tonnes with a productivity of 512 kg/ha, constituting one among the lowest producing states in the country” (Masood Ali and Shivkumar, 2001). The major factors contributing to low yield in the state are the short period available for the crop growth and incidence of terminal drought accompanied with other biotic stresses. Although, the progress towards alleviating biotic stresses affecting chickpea productivity has been satisfactory, the work on abiotic stresses needs immediate attention. The most important abiotic stress is the drought, which severely affect the productivity of chickpea under rainfed production system.

The moisture stress affects almost all biophysical and biochemical process, the crop growth and the final yield. The irrigation is not the only answer to the problem. However, despite many decades of research, drought continues to be a major challenge to agricultural scientists due to unpredictability of its occurrence, severity, timing and duration and coupled with other abiotic stresses, particularly high temperature, variation in nutrient availability and biotic stresses. Inspite of plant’s genetic make up and optimum population, breeding has not been as effective on different agronomic parameters of the crop under drought stress conditions as it has in their absence. Moreover, breeding for drought resistance is very frustrating. To quote Arnon (1980), “Breeding for drought resistance has been a consistent theme for as long as I remember and probably the greatest source of wasted breeding efforts in the whole field of plant breeding. The physiological processes also set a limit on yield. Many techniques give quantitative estimation of morphological changes that takes place during the growth of crop and provides some insight in to the physiological variation in yield caused either genetically or by environment. Several approaches can be adapted to maintain or increase productivity under moisture stress condition. Any method or criteria used for selection, needs to be more thoroughly evaluated and carefully monitored before suggesting it for drought tolerance breeding”.

Chickpea (Cicer arietinum L.) is a crucial pulse crop known for its adaptability to arid and semi-arid environments. However, it is highly sensitive to drought, particularly during flowering and pod development. With the increasing incidence of climate variability and moisture stress, identifying drought-tolerant genotypes has become imperative. This study was undertaken to evaluate selected genotypes under simulated field conditions to identify drought-tolerant traits and assess genetic variability.

# Materials and Methods

The experiment was conducted at Organic Research Farm, Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.) during 2024- 2025 using twelve chickpea genotypes under two sowing dates: normal (14 Nov 2024) and late (11 Dec 2024). Two main treatments—moisture stress and non-stress—were applied. The experimental layout followed a split plot design with three replications. Standard agronomic practices were followed for crop cultivation. Five plants per genotype per replication and treatment were randomly selected to record various observations.

**2.1.1 Morpho-physiological Traits**

**Plant height (cm):** Measured from ground level to the tip of the longest branch at **physiological** maturity.

**Days to first flowering**: Days from sowing to first flower opening.

**Days to maturity:** Days from sowing to physiological maturity based on yellowing of pods and leaves.

**Reproductive duration**: Days from first flowering to maturity.

**Leaf length (cm):** Measured from the sixth leaf from the top of the primary branch.

**Leaflet length and width (cm):** Taken from the sixth leaflet of the measured leaf.

**2.1.2 Yield and Yield Components**

**Branches per plant**: Counted at maturity on five randomly selected plants.

**Pods per plant**: Total seed-bearing pods counted per plant and averaged.

**Seeds per pod:** Average from 10 pods per plant.

**Test weight (g):** Weight of 100 randomly selected seeds.

**Seed yield per plant (g):** Grain weight per plant.

**2.1.3 Drought Susceptibility Index (DSI)**

DSI for seed yield was calculated using the formula by Fischer and Maurer (1978):

***DSI = (1 - YD/YP) / D, where D = 1 - (ȲD / ȲP)***

- YD = Yield under stress
- YP = Yield under non-stress
- ȲD, ȲP = Mean yields across all genotypes under stress and non-stress respectively

**Statistical Analysis**

The experimental data recorded for various morpho-physiological, yield, and drought tolerance traits were subjected to statistical analysis using Analysis of Variance (ANOVA) appropriate for a split-plot design. Significance of differences among treatments and genotypes was tested at 5% probability level. Mean values were compared using the Critical Difference (CD) test. The data analysis was performed using standard statistical software such as OPSTAT and Microsoft Excel. The Drought Susceptibility Index (DSI) was computed as per the formula proposed by Fischer and Maurer (1978) to assess the relative performance of genotypes under stress and non-stress conditions.

The analysis of variance revealed significant differences among genotypes, treatments, and their interactions for most morpho-physiological and yield-related traits under both normal (E1) and late sown (E2) conditions. The variability indicates substantial scope for identifying drought-resilient genotypes based on their performance across different environments.

**RESULT and DISCUSSION**

**3.1 Morpho-Physiological Traits**

**Plant Height:**

Genotypic variation for plant height was significant under both stress and non-stress conditions. Genotype IC-305595 showed maximum plant height under non-stress in both normal and late sown crops. The mean reduction in plant height due to stress was 8.07 cm in normal and 7.02 cm in late sown crops. Genotypes like IC-327723 and ICC4958 maintained moderate height under stress, indicating resilience. Similar genotypic differences in height reduction due to drought have been reported in legumes by Khan et al. (2010) and confirmed in chickpea by Sharma et al. (2016), indicating inherent variation in drought responsiveness.

**Days to First Flowering and Maturity:**

Moisture stress led to early flowering and early physiological maturity. IC-305593 showed the earliest flowering (29.65 days under normal) and was also early to mature, which suggests its potential as a drought escape genotype. The reproductive duration was highest in IC-305593 under non-stress but was significantly reduced under stress, particularly in normal sown conditions., a characteristic commonly linked to drought escape (Kumar et al., 2012; Tuberosa, 2012). Early-maturing genotypes often escape terminal drought, enhancing their adaptive advantage under rainfed conditions.

**Reproductive Duration:**

The reproductive phase was highly variable and significantly affected by drought. IC-305595 and IC-305477 maintained longer durations under non-stress but reduced sharply under stress. The average reduction in reproductive duration was greater in normal sowing (6.29 days) than in late sowing (3.27 days). These findings align with Farooq et al. (2009), who observed reproductive stages to be the most drought-sensitive in legumes. Maintaining reproductive duration under stress may enhance yield potential.

**Leaf Traits (Length, Leaflet Size):**

Leaf length, leaflet length, and leaflet width were all negatively impacted by stress. IC-327509 and IC-327156 maintained superior leaf traits under stress, suggesting better water retention and photosynthetic efficiency. Mean leaflet length and width under stress were 0.745 cm and 0.49 cm respectively, showing considerable reduction compared to non-stress conditions. Reddy et al. (2021) emphasized the role of leaf morphological traits in photosynthetic retention and water-use efficiency under stress. Similarly, Sivasakthi et al. (2017) highlighted leaf area reduction as an early indicator of drought response in chickpea.

**Relative Water Content (RWC):**

RWC was fairly stable in genotypes like IC-305593 and IC-305477 across both environments, suggesting osmotic adjustment and efficient water uptake. Maximum RWC drop was observed in IC-327534, indicating susceptibility. The stability of RWC suggests efficient osmotic regulation or deep rooting ability, as noted in the studies by Iqbal et al. (2019) and Devi et al. (2014). This trait is useful for screening genotypes with physiological resilience.

**2.2 Yield and Related Traits**

**Number of Branches and Pods per Plant:**

Stress significantly reduced branching. IC-305477 and IC-305595 showed high branching under non-stress but reduced considerably under stress. Mean branches per plant dropped from 11.0 to 7.5 in normal sowing and from 8.25 to 6.0 in late sowing. Pod number declined significantly under stress. IC-305477 had the highest pod number (80 under non-stress in normal sowing), while IC-327723 had the lowest. IC-305595 and IC-328020 maintained better pod numbers even under late sowing and stress conditions, reflecting good reproductive efficiency. Similar trends were observed by Sharma et al. (2016) and Varshney et al. (2014), who reported reduced reproductive success under moisture stress in chickpea.

**Test Weight:**

Test weight remained relatively stable across conditions, with slight declines observed under stress. Genotypes like IC-327723 and K-850 maintained higher test weight under stress in both sowings, indicating assimilate partitioning stability. Pandey et al. (2015) and Passioura (2012) also observed that final seed weight often exhibits greater stability under drought due to conservative assimilate partitioning.

**Seed Yield:**

Seed yield was most affected by moisture stress, especially in late sown crops. K-850, ICC4958, and IC-305595 had higher yields under both stress and non-stress, reflecting drought tolerance. The mean seed yield under non-stress was 13.07 g and dropped to 8.18 g under stress in normal sown crops. In late sown crops, it dropped from 9.76 g to 6.51 g. These results are consistent with previous work by Varshney et al. (2014) and Sharma et al. (2016), who emphasized yield stability as a key selection index under drought.

**Drought Susceptibility Index (DSI):**

DSI values distinguished tolerant and susceptible genotypes. K-850 and ICC4958 had low DSI values, indicating drought resilience, while IC-305477 and IC-328020 had higher DSI values, indicating higher susceptibility. This index, introduced by Fischer and Maurer (1978), remains a robust tool for screening genotype response under differential moisture regimes.

**Table 1. Analysis of variance (ANOVA) for morpho-physiological, yield and yield related traits under non-stress and stress treatments in normal sown experiment (E1) of chickpea genotypes**

| **Source of Variation** | **df** | **Plant height (cm)** | **Days to first flowering** | **Days to maturity** | **Reproductive phase** | **Leaf length (cm)** | **Leaflet length (cm)** | **Leaflet width (cm)** | **RWC (%)** | **No. of branches/plant** | **No. of pods/plant** | **Test weight (g)** | **Seed yield/plant (g)** | **Biological yield/plant (g)** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Replication** | 1 | 0.71 | 0.94 | 0.11 | 0.96 | 0.018 | 0.052 | 0.061 | 0.05 | 0.33 | 14.23 | 12.04 | 2.78 | 0.67 |
| **Treatment** | 1 | 765.24\*\* | 578.63 | 1873.44\* | 443.12\* | 898.12 | 1.745\* | 1.108 | 0.24 | 129.67 | 3271.44\* | 85.12 | 365.73 | 695.34 |
| **Error (a)** | 1 | 0.17 | 8.94 | 1.42 | 2.43 | 0.09 | 0.0018 | 0.007 | 0.014 | 2.59 | 12.35 | 1.22 | 5.43 | 10.21 |
| **Genotypes (G)** | 11 | 47.03\*\* | 248.12\*\* | 211.65\*\* | 35.92\*\* | 2.93\*\* | 61.48\*\* | 0.158\*\* | 0.0058\*\* | 8.14\*\* | 342.12\*\* | 106.84\*\* | 15.62\*\* | 41.75\*\* |
| **G × T Interaction** | 11 | 17.34\*\* | 6.57\* | 5.43\*\* | 5.74\*\* | 1.69\*\* | 0.031 | 0.045\*\* | 0.0019 | 2.54\* | 58.13\*\* | 3.48 | 6.94\*\* | 18.25\*\* |
| **Error (b)** | 22 | 1.17 | 2.22 | 1.81 | 1.38 | 0.016 | 0.0051 | 0.0022 | 0.0021 | 1.22 | 6.43 | 28.91 | 1.88 | 2.84 |

**RWC: Relative water content\ DF: Degrees of Freedom\ G: Genotype \T: Treatment.**

**Table 2. Analysis of variance (ANOVA) for morpho-physiological, yield and yield related traits under non-stress and stress treatments in late sown experiment (E2) of chickpea genotypes**

| **Source of Variation** | **DF** | **Plant height (cm)** | **Days to first flowering (Days)** | **Days to maturity (Days)** | **Reproductive phase (Days)** | **RWC (%)** | **No. of branches/plant** | **No. of pods/plant** | **Test weight (g)** | **Seed yield/plant (g)** | **Biological yield/plant (g)** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Replication** | 1 | 3.95 | 10.42 | 1.37 | 5.12 | 0.014 | 0.71 | 12.36 | 1.67 | 2.91 | 5.23 |
| **Treatment** | 1 | 891.14\*\* | 158.34\* | 493.76\* | 126.85\* | 85.12 | 55.67\* | 1376.48\* | 39.77\* | 146.21\* | 371.56\* |
| **Error (a)** | 1 | 0.091 | 0.29 | 2.08 | 0.15 | 0.000 | 0.26 | 0.48 | 1.43 | 0.64 | 1.14 |
| **Genotypes** | 12 | 54.63\*\* | 240.17\*\* | 314.98\*\* | 46.83\*\* | 0.006 | 5.34\*\* | 318.73\*\* | 149.04\*\* | 6.52\*\* | 34.28\*\* |
| **G × T Interaction** | 12 | 17.29\*\* | 6.85\*\* | 2.09 | 8.34\*\* | 0.003 | 0.893 | 39.42\*\* | 0.92 | 3.15 | 13.87\*\* |
| **Error (b)** | 24 | 1.43 | 0.98 | 1.76 | 0.61 | 0.006 | 0.49 | 7.86 | 1.48 | 1.61 | 3.78 |

**RWC: Relative water content\ DF: Degrees of Freedom\ G: Genotype\T: Treatment.**

**TABLE 3. PLANT HEIGHT (CM) OF DIFFERENT GENOTYPES OF CHICKPEA UNDER STRESS AND NON-STRESS TREATMENTS IN NORMAL AND LATE SOWN EXPERIMENTS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Sown (14 Nov 2024)Non-stress | Stress | Mean | N-S | Late Sown (11 Dec 2024)Non-stress | Stress | Mean | N-S |
| K-850 | 44.2 | 42.1 | 43.15 | 2.1 | 41.6 | 31.8 | 36.7 | 9.8 |
| ICC-4958 | 41.2 | 38.9 | 40.05 | 2.3 | 38.7 | 36.1 | 37.4 | 2.6 |
| IC-305595 | 45.0 | 38.7 | 41.85 | 6.3 | 44.2 | 35.9 | 40.05 | 8.3 |
| IC-327373 | 42.9 | 30.6 | 36.75 | 12.3 | 34.3 | 26.8 | 30.55 | 7.5 |
| IC-305536 | 41.9 | 31.2 | 36.55 | 10.7 | 41.1 | 28.6 | 34.85 | 12.5 |
| IC-327509 | 50.1 | 39.1 | 44.6 | 11.0 | 43.1 | 36.3 | 39.7 | 6.8 |
| IC-305593 | 42.6 | 36.1 | 39.35 | 6.5 | 37.6 | 33.1 | 35.35 | 4.5 |
| IC-328020 | 43.5 | 33.8 | 38.65 | 9.7 | 40.7 | 32.4 | 36.55 | 8.3 |
| IC-305477 | 50.4 | 37.9 | 44.15 | 12.5 | 45.3 | 36.1 | 40.7 | 9.2 |
| IC-327156 | 41.4 | 33.1 | 37.25 | 8.3 | 39.2 | 31.1 | 35.15 | 8.1 |
| IC-327534 | 48.8 | 41.9 | 45.35 | 6.9 | 44.1 | 37.3 | 40.7 | 6.8 |
| IC-327723 | 43.4 | 38.0 | 40.7 | 5.4 | 43.5 | 36.8 | 40.15 | 6.7 |
| Mean | 44.15 | 36.08 | 40.12 | 8.07 | 41.82 | 34.8 | 38.31 | 7.02 |

 CD (Critical Difference) at 5% Level

|  |  |  |
| --- | --- | --- |
| Comparison | Normal Sown | Late Sown |
| Between two main treatments | 1.48 | 4.65 |
| Between two sub means | 1.55 | 1.34 |
| Between two sub means at same main | 2.24 | 1.68 |
| Between two sub means at same or different sub treatments | 2.02 | 1.95 |

**N: Non- stress\S: Stress/ N-S: Non-stress - Stress**

#### TABLE 4. NUMBER OF DAYS TAKEN TO FIRST FLOWERING OF CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS IN NORMAL AND LATE SOWN EXPERIMENTS

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Sown (14 Nov 2024)Non-stress | Stress | Mean | N-S | Late Sown (11 Dec 2024)Non-stress | Stress | Mean | N-S |
| K-850 | 59.1 | 53.6 | 56.35 | 5.5 | 54.2 | 47.1 | 50.65 | 7.1 |
| ICC-4958 | 55.0 | 48.2 | 51.6 | 6.8 | 48.6 | 45.2 | 46.9 | 3.4 |
| IC-305595 | 49.6 | 42.1 | 45.85 | 7.5 | 39.8 | 38.2 | 39.0 | 1.6 |
| IC-327373 | 53.1 | 44.0 | 48.55 | 9.1 | 41.5 | 36.5 | 39.0 | 5.0 |
| IC-305536 | 53.7 | 47.2 | 50.45 | 6.5 | 48.0 | 37.6 | 42.8 | 10.4 |
| IC-327509 | 58.6 | 51.4 | 55.0 | 7.2 | 49.0 | 48.4 | 48.7 | 0.6 |
| IC-305593 | 31.0 | 28.3 | 29.65 | 2.7 | 28.1 | 23.9 | 26.0 | 4.2 |
| IC-328020 | 54.7 | 44.0 | 49.35 | 10.7 | 39.1 | 37.9 | 38.5 | 1.2 |
| IC-305477 | 53.6 | 44.5 | 49.05 | 9.1 | 37.4 | 32.9 | 35.15 | 4.5 |
| IC-327156 | 35.6 | 31.8 | 33.7 | 3.8 | 29.5 | 27.8 | 28.65 | 1.7 |
| IC-327534 | 57.6 | 48.1 | 52.85 | 9.5 | 47.4 | 44.3 | 45.85 | 3.1 |
| IC-327723 | 58.1 | 49.1 | 53.6 | 9.0 | 49.1 | 44.2 | 46.65 | 4.9 |
| Mean | 51.73 | 44.35 | 48.04 | - | 41.85 | 37.93 | 39.89 | - |

CD (Critical Difference) at 5% Level

|  |  |  |
| --- | --- | --- |
| Comparison | Normal Sown | Late Sown |
| Between two main treatments | 10.958 | 1.990 |
| Between two sub means | 2.215 | 1.550 |
| Between two sub means at same main | 2.980 | 2.120 |
| Between two sub means at same or different sub treatments | 3.356 | 2.088 |

**N: Non-stress\ S: Stress\ N-S: Non-stress – Stress**

**Table 5. Number of days taken to maturity of chickpea genotypes under moisture stress and non-stress treatments in normal and late sown experiments**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Sown (14 Nov 2024)Non-stress | Stress | Mean | N-S | Late Sown (11 Dec 2024)Non-stress | Stress | Mean | N-S |
| K-850 | 112.0 | 97.2 | 104.6 | 14.8 | 91.2 | 86.3 | 88.75 | 4.9 |
| ICC4958 | 96.1 | 87.4 | 91.75 | 8.7 | 78.3 | 73.8 | 76.05 | 4.5 |
| IC-305595 | 102.2 | 85.1 | 93.65 | 17.1 | 76.2 | 71.1 | 73.65 | 5.1 |
| IC-327373 | 100.8 | 85.3 | 93.05 | 15.5 | 76.8 | 71.1 | 73.95 | 5.7 |
| IC-305536 | 98.1 | 86.7 | 92.4 | 11.4 | 77.8 | 71.8 | 74.8 | 6.0 |
| IC-327509 | 111.8 | 97.0 | 104.4 | 14.8 | 91.0 | 86.1 | 88.55 | 4.9 |
| IC-305593 | 86.1 | 74.1 | 80.1 | 12.0 | 64.1 | 54.3 | 59.2 | 9.8 |
| IC-328020 | 96.9 | 86.2 | 91.55 | 10.7 | 79.3 | 73.4 | 76.35 | 5.9 |
| IC-305477 | 98.2 | 86.1 | 92.15 | 12.1 | 80.1 | 72.1 | 76.1 | 8.0 |
| IC-327156 | 87.8 | 77.0 | 82.4 | 10.8 | 70.2 | 64.4 | 67.3 | 5.8 |
| IC-327534 | 105.3 | 91.3 | 98.3 | 14.0 | 85.2 | 77.4 | 81.3 | 7.8 |
| IC-327723 | 105.4 | 92.3 | 98.85 | 13.1 | 85.6 | 78.7 | 82.15 | 6.9 |
| Mean | 100.18 | 87.11 | 93.64 | - | 78.54 | 72.12 | 75.33 | - |

CD (Critical Difference) at 5% Level

|  |  |  |
| --- | --- | --- |
| Comparison | Normal Sown | Late Sown |
| Between two main treatments | 4.108 | 4.890 |
| Between two sub means | 1.912 | 1.950 |
| Between two sub means at same main | 2.705 | --- |
| Between two sub means at same or different sub treatments | 2.680 | --- |

N: Non- stress\S: Stress/ N-S: Non-stress – Stress

#### TABLE 6. DURATION OF REPRODUCTIVE PHASE (DAYS) OF DIFFERENT CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON- STRESS TREATMENTS OF NORMAL AND LATE SOWN EXPERIMENTS

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Sown (Non-stress) | Normal Sown (Stress) | Normal Sown (Mean) | Normal Sown (N-S) | Late Sown (Non-stress) | Late Sown (Stress) | Late Sown (Mean) | Late Sown (N-S) |
| K-850 | 51.5 | 44.0 | 47.75 | 7.5 | 38.5 | 37.5 | 38.0 | 1.0 |
| ICC4958 | 45.0 | 41.0 | 43.0 | 4.0 | 31.5 | 28.5 | 30.0 | 3.0 |
| IC-305595 | 50.5 | 40.5 | 45.5 | 10.0 | 36.0 | 32.0 | 34.0 | 4.0 |
| IC-327373 | 46.5 | 38.5 | 42.5 | 8.0 | 35.5 | 34.0 | 33.75 | 1.5 |
| IC-305536 | 43.5 | 37.5 | 40.5 | 6.0 | 35.5 | 32.5 | 34.0 | 3.0 |
| IC-327509 | 52.5 | 43.5 | 48.0 | 9.0 | 41.5 | 38.5 | 40.0 | 3.0 |
| IC-305593 | 54.0 | 46.0 | 50.0 | 8.0 | 35.5 | 30.5 | 33.0 | 5.0 |
| IC-328020 | 42.5 | 41.0 | 41.75 | 1.5 | 38.5 | 34.5 | 36.5 | 4.0 |
| IC-305477 | 44.5 | 40.5 | 42.5 | 4.0 | 41.0 | 41.0 | 41.0 | 0.0 |
| IC-327156 | 52.5 | 45.5 | 49.0 | 7.0 | 39.0 | 37.0 | 38.0 | 2.0 |
| IC-327534 | 48.5 | 42.5 | 45.5 | 6.0 | 39.0 | 33.0 | 36.0 | 6.0 |
| IC-327723 | 48.5 | 44.0 | 46.25 | 4.5 | 36.5 | 33.0 | 34.75 | 3.5 |
| Mean | 48.33 | 42.04 | 45.19 | - | 36.89 | 33.62 | 34.25 | - |

Critical Difference (CD) at 5%

|  |  |  |
| --- | --- | --- |
| Comparison Type | Normal Sown Crop | Late Sown Crop |
| Between two main treatments | 5.81 | 1.459 |
| Between two sub means | 1.68 | 1.183 |
| Between two sub means at same main | 2.38 | 1.673 |
| Between two sub means at same or different sub treatments | 2.47 | 1.625 |

**N: Non- stress\S: Stress/ N-S: Non-stress - Stress**

#### TABLE 7. LEAF LENGTH, LEAFLET LENGTH AND LEAFLET DIAMETER (CM) OF DIFFERENT GENOTYPES OF CHICKPEA UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS OF NORMAL SOWN EXPERIMENT

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Leaf length (Non-stress) | Leaf length (Stress) | Leaf length (Mean) | N-S | Leaflet length (Non-stress) | Leaflet length (Stress) | Leaflet length (Mean) | N-S | Leaflet width (Non-stress) | Leaflet width (Stress) | Leaflet width (Mean) | N-S |
| K-850 | 4.65 | 3.35 | 4.0 | 1.3 | 1.28 | 0.71 | 0.99 | 0.57 | 0.96 | 0.49 | 0.73 | 0.47 |
| ICC4958 | 4.55 | 3.4 | 3.98 | 1.15 | 1.21 | 0.59 | 0.9 | 0.62 | 0.73 | 0.42 | 0.58 | 0.31 |
| IC-305595 | 5.5 | 3.3 | 4.4 | 2.2 | 1.12 | 0.69 | 0.91 | 0.43 | 0.84 | 0.35 | 0.6 | 0.49 |
| IC-327373 | 4.6 | 3.2 | 3.9 | 1.4 | 0.91 | 0.58 | 0.75 | 0.33 | 0.56 | 0.43 | 0.5 | 0.13 |
| IC-305536 | 3.9 | 2.8 | 3.35 | 1.1 | 0.78 | 0.49 | 0.64 | 0.29 | 0.57 | 0.37 | 0.47 | 0.2 |
| IC-327509 | 5.5 | 3.35 | 4.45 | 2.15 | 1.31 | 0.83 | 1.07 | 0.48 | 1.39 | 0.53 | 0.96 | 0.86 |
| IC-305593 | 3.55 | 2.4 | 2.98 | 1.15 | 0.92 | 0.5 | 0.71 | 0.42 | 0.61 | 0.34 | 0.48 | 0.27 |
| IC-328020 | 4.0 | 3.25 | 3.63 | 0.75 | 0.88 | 0.64 | 0.76 | 0.24 | 0.61 | 0.39 | 0.5 | 0.22 |
| IC-305477 | 5.3 | 3.45 | 4.38 | 1.85 | 0.95 | 0.49 | 0.72 | 0.46 | 0.51 | 0.35 | 0.43 | 0.16 |
| IC-327156 | 6.25 | 4.1 | 5.18 | 2.15 | 1.78 | 1.07 | 1.43 | 0.71 | 1.1 | 0.67 | 0.89 | 0.43 |
| IC-327534 | 4.65 | 3.95 | 4.3 | 0.7 | 1.42 | 1.2 | 1.31 | 0.22 | 0.93 | 0.7 | 0.82 | 0.23 |
| IC-327723 | 4.75 | 4.35 | 4.45 | 0.4 | 1.19 | 1.15 | 1.17 | 0.05 | 0.85 | 0.84 | 0.85 | 0.01 |
| Mean | 4.31 | 3.41 | 3.86 | - | 1.146 | 0.745 | 0.945 | 0.401 | 0.805 | 0.49 | 0.648 | - |

Critical Difference (CD) at 5%

|  |  |  |  |
| --- | --- | --- | --- |
| Comparison Type | Leaf Length | Leaflet Length | Leaflet Width |
| Between two main treatments | 1.161 | 0.143 | 0.328 |
| Between two sub means | 0.176 | 0.092 | - |
| Between two sub means at same main | 0.249 | 0.130 | - |
| Between two sub means at same or different sub treatments | 0.305 | 0.127 | - |

N: Non- stress\S: Stress/ N-S: Non-stress - Stress

#### TABLE 8. RELATIVE WATER CONTENT (%) AT 60 DAS OF DIFFERENT CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS IN NORMAL AND LATE SOWN EXPERIMENTS

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Sown (Non-stress) | Normal Sown (Stress) | Normal Sown (Mean) | N-S | Late Sown (Non-stress) | Late Sown (Stress) | Late Sown (Mean) | N-S |
| K-850 | 64.4 | 53.5 | 59.0 | 10.9 | 81.4 | 69.8 | 75.6 | 11.6 |
| ICC4958 | 60.1 | 49.9 | 55.0 | 10.2 | 70.8 | 61.2 | 66.0 | 9.6 |
| IC-305595 | 65.7 | 54.6 | 60.2 | 11.1 | 76.6 | 72.4 | 74.5 | 4.2 |
| IC-327373 | 56.3 | 42.2 | 49.2 | 14.1 | 78.6 | 60.9 | 69.7 | 17.7 |
| IC-305536 | 60.6 | 46.6 | 53.6 | 14.0 | 68.7 | 65.7 | 67.2 | 3.0 |
| IC-327509 | 64.9 | 50.2 | 57.5 | 14.7 | 71.2 | 63.1 | 67.1 | 8.1 |
| IC-305593 | 71.4 | 53.8 | 62.6 | 17.6 | 77.2 | 74.4 | 75.8 | 2.8 |
| IC-328020 | 68.2 | 53.7 | 60.9 | 14.5 | 79.3 | 67.4 | 73.3 | 11.9 |
| IC-305477 | 65.7 | 49.4 | 57.0 | 16.3 | 75.0 | 71.3 | 73.1 | 3.7 |
| IC-327156 | 67.7 | 56.6 | 62.1 | 11.1 | 74.8 | 71.0 | 72.9 | 3.8 |
| IC-327534 | 71.8 | 48.7 | 60.2 | 23.1 | 72.6 | 71.8 | 72.2 | 0.8 |
| IC-327723 | 71.8 | 51.7 | 61.7 | 20.1 | 77.3 | 71.8 | 74.6 | 5.5 |
| Mean | 65.7 | 50.9 | 58.3 | - | 74.9 | 69.2 | 72.1 | - |

Critical Difference (CD) at 5%

|  |  |  |
| --- | --- | --- |
| Comparison Type | Normal Sown | Late Sown |
| Between two main treatments | 25.01 | 07.60 |
| Between two sub means | 05.70 | 10.30 |
| Between two sub means at same main | --- | --- |
| Between two sub means at same or different sub treatments | --- | --- |

**N: Non- stress\S: Stress/ N-S: Non-stress – Stress**

**TABLE 9. NUMBER OF BRANCHES PER PLANT OF DIFFERENT CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS IN NORMAL AND LATE SOWN EXPERIMENTS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Non-stress | Normal Stress | Normal Genotype Mean | Normal N-S | Late Non-stress | Late Stress | Late Genotype Mean | Late N-S |
| K-850 | 11.2 | 8.4 | 9.8 | 2.8 | 9.0 | 6.2 | 7.6 | 2.8 |
| ICC4958 | 11.0 | 9.0 | 10.0 | 2.0 | 8.0 | 7.0 | 7.5 | 1.0 |
| IC-305595 | 12.1 | 6.0 | 9.05 | 6.1 | 9.5 | 6.0 | 7.75 | 3.5 |
| IC-327373 | 9.0 | 7.0 | 8.0 | 2.0 | 8.5 | 5.5 | 7.0 | 3.0 |
| IC-305536 | 10.2 | 8.0 | 9.1 | 2.2 | 10.0 | 7.0 | 8.5 | 3.0 |
| IC-327509 | 11.5 | 7.0 | 9.25 | 4.5 | 10.2 | 6.5 | 8.35 | 3.7 |
| IC-305593 | 6.5 | 5.2 | 5.85 | 1.3 | 6.0 | 4.0 | 5.0 | 2.0 |
| IC-328020 | 13.0 | 7.0 | 10.0 | 6.0 | 8.0 | 6.5 | 7.25 | 1.5 |
| IC-305477 | 15.0 | 9.0 | 12.0 | 6.0 | 8.2 | 7.0 | 7.6 | 1.2 |
| IC-327156 | 9.5 | 6.0 | 7.75 | 3.5 | 7.5 | 5.5 | 6.5 | 2.0 |
| IC-327534 | 12.0 | 7.0 | 9.5 | 5.0 | 6.8 | 6.0 | 6.4 | 0.8 |
| IC-327723 | 10.5 | 8.0 | 9.25 | 2.5 | 7.0 | 5.5 | 6.25 | 1.5 |
| Mean | 11.0 | 7.5 | 9.25 | - | 8.25 | 6.0 | 7.12 | - |
| CD at 5% |  |  |  |  |  |  |  |  |
| Between two main treatments | 6.0 |  |  |  | 2.000 |  |  |  |
| Between two sub means | 1.70 |  |  |  | 1.000 |  |  |  |
| Between two sub means at same main | 2.5 |  |  |  | --- |  |  |  |
| Between two sub means at same or different sub treatments | 2.60 |  |  |  | --- |  |  |  |

N: Non- stress\S: Stress/ N-S: Non-stress - Stress

**TABLE 10. NUMBER OF PODS PER PLANT OF DIFFERENT CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS OF NORMAL AND LATE SOWN EXPERIMENTS**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Genotypes | Normal Non-stress | Normal Stress | Genotypes Mean | Normal N-S | Late Non-stress | Late Stress | Genotype Mean | Late N-S |
| K-850 | 36.0 | 28.0 | 32.0 | 8.0 | 30.5 | 23.0 | 26.75 | 7.5 |
| ICC4958 | 55.0 | 47.0 | 51.0 | 8.0 | 38.0 | 33.0 | 35.5 | 5.0 |
| IC-305595 | 62.0 | 35.0 | 48.5 | 27.0 | 52.0 | 36.0 | 44.0 | 16.0 |
| IC-327373 | 39.0 | 29.0 | 34.0 | 10.0 | 32.0 | 22.0 | 27.0 | 10.0 |
| IC-305536 | 61.0 | 38.0 | 49.5 | 23.0 | 50.0 | 36.0 | 43.0 | 14.0 |
| IC-327509 | 52.0 | 36.0 | 44.0 | 16.0 | 32.0 | 26.0 | 29.0 | 6.0 |
| IC-305593 | 48.0 | 33.0 | 40.5 | 15.0 | 47.0 | 28.0 | 37.5 | 19.0 |
| IC-328020 | 57.0 | 34.0 | 45.5 | 23.0 | 50.0 | 29.0 | 39.5 | 21.0 |
| IC-305477 | 80.0 | 50.0 | 65.0 | 30.0 | 55.0 | 38.0 | 46.5 | 17.0 |
| IC-327156 | 49.0 | 39.0 | 44.0 | 10.0 | 27.0 | 18.0 | 22.5 | 9.0 |
| IC-327534 | 42.0 | 29.0 | 35.5 | 13.0 | 24.0 | 19.0 | 21.5 | 5.0 |
| IC-327723 | 43.0 | 24.0 | 33.5 | 19.0 | 21.0 | 20.0 | 20.5 | 1.0 |
| Mean | 52.33 | 35.0 | 43.67 | - | 38.29 | 27.92 | 33.1 | - |
| CD at 5% |  |  |  |  |  |  |  |  |
| Between two main treatments | 12.50 |  |  |  | 2.500 |  |  |  |
| Between two sub means | 3.80 |  |  |  | 4.000 |  |  |  |
| Between two sub means at same main | 5.30 |  |  |  | 5.700 |  |  |  |
| Between two sub means at same or different sub treatments | 5.50 |  |  |  | 5.500 |  |  |  |

**N: Non- stress\S: Stress/ N-S: Non-stress - Stress**

#### TABLE 11. TEST WEIGHT (G) OF DIFFERENT CHICKPEA GENOTYPES UNDER MOISTURE STRESS AND NON-STRESS TREATMENTS OF NORMAL AND LATE SOWN EXPERIMENTS

| **Genotypes** | **Normal Non-stress** | **Normal Stress** | **Genotype Mean** | **Normal N-S** | **Late Non-stress** | **Late Stress** | **Genotype Means** | **Late N-S** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| K-850 | 32.00 | 30.50 | 31.25 | 1.50 | 29.00 | 28.20 | 28.60 | 0.80 |
| ICC4958 | 26.00 | 22.50 | 24.25 | 3.50 | 17.50 | 15.00 | 16.25 | 2.50 |
| IC-305595 | 20.00 | 17.00 | 18.50 | 3.00 | 19.00 | 14.50 | 16.75 | 4.50 |
| IC-327373 | 17.00 | 14.00 | 15.50 | 3.00 | 13.00 | 11.00 | 12.00 | 2.00 |
| IC-305536 | 21.00 | 20.00 | 20.50 | 1.00 | 17.00 | 16.00 | 16.50 | 1.00 |
| IC-327509 | 28.00 | 25.00 | 26.50 | 3.00 | 25.00 | 23.00 | 24.00 | 2.00 |
| IC-305593 | 24.00 | 20.00 | 22.00 | 4.00 | 16.50 | 14.00 | 15.25 | 2.50 |
| IC-328020 | 19.00 | 15.00 | 17.00 | 4.00 | 18.50 | 15.00 | 16.75 | 3.50 |
| IC-305477 | 21.00 | 18.00 | 19.50 | 3.00 | 20.00 | 17.00 | 18.50 | 3.00 |
| IC-327156 | 31.00 | 23.00 | 27.00 | 8.00 | 25.50 | 21.00 | 23.25 | 4.50 |
| IC-327534 | 30.00 | 28.00 | 29.00 | 2.00 | 26.00 | 24.00 | 25.00 | 2.00 |
| IC-327723 | 33.00 | 30.00 | 31.50 | 3.00 | 30.00 | 28.00 | 29.00 | 2.00 |
| **Mean** | **24.83** | **21.83** | **23.33** | - | **23.04** | **20.38** | **21.71** | - |
| **CD @ 5%** |  |  |  |  |  |  |  |  |
| Between two main treatments | 4.00 |  |  |  | 4.400 |  |  |  |
| Between two sub means | 8.10 |  |  |  | 1.850 |  |  |  |
| Between two sub means at same main | --- |  |  |  | --- |  |  |  |
| Between two sub means at same or different sub treatments | --- |  |  |  | --- |  |  |  |

**N: Non- stress\S: Stress/ N-S: Non-stress - Stress**

**Table 12. Seed yield per plant (g) of different chickpea genotypes under moisture stress and non-stress treatments of normal and late sown experiments**

| **Genotypes** | **Normal Non-stress** | **Normal Stress** | **Genotype Mean** | **Normal N-S** | **Late Non-stress** | **Late Stress** | **Genotype Mean** | **Late N-S** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| K-850 | 12.40 | 9.25 | 10.83 | 3.15 | 9.80 | 6.85 | 8.33 | 2.95 |
| ICC4958 | 13.05 | 10.30 | 11.68 | 2.75 | 11.60 | 8.75 | 10.18 | 2.85 |
| IC-305595 | 14.20 | 8.10 | 11.15 | 6.10 | 13.30 | 7.05 | 10.18 | 6.25 |
| IC-327373 | 8.70 | 5.15 | 6.93 | 3.55 | 6.50 | 3.20 | 4.85 | 3.30 |
| IC-305536 | 13.80 | 9.90 | 11.85 | 3.90 | 11.20 | 8.15 | 9.68 | 3.05 |
| IC-327509 | 15.60 | 7.50 | 11.55 | 8.10 | 8.60 | 4.60 | 6.60 | 4.00 |
| IC-305593 | 10.20 | 6.25 | 8.23 | 3.95 | 7.80 | 5.00 | 6.40 | 2.80 |
| IC-328020 | 11.50 | 5.35 | 8.43 | 6.15 | 10.40 | 4.25 | 7.33 | 6.15 |
| IC-305477 | 17.10 | 9.20 | 13.15 | 7.90 | 8.50 | 5.30 | 6.90 | 3.20 |
| IC-327156 | 13.30 | 6.10 | 9.70 | 7.20 | 10.10 | 5.90 | 8.00 | 4.20 |
| IC-327534 | 12.60 | 9.55 | 11.08 | 3.05 | 9.10 | 6.50 | 7.80 | 2.60 |
| IC-327723 | 14.80 | 10.00 | 12.40 | 4.80 | 11.50 | 7.95 | 9.73 | 3.55 |
| **Mean** | **13.07** | **8.18** | **10.62** | - | **9.76** | **6.51** | **8.13** | - |
| **Comparison** | **Normal** |  |  |  | **Late** |  |  |  |
| **Between two main treatments** | **7.900** |  |  |  | **2.75** |  |  |  |
| **Between two sub means** | **3.455** |  |  |  | **1.78** |  |  |  |
| **Between two sub means at same main** | **5.010** |  |  |  | **---** |  |  |  |
| **Between two sub means at same or different sub treatments** | **4.998** |  |  |  | **---** |  |  |  |

N: Non- stress\S: Stress/ N-S: Non-stress – Stress

**Conclusion**

The present study demonstrated significant genotypic variability in response to drought stress across a range of morpho-physiological and yield-related traits under both normal (E1) and late sown (E2) conditions. Moisture stress markedly affected key developmental traits such as plant height, days to maturity, reproductive duration, and pod number, while relative water content (RWC) and test weight remained relatively stable, indicating their potential as drought-resilient traits.

Genotypes such as **K-850** and **ICC 4958** emerged as promising candidates for drought tolerance, exhibiting stable performance and lower drought susceptibility indices (DSI) under stress conditions. Conversely, genotypes like **IC-328020** and **IC-305477** were more vulnerable to water deficit, as reflected by their high DSI values and yield reduction. Early flowering and maturity observed in **IC-305593** suggest its potential as a drought escape genotype, a valuable trait in terminal drought-prone environments.

The findings emphasize the importance of selecting genotypes with favorable morpho-physiological traits and yield stability under stress, which can contribute to breeding programs aimed at improving drought resilience. The study also reinforces the value of evaluating germplasm under varied sowing conditions to identify genotypes with consistent performance, aiding in the development of climate-resilient cultivars.

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