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# GENETIC INSIGHTS INTO DROUGHT TOLERANCE OF BREAD WHEAT GENOTYPES AT THE SEEDLING STAGE

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**Abstract**
Current water scarcity in different parts of the world has drastically affected the yield of different cultivated crops, including wheat. An experiment was conducted to evaluate the drought tolerance of various bread wheat genotypes at the seedling stage. One hundred bread wheat genotypes were evaluated under controlled drought conditions using Poly Ethylene Glycol-6000 (PEG-6000) in a complete randomized design (CRD) with three replicates. Analysis of variance showed that there was significant variation among all the evaluated genotypes. In both normal and drought conditions, the trait root to shoot ratio had the highest value of genotypic correlation with root length (0.94**, 0.94**), followed by relative water content (0.72**, 0.76**) and the association of relative water content with root to shoot ratio (0.68**, 0.69**); thus, it can be concluded that the variation among the traits is due to the genetic effect rather than environmental interaction. For mean performance, the genotypes were screened and evaluated based on their performance under both normal and drought conditions: G20, followed by G15, G90, G35, G43, G25, G44, and G45 performed well, while the genotypes that performed worst were G82, G42, G76, and G86. All traits exhibited high heritability with a high genetic advancement percentage, except for relative water content. These results signify the role of attributes in regulating the drought response of plants and suggest that the selection of best-performing traits helps to improve plant growth under water stress. The development of such cultivars that are tolerant to drought could be used to overcome food shortage where limited water is available.

**Keywords:** Drought; wheat; stress; relative water content; attribute

## Introduction
Wheat is a global source of food for humans. One of the most popular cereal crops wheat (*Triticum aestivum* L.), provides around 20% of the daily calories and protein needed for an adult (Kugler et al. 2013). Total wheat production in Pakistan during 2020-21 was 27.293 million tonnes (Economic survey 2020-21). Wheat cultivation must be increased over the world to ensure food security for the

world's population. Wheat straw is also used as feed for cattle, making it an important agricultural crop not only for humans but also for cattle (Rahmani et. Al, 2022, Wang et. Al., 2022 Hegazy SA., et. al., 2023 and Fathy et. al., 2023). Wheat breeding is the main goal in this period of global climate change and increased population, there is a need to generate varieties with greater yields, quality, and tolerance to abiotic and biotic stresses (Ahmed et al., 2019).

Wheat is also an important staple food crop in Pakistan. Agriculture is the major contributor to the national GDP of Pakistan. About 19.2 percent, of agriculture, contributes to the GDP. Wheat contributes 1.8 percent to the national GDP of Pakistan (Economic survey 2020-21).

Global climate changes have a significant impact on wheat production in many regions of the world, including regions of south and central Asia. Urbanization, deforestation, a high level of population increase, and the inclusion of greenhouse and hazardous gases all contribute to global climate change (Hussain et al. 2019). These worldwide climate changes may have resulted in the creation of new disease races, altered plant phenology, and shorten the stress-free growth period of the plant. As a result, they may negatively impact wheat production, affecting the majority of people in the world and increasing global food insecurity (Zhou et al. 2019). Mostly drought stress is the most affected stress, that decreased wheat production to about 50% (Ali et al. 2017).

Drought, often known as a water shortage, is abiotic stress that inhibits plant development and reduces crop yields in many regions of the world (Comas et al. 2013). New wheat varieties don't have much potential against environmental stresses. There are many methods to develop the potential tolerance against the stresses like drought. An effective method for creating new cultivars is to utilize new gene resources from parents and related species. Wild relatives of common wheat have a long history of use in wheat breeding, primarily for salinity, drought, heat, and cold tolerance. They are an excellent source of genes linked to biotic and abiotic stress resistance (Zamani Bangohari et al. 2013; Arabbeigi et al. 2014; Ramaiyulis et. al., 2023, Kiani et al. 2015, Noman et. al., 2023). Due to the negative impacts of abiotic stresses (drought, extremely high temperatures, cold, and salt), wheat production is gradually and steadily decreasing. However, compared to other types of stress, drought, which is the most devastating stress, lowers the overall yield. (Ahmadizadeh et al. 2013, Ramzan et., 2023).

Drought at the seedling stage is a difficult time for the plants to survive in this condition. Because this type of stress causes a major loss in wheat yield. The seedling stage is an important stage for the plant. Drought at this stage slows down plant growth. This automatically reduces wheat productivity. Drought stress may reduce leaf water potential, lowering the moisture, root length, root shoot ratio and relative water content, as a result, decreasing wheat growth and production. Drought is the biggest and major issue during the seedling stage of a wheat plant. (Chen et al. 2012). Drought stress is one of the most significant abiotic variables that affect agricultural plant development and production, including wheat (El-Rawy and Hassan 2014, Nawaz et. al., 2023). The physiological traits at the seedling stage like root, shoot length, root, shoot ratio relative to water content and others are important. These traits are considered useful traits for breeding purposes (Gupta, Kızılgeçi, et al. 2017, Adélaïde at. Al., 2023). Due to a rise in the frequency and severity of drought at this stage, improving drought tolerance at the seedlings stage is becoming a much more significant aim for wheat breeders. Seed germination root, shoot length, root, and shoot ratio are all important factors in the successful establishment of crops, and the degree of germination and seedling is a major aspect that determines maturity and yield timing (Singh et al. 2013). The plant survival under drought stress requires the activity of many mechanisms at the same time. Escape, avoidance or tolerance, and resistance mechanism are three primary types of mechanisms involved in drought and salinity stress conditions (Ahmed et al. 2014, Liaqat at. al., 2023, Nawaz et. al., 2023, Haroon et al., 2023, Sultana et. al., 2023). The plant completes its life cycle before drought occurs in the escape mechanism. Plants compete with water-deficient situations, such as stomata closure and lower transpiration rate, in the tolerance process. During a drought-resistant mechanism, the plant maintains regular development phases by increasing the number of photosynthetic pigments and maintaining the root-to-shoot ratio for the equal distribution of total assimilates (Ashfaq et al. 2016). Root length is an important trait of a wheat plant at the seedling stage under drought conditions. Root length directly influenced the plant growth as well as yield. Roots are essential organs for absorption and metabolism, as well as contributors to grain yield, in this context. The quantity, distribution, metabolism, and variation of the root system all have an impact on the growth and development of above-ground structures (Man et al. 2016, Saeed et. al., 2023). In wheat at the seedlings stage, water stress resulted in deeper roots and a bigger root surface area but lower the shoot development of a plant. Root attributes are essential for crop performance, especially in the case of wheat, which is farmed as a crop in water stress, rainfed areas with low rainfall (Chen et al. 2018; Preethi et al. 2020). The size of the root system is an important factor in wheat's ability to efficiently absorb water and nitrogen (Tian et. al., 2019). The size of the root system is an important factor in wheat's ability to efficiently absorb water and nitrogen. Root system traits are significant because they convey information about the soil and the resources contained within it. Root system structure and morphology are two components that are used to describe root system attributes. Root morphology describes the features of the main root axis, such as root hairs, and root diameter.

Relative water content (RWC) is also an essential trait at the seedling stage. Selection can be made based on relative water content. Relative water content is the amount of water absorbed and hold by the plant cells. The relative water content in the plant cells, which this distributed and expelled out through transpiration, all are controlled by the plant cells. RWC plays a major role in the higher yield at the seedling stage (Arjenaki et al. 2014). Choosing the wheat cultivars based on seedling traits is comfortable, inexpensive and easily manageable. These selected cultivars performed the best under the water deficiency condition. Similarly, seedling parameters indicate moderate-to-high variability across situations, with an additive gene effect (Ahmed et al. 2017). All of these studies emphasize the importance of early drought tolerance of cultivars at the seedling stage. Our goal is to discover important features and the role of genotypes in early stress tolerance. The objective of this research is to determine wheat genotypes to drought stress imposed at the seedling stage to identify water stress tolerant genotypes, adaptive traits and their association with grain yield. To determine the genotypes with better results, which perform well under drought stress.

## Material and Methods

### Plant materials

Table 3.1 lists a hundred bread wheat genotypes (*T. aestivum* L.) that were used in an experiment, to find a reproducible, fast, and easy technique for screening wheat genotypes for drought tolerance.

**Table-3.1. List of genotypes studied**

| Genotypes | Name | Source | Genotypes | Name | Source |
|---|---|---|---|---|---|
| G1 | 824 | RARI Bahawalpur | G51 | 52r - 279 | RARI Bahawalpur |
| G2 | 850 | RARI Bahawalpur | G52 | 53r | RARI Bahawalpur |
| G3 | 857 | RARI Bahawalpur | G53 | 20-21r E-668 | RARI Bahawalpur |
| G4 | 858 | RARI Bahawalpur | G54 | 32r -265 | RARI Bahawalpur |
| G5 | 870 | RARI Bahawalpur | G55 | 121 | RARI Bahawalpur |
| G6 | 876 | RARI Bahawalpur | G56 | 56r | RARI Bahawalpur |
| G7 | 906 | RARI Bahawalpur | G57 | 17r | RARI Bahawalpur |
| G8 | 926 | RARI Bahawalpur | G58 | 122 | RARI Bahawalpur |
| G9 | 938 | RARI Bahawalpur | G59 | 20r-259 | RARI Bahawalpur |
| G10 | 887 | RARI Bahawalpur | G60 | 291 | RARI Bahawalpur |
| G11 | 856 | RARI Bahawalpur | G61 | 55r - 281 | RARI Bahawalpur |
| G12 | 876 | RARI Bahawalpur | G62 | 57r- 282 | RARI Bahawalpur |
| G13 | 890 | RARI Bahawalpur | G63 | CBI(20-21)r E-161 | RARI Bahawalpur |
| G14 | Akbar19 | RARI Bahawalpur | G64 | 41r - 269 | RARI Bahawalpur |
| G15 | 910 | RARI Bahawalpur | G65 | 64r - 285 | RARI Bahawalpur |
| G16 | 851 | RARI Bahawalpur | G66 | 81 | RARI Bahawalpur |
| G17 | 843 | RARI Bahawalpur | G67 | 147 | RARI Bahawalpur |
| G18 | 949 | RARI Bahawalpur | G68 | 68r | RARI Bahawalpur |
| G19 | 924 | RARI Bahawalpur | G69 | 21r - 256 | RARI Bahawalpur |

| | | | | | |
|---|---|---|---|---|---|
| G20 | 941 | RARI Bahawalpur | G70 | 166 - | RARI Bahawalpur |
| G21 | B6-satluj | RARI Bahawalpur | G71 | 53r - 280 | RARI Bahawalpur |
| G22 | 918 | RARI Bahawalpur | G72 | 294 | RARI Bahawalpur |
| G23 | 895 | RARI Bahawalpur | G73 | 43r - 271 | RARI Bahawalpur |
| G24 | Akbar (C) | RARI Bahawalpur | G74 | 30r - 263 | RARI Bahawalpur |
| G25 | 842 | RARI Bahawalpur | G75 | 132 | RARI Bahawalpur |
| G26 | 886 | RARI Bahawalpur | G76 | 19r - 290 | RARI Bahawalpur |
| G27 | 850 | RARI Bahawalpur | G77 | 51r - 278 | RARI Bahawalpur |
| G28 | Ghazi-19 | RARI Bahawalpur | G78 | 19r - 258 | RARI Bahawalpur |
| G29 | Aas-11 | RARI Bahawalpur | G79 | 12464 | RARI Bahawalpur |
| G30 | Fareed | RARI Bahawalpur | G80 | 65r - 286 | RARI Bahawalpur |
| G31 | Johar-16 | RARI Bahawalpur | G81 | 296 | RARI Bahawalpur |
| G32 | Sehar | RARI Bahawalpur | G82 | 288 Gold | RARI Bahawalpur |
| G33 | Galaxy | RARI Bahawalpur | G83 | 295 | RARI Bahawalpur |
| G34 | Johar-1 | RARI Bahawalpur | G84 | 119 | RARI Bahawalpur |
| G35 | Fsd-8 | RARI Bahawalpur | G85 | 40r - 268 | RARI Bahawalpur |
| G36 | T.D-1 | RARI Bahawalpur | G86 | 59r - 283 | RARI Bahawalpur |
| G37 | Anaaj | RARI Bahawalpur | G87 | 12r - 255 | RARI Bahawalpur |
| G38 | Akbar | RARI Bahawalpur | G88 | 18r - 257 | RARI Bahawalpur |
| G39 | Abdul Sattar | RARI Bahawalpur | G89 | 170 | RARI Bahawalpur |
| G40 | Check Vaiety | RARI Bahawalpur | G90 | 85 | RARI Bahawalpur |
| G41 | 42r | RARI Bahawalpur | G91 | 86 | RARI Bahawalpur |
| G42 | 35r | RARI Bahawalpur | G92 | 87 | RARI Bahawalpur |
| G43 | 43r | RARI Bahawalpur | G93 | 88 | RARI Bahawalpur |
| G44 | 49r | RARI Bahawalpur | G94 | 89 | RARI Bahawalpur |
| G45 | 45r - 273 | RARI Bahawalpur | G95 | 90 | RARI Bahawalpur |
| G46 | 46r - 274 | RARI Bahawalpur | G96 | 91 | RARI Bahawalpur |
| G47 | 47r - 275 | RARI Bahawalpur | G97 | 92 | RARI Bahawalpur |
| G48 | 277 | RARI Bahawalpur | G98 | 93 | RARI Bahawalpur |
| G49 | 50r | RARI Bahawalpur | G99 | 94 | RARI Bahawalpur |
| G50 | 83 | RARI Bahawalpur | G100 | 95 | RARI Bahawalpur |

**Experimental site**

The experiment was conducted at the experimental wire house of the Plant Breeding and Genetics department, the Islamia University of Bahawalpur, Pakistan. Pots with dimensions of 4 x 6 inches for this experiment were used. The pot weighed 4 grams, while the soil weighed 296g. Then 45ml of water was added. The pot used to have a net weight of 350g. This experiment was carried out using the CRD design with three replications 100 pots in each replication.5 seeds were grown in each pot with loamy soil and 1mm of depth. The experimental plot is made up of three rows, each sized 30 cm long and 15cm in width. Thinning was done after 5 days of germination and two healthier plants were selected for data analysis. After seven days of germination, we used distilled water for drought, 15 percent PEG (polyethylene glycol-6000). The solution is prepared according to weight by volume, with 0 g (N, distilled water, control), 150 g (D) PEG dissolved in 850 ml of distilled water. Until 14 days of seedling, the controlled treatment was well watered as needed during the development period to avoid water shortages.

**Data collection**

After 14 days of PEG application, seedling data were recorded. For each genotype, two monitored plants were randomly selected from each pot for agronomic parameters analysis. Shoot length, root length and shoot/root ratio were all measured at different moisture levels.

The data were recorded of following parameters;

**Root length and shoot length (cm)**
After soaking the discs (shoots) in distilled water for 16 to 18 hours, turgid weight was measured. Before determining turgid weight, discs were rapidly and properly dried dry with tissue paper after soaking. After drying the discs sample for 72 hours at 70ºc for 48 hours, the dry weight was determined. The following equation was used to determine the relative water content:

RWC = [(fresh weight – dry weight)/ (turgid weight- dry weight)] x 100

**Statistical analysis**
The experiment was carried out in a Complete Randomized Design (CRD). Analysis of variance (ANOVA) was done using statistics 8.1 software. The mean performance of the genotypes under normal and drought conditions were also calculated. After analysis of variance the data were subjected to the phenotypic and genotypic Correlation analysis along with the heritability and genetic advance which was done by using software R-studio.

**Results and Discussion**
The interactive ANOVA of the given bread wheat 100 genotypes under normal and drought conditions showed highly significant variation among them which is given in the table No. 1.

**Table No. 1: showed the Interactive ANOVA of the 100 bread wheat genotypes under normal and drought conditions**

| **Source** | **DF** | **RL** | **SL** | **RS** | **RWC** | **ELWL** |
|---|---|---|---|---|---|---|
| Get | 99 | 66.13 | 23.02 | 0.12583 | 30.675 | 1.5228 |
| Env | 1 | 4812.25 | 6042.72 | 0.78446 | 985.204 | 4.7955 |
| Get*Env | 99 | 1.56** | 0.86** | 0.00359** | 0.891** | 0.0589** |
| Rep | 2 | 113.7 | 332.32 | 0.0034 | 359.554 | 11.0659 |
| Error | 398 | 1.19 | 1.15 | 0.00094 | 0.403 | 0.0118 |
| Total | 599 | | | | | |

** highly significant, DF degree of freedom, Get genotype, Env environment, Rep Replication, RL root length, SL shoot length, RS root shoot ratio, RWC relative water content, ELWL excise leaf water loss

**Description statistics of the seedling traits**
The mean values in the root length trait ranged from 13.57cm to 28.57cm with the average value of 17.93cm under normal condition while in the drought condition it ranged from 8.59cm to 23.22cm with the average values of 12.62cm. For the drought stress, the root length appeared an important attribute that was reported by many researchers in their studies (Leishman, et al. 1994). The standard deviation of the given 100 wheat genotypes was 3.44 under normal environment with the CV value of 19.19 while under drought environment its value was 3.41 with the CV value of 27.05 as showed in the Table No. 2.
The mean values of the shoot length attribute of the given 100 genotypes under the normal condition ranged from 22.9cm to 32.29cm with the average value of 27.66cm, the standard deviation of the trait was 2.02 with the CV value of 7.31 while in the drought condition the values ranged from 18.13cm to 27.56cm with the average value of 21.76, the calculated standard deviation of SL was 2.07 with the CV value of 9.51 as showed in the Table No. 2
The attribute root shoot ratio showed the maximum and minimum mean values ranged from 0.42 to 0.97 with the average value of 0.65 under the normal environmental condition, the standard deviation with value of 0.13 and the value of CV was calculated 20.96 while in the drought environment the value ranged from 0.33 to 0.97 with the average value of 0.58, the standard deviation value was 0.16 with the CV of 28.10 as showed in the table No. 2. The stress of the water has major effect on the early stage traits of the wheat plant (root length, shoot length, dry weight) the mean range is decreased in all the among given traits except root shoot ratio in the drought condition as compared to normal (Ahmad, et al. 2014).

The mean values in the relative water content trait ranged from 68.94 to 82.96 with the average value of 73.65 under normal condition while in the drought condition it ranges from 65.12 to 81.23 with the average values of 70.78. The standard deviation of the given 100 wheat genotypes was 2.21 under normal environment with the CV value of 3.00 while under drought environment its value was 2.59 with the CV value of 3.67 as showed in the Table No. 2.

The mean values of the excised leaf water loss attribute of the given 100 genotypes under the normal condition ranged from 2.26 to 4.66 with the average value of 3.61, the standard deviation of the trait was 0.509 with the CV value of 14.08 while in the drought condition the values ranged from 2.11 to 4.73 with the average value of 3.54, the calculated standard deviation of ELWL was 0.53 with the CV value of 14.96 as showed in the table No. 2. Excise leaf water loss attribute as selection criteria for drought tolerance had been widely used in many crops (Bhutta, 2007; Ali et al., 2017). The plant having capability of maintaining high leaf water content if combined with extensive root system can perform better and will have superior adaptation to the dry environment and water scarcity condition. The similar aspect was also been drawn by Hurd and Spratt, et al. (1975).

**Table No. 2: Descriptive Statistics of seedling attributes in 100 wheat genotypes under normal and drought conditions**

| Traits | Env | Minimum | Maximum | Mean | SD | C.V |
|---|---|---|---|---|---|---|
| **RL** | **N** | 13.57 | 28.57 | 17.934 | 3.4424 | 19.195 |
| | **D** | 8.59 | 23.22 | 12.628 | 3.417 | 27.059 |
| **SL** | **N** | 22.9 | 32.29 | 27.667 | 2.0251 | 7.3193 |
| | **D** | 18.13 | 27.56 | 21.761 | 2.0715 | 9.5193 |
| **RS** | **N** | 0.42 | 0.97 | 0.6527 | 0.1368 | 20.968 |
| | **D** | 0.33 | 0.97 | 0.5852 | 0.1645 | 28.108 |
| **RWC** | **N** | 68.947 | 82.964 | 73.652 | 2.2145 | 3.0067 |
| | **D** | 65.12 | 81.23 | 70.781 | 2.5983 | 3.6709 |
| **ELWL** | **N** | 2.2683 | 4.6683 | 3.6149 | 0.509 | 14.08 |
| | **D** | 2.11 | 4.73 | 3.547 | 0.5309 | 14.969 |

**Reduction percentage of studied genotypes**

The analysis for the reduction percentage indicates that the genotype performed best and worst in normal and drought conditions. The genotypes which had a minimum value of reduction percentage indicated their best performance in both environments whereas the genotypes having a maximum value of reduction percentage performed worst in both environments.

In the root length trait, the genotypes that performed best and showed minimum reduction percentage in the stress condition were G20 (18.72), G25 (18.94), G43 (19.63), G44 (20.05), G90 (20.42), G45 (22.69), G15 (22.69) while the genotypes that performed worst and had maximum reduction percentage were G82 (37.51), G42 (36.77), G76 (36.73), G86 (36.70) as showed in the table 3-A. The improvement in the wheat breeding program was recommended for resistance to drought can be predicted for the selection of the maximum length of the root (Dhanda, et al. 2004). The work on the stimulated root growth in water-scarce conditions was also described by many scientists (Seghal, et al. 2015).

In the mean performance of shoot length attribute the genotypes that performed best and showed minimum reduction percentage in the stress condition were G15 (27.26), G90 (27.44), G45 (25.86), G25 (25.61), G44 (25.59), G43 (25.29), G20 (24.58), G35 (24.57) while the genotypes that performed worst and had maximum reduction percentage were G76 (12.98), G42 (12.89), G82 (14.31), G86 (14.64) as showed in the Table 3-A.The evaluation that is based upon shoot length along with a good root system gives a good adaptation in the rain-fed areas. Many researchers (Ahmad, et al. 2013; Faisal, et al. 2017) assessed the poor growth, length, and weight of the seedlings with drought conditions, the experiments were also similar to the current experiment.

The genotypes in the root shoot ratio attribute that performed best and showed minimum reduction percentage in the stress condition were G25 (-0.97), G90 (-0.95), G44 (-0.66), G20 (0.21), G45 (0.38), G15 (1.45), G43 (1.73), G35 (1.98) while the genotypes that performed worst and had maximum reduction percentage were G82 (22.83), G42 (21.66), G86 (21.44), G76 (21.36) as showed in the table 3-A. The traits related to plant growth, such as root length, and shoot length are characterized as major selection criteria for the selection of drought-resistant genotypes (Foito, et al. 2009). Similar results were concluded by the scientist as the increase in the drought conditions the decrease in the growth of the plant is recorded (Khodarahmpour, et al. 2011)

In the relative water content trait, the genotypes that performed best and showed minimum reduction percentage in the stress condition were G15 (0.84), G44 (1.38), G43 (1.39), G35 (1.76), G25 (1.85), G45 (2.00), G20 (2.09), G90 (2.41) while the genotypes that performed worst and had maximum reduction percentage were G82 (5.81), G86 (5.55), G76 (5.44), G42 (5.17) as showed in the table 3-B. Deficit Moisture in the soil is an adverse factor in arid and semi-arid zones, lowering the crop potential and productivity (Esfandiari, et al. 2007). Similarly, a higher reduction in relative water content in drought-susceptible wheat genotypes as compared to drought-tolerant ones was also observed earlier (Subrahmanyam, et al. 2006; Pour-Aboughadareh, et al. 2017).

In the excised leaf water loss attribute the mean maximum performance of the genotypes that performed best and showed minimum reduction percentage in the stress condition was G20 (6.98), G15 (6.70), G90 (6.44), G35 (6.01), G43 (4.61), G25 (4.57), G44 (4.43), G45 (4.28) while the genotypes that performed worst and had maximum reduction percentage were G82 (-2.05), G42 (-1.85), G76 (-1.68), G86 (-1.32) as showed in the table 3-B. Delayed selection until 3 or 4 generations should be suggested to accumulate genes reducing water loss in plants. Similar kind of results was presented by Dhanda and Sethi (1998) and contradictory results were shown by Farshadfar et al. (2001b); Kumar and Sharma (2007).

**Table 3-A: showed the mean reduction percentage of root length, shoot length and root shoot ratio of the given 100 bread wheat genotypes under normal and drought conditions.**

| Gen | RL | | | SL | | | RS | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | D | R% | N | D | R% | N | D | R% |
| G1 | 17.90 | 12.56 | 29.87 | 29.11 | 23.23 | 20.20 | 0.62 | 0.54 | 12.28 |
| G2 | 22.52 | 17.17 | 23.75 | 26.56 | 20.68 | 22.14 | 0.84 | 0.81 | 4.00 |
| G3 | 19.07 | 13.72 | 28.04 | 26.90 | 21.02 | 21.86 | 0.70 | 0.65 | 6.62 |
| G4 | 23.24 | 17.89 | 23.01 | 27.06 | 21.18 | 21.73 | 0.86 | 0.84 | 2.29 |
| G5 | 23.13 | 17.78 | 23.12 | 27.44 | 21.56 | 21.43 | 0.85 | 0.83 | 2.47 |
| G6 | 17.90 | 12.63 | 29.48 | 26.34 | 20.45 | 22.36 | 0.68 | 0.62 | 9.59 |
| G7 | 17.68 | 12.40 | 29.85 | 27.12 | 21.23 | 21.72 | 0.65 | 0.58 | 10.36 |
| G8 | 17.35 | 12.07 | 30.42 | 25.94 | 20.05 | 22.70 | 0.67 | 0.60 | 9.91 |
| G9 | 17.24 | 11.96 | 30.62 | 26.44 | 20.55 | 22.28 | 0.65 | 0.58 | 10.58 |
| G10 | 17.24 | 11.96 | 30.62 | 26.76 | 20.87 | 22.01 | 0.64 | 0.57 | 10.85 |
| G11 | 15.24 | 9.96 | 34.64 | 29.73 | 23.84 | 19.81 | 0.51 | 0.42 | 18.36 |
| G12 | 15.24 | 9.96 | 34.64 | 29.89 | 24.00 | 19.70 | 0.51 | 0.42 | 18.47 |
| G13 | 15.07 | 9.79 | 35.02 | 29.90 | 24.01 | 19.70 | 0.50 | 0.41 | 18.95 |
| G14 | 14.57 | 9.29 | 36.22 | 30.06 | 24.17 | 19.59 | 0.48 | 0.38 | 20.54 |
| G15 | 23.57 | 18.22 | 22.69 | 26.81 | 19.45 | 27.46 | 0.88 | 0.87 | 1.45 |
| G16 | 19.57 | 14.22 | 27.33 | 27.22 | 21.34 | 21.60 | 0.72 | 0.67 | 7.35 |
| G17 | 17.94 | 12.59 | 29.81 | 26.27 | 20.39 | 22.38 | 0.68 | 0.62 | 9.44 |
| G18 | 18.31 | 12.96 | 29.21 | 26.44 | 20.56 | 22.24 | 0.70 | 0.63 | 9.20 |
| G19 | 19.24 | 13.89 | 27.80 | 26.44 | 20.56 | 22.24 | 0.73 | 0.68 | 7.29 |
| G20 | 28.57 | 23.22 | 18.72 | 29.57 | 22.30 | 24.58 | 0.97 | 0.97 | 0.21 |
| G21 | 19.90 | 14.56 | 26.87 | 25.84 | 19.96 | 22.76 | 0.77 | 0.73 | 5.27 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| G22 | 19.24 | 13.89 | 27.80 | 25.95 | 20.07 | 22.66 | 0.74 | 0.69 | 6.62 |
| G23 | 19.90 | 14.56 | 26.87 | 25.67 | 19.79 | 22.90 | 0.78 | 0.74 | 5.02 |
| G24 | 19.57 | 14.22 | 27.33 | 26.17 | 20.29 | 22.47 | 0.75 | 0.70 | 6.35 |
| G25 | 28.24 | 22.89 | 18.94 | 29.74 | 22.12 | 25.61 | 0.95 | 0.96 | -0.97 |
| G26 | 18.57 | 13.22 | 28.80 | 25.34 | 19.46 | 23.20 | 0.73 | 0.68 | 7.20 |
| G27 | 18.57 | 13.22 | 28.80 | 25.67 | 19.79 | 22.90 | 0.73 | 0.67 | 7.77 |
| G28 | 17.57 | 12.22 | 30.44 | 25.01 | 19.13 | 23.51 | 0.70 | 0.64 | 9.01 |
| G29 | 17.90 | 12.56 | 29.87 | 29.11 | 23.23 | 20.20 | 0.62 | 0.54 | 12.28 |
| G30 | 20.51 | 15.17 | 26.07 | 26.01 | 20.13 | 22.61 | 0.79 | 0.75 | 4.31 |
| G31 | 19.24 | 13.89 | 27.80 | 26.01 | 20.13 | 22.61 | 0.74 | 0.69 | 6.55 |
| G32 | 17.24 | 11.89 | 31.02 | 29.74 | 23.86 | 19.77 | 0.59 | 0.50 | 15.04 |
| G33 | 17.57 | 12.22 | 30.44 | 24.01 | 18.13 | 24.49 | 0.73 | 0.68 | 7.86 |
| G34 | 19.24 | 13.89 | 27.80 | 24.01 | 18.13 | 24.49 | 0.80 | 0.77 | 4.26 |
| G35 | 27.51 | 22.17 | 19.44 | 28.71 | 21.66 | 24.57 | 0.96 | 0.94 | 1.98 |
| G36 | 14.57 | 9.22 | 36.70 | 22.90 | 18.56 | 18.95 | 0.64 | 0.54 | 14.69 |
| G37 | 15.24 | 9.89 | 35.10 | 23.73 | 18.45 | 22.25 | 0.64 | 0.55 | 13.59 |
| G38 | 17.90 | 12.56 | 29.87 | 24.06 | 18.18 | 24.44 | 0.74 | 0.69 | 7.13 |
| G39 | 18.90 | 13.56 | 28.29 | 24.73 | 18.85 | 23.78 | 0.77 | 0.72 | 5.87 |
| G40 | 14.57 | 9.22 | 36.70 | 24.73 | 18.85 | 23.78 | 0.59 | 0.49 | 16.81 |
| G41 | 14.57 | 9.22 | 36.70 | 24.90 | 19.02 | 23.62 | 0.58 | 0.49 | 16.98 |
| G42 | 14.54 | 9.20 | 36.77 | 25.39 | 22.12 | 12.89 | 0.57 | 0.45 | 21.66 |
| G43 | 27.24 | 21.89 | 19.63 | 28.56 | 21.34 | 25.29 | 0.95 | 0.94 | 1.73 |
| G44 | 26.67 | 21.32 | 20.05 | 28.53 | 21.23 | 25.59 | 0.94 | 0.94 | -0.66 |
| G45 | 23.57 | 18.22 | 22.69 | 26.23 | 19.45 | 25.86 | 0.90 | 0.90 | 0.38 |
| G46 | 23.24 | 17.89 | 23.01 | 26.40 | 20.52 | 22.27 | 0.88 | 0.84 | 4.70 |
| G47 | 20.57 | 15.22 | 26.00 | 26.56 | 20.68 | 22.14 | 0.78 | 0.74 | 4.93 |
| G48 | 19.57 | 14.22 | 27.33 | 26.56 | 20.68 | 22.14 | 0.74 | 0.69 | 6.62 |
| G49 | 18.57 | 13.25 | 28.67 | 26.62 | 20.74 | 22.09 | 0.70 | 0.64 | 8.59 |
| G50 | 17.90 | 12.63 | 29.48 | 26.34 | 20.45 | 22.36 | 0.68 | 0.62 | 9.59 |
| G51 | 17.68 | 12.40 | 29.85 | 27.12 | 21.23 | 21.72 | 0.65 | 0.58 | 10.36 |
| G52 | 17.35 | 12.07 | 30.42 | 25.94 | 20.05 | 22.70 | 0.67 | 0.60 | 9.91 |
| G53 | 17.24 | 11.96 | 30.62 | 26.44 | 20.55 | 22.28 | 0.65 | 0.58 | 10.58 |
| G54 | 17.24 | 11.96 | 30.62 | 26.76 | 20.87 | 22.01 | 0.64 | 0.57 | 10.85 |
| G55 | 16.79 | 11.52 | 31.43 | 26.77 | 20.88 | 22.00 | 0.63 | 0.55 | 11.94 |
| G56 | 16.57 | 11.29 | 31.85 | 26.77 | 20.88 | 22.00 | 0.62 | 0.54 | 12.51 |
| G57 | 16.35 | 11.07 | 32.28 | 26.77 | 20.88 | 22.00 | 0.61 | 0.53 | 13.02 |
| G58 | 15.79 | 10.52 | 33.42 | 26.76 | 20.87 | 22.01 | 0.59 | 0.50 | 14.48 |
| G59 | 15.79 | 10.52 | 33.42 | 26.74 | 20.85 | 22.03 | 0.59 | 0.50 | 15.10 |
| G60 | 15.57 | 10.29 | 33.90 | 27.46 | 21.57 | 21.45 | 0.57 | 0.48 | 15.78 |
| G61 | 15.50 | 10.23 | 34.04 | 27.51 | 21.62 | 21.41 | 0.56 | 0.47 | 16.06 |
| G62 | 15.50 | 10.23 | 34.04 | 26.78 | 20.89 | 21.99 | 0.58 | 0.49 | 15.31 |
| G63 | 16.87 | 11.59 | 31.28 | 27.68 | 21.79 | 21.28 | 0.61 | 0.53 | 12.39 |
| G64 | 15.47 | 10.19 | 34.11 | 28.56 | 22.67 | 20.62 | 0.54 | 0.45 | 16.88 |
| G65 | 17.54 | 12.26 | 30.09 | 29.06 | 23.17 | 20.27 | 0.60 | 0.53 | 11.93 |
| G66 | 15.47 | 10.19 | 34.11 | 29.06 | 23.17 | 20.27 | 0.53 | 0.44 | 17.25 |
| G67 | 15.37 | 10.09 | 34.34 | 29.06 | 23.17 | 20.27 | 0.53 | 0.44 | 17.52 |
| G68 | 15.24 | 9.96 | 34.64 | 29.06 | 23.17 | 20.27 | 0.52 | 0.43 | 17.90 |
| G69 | 15.24 | 9.96 | 34.64 | 29.23 | 23.34 | 20.15 | 0.52 | 0.43 | 18.01 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| G70 | 15.24 | 9.96 | 34.64 | 29.23 | 23.34 | 20.15 | 0.52 | 0.43 | 18.02 |
| G71 | 15.24 | 9.96 | 34.64 | 29.73 | 23.84 | 19.81 | 0.51 | 0.42 | 18.36 |
| G72 | 15.24 | 9.96 | 34.64 | 29.89 | 24.00 | 19.70 | 0.51 | 0.42 | 18.47 |
| G73 | 15.07 | 9.79 | 35.02 | 29.90 | 24.01 | 19.70 | 0.50 | 0.41 | 18.95 |
| G74 | 14.57 | 9.29 | 36.22 | 30.06 | 24.17 | 19.59 | 0.48 | 0.38 | 20.54 |
| G75 | 14.67 | 9.39 | 35.97 | 30.06 | 24.17 | 19.59 | 0.49 | 0.39 | 20.23 |
| G76 | 14.37 | 9.09 | 36.73 | 30.40 | 26.45 | 12.98 | 0.47 | 0.37 | 21.36 |
| G77 | 15.24 | 9.96 | 34.64 | 30.23 | 24.34 | 19.48 | 0.50 | 0.41 | 18.69 |
| G78 | 15.57 | 10.29 | 33.90 | 30.40 | 24.51 | 19.38 | 0.51 | 0.42 | 17.88 |
| G79 | 18.57 | 13.29 | 28.42 | 30.40 | 24.51 | 19.38 | 0.61 | 0.54 | 11.15 |
| G80 | 16.90 | 11.63 | 31.22 | 29.44 | 23.55 | 20.01 | 0.57 | 0.49 | 13.90 |
| G81 | 14.90 | 9.63 | 35.41 | 30.11 | 24.22 | 19.56 | 0.49 | 0.40 | 19.56 |
| G82 | 14.07 | 8.79 | 37.51 | 31.23 | 26.76 | 14.31 | 0.45 | 0.35 | 22.83 |
| G83 | 16.24 | 10.96 | 32.50 | 30.77 | 24.88 | 19.14 | 0.53 | 0.44 | 16.37 |
| G84 | 15.24 | 9.96 | 34.64 | 29.01 | 23.12 | 20.31 | 0.52 | 0.43 | 17.83 |
| G85 | 15.90 | 10.63 | 33.18 | 29.01 | 23.12 | 20.31 | 0.55 | 0.46 | 16.11 |
| G86 | 13.57 | 8.59 | 36.70 | 32.29 | 27.56 | 14.64 | 0.42 | 0.33 | 21.44 |
| G87 | 17.57 | 12.29 | 30.04 | 30.96 | 25.07 | 19.02 | 0.57 | 0.49 | 13.68 |
| G88 | 14.57 | 9.29 | 36.22 | 30.30 | 24.41 | 19.44 | 0.48 | 0.38 | 20.95 |
| G89 | 17.57 | 12.29 | 30.04 | 30.16 | 24.27 | 19.53 | 0.58 | 0.51 | 13.06 |
| G90 | 26.18 | 20.84 | 20.42 | 27.73 | 20.12 | 27.44 | 0.95 | 0.95 | -0.95 |
| G91 | 22.52 | 12.07 | 46.39 | 26.56 | 23.30 | 12.29 | 0.84 | 0.60 | 28.60 |
| G92 | 19.07 | 11.96 | 37.29 | 26.90 | 20.55 | 23.60 | 0.70 | 0.58 | 16.79 |
| G93 | 23.24 | 11.96 | 48.53 | 27.06 | 20.87 | 22.90 | 0.86 | 0.57 | 33.28 |
| G94 | 23.13 | 11.52 | 50.21 | 27.44 | 20.88 | 23.89 | 0.85 | 0.55 | 34.82 |
| G95 | 17.90 | 11.29 | 36.92 | 26.34 | 20.88 | 20.72 | 0.68 | 0.54 | 20.82 |
| G96 | 15.24 | 11.07 | 27.34 | 29.06 | 28.90 | 0.56 | 0.52 | 0.51 | 2.60 |
| G97 | 15.24 | 10.52 | 30.99 | 29.23 | 28.70 | 1.81 | 0.52 | 0.50 | 3.16 |
| G98 | 15.24 | 10.52 | 30.99 | 29.23 | 29.30 | -0.23 | 0.52 | 0.50 | 3.07 |
| G99 | 15.24 | 10.29 | 32.45 | 29.73 | 28.60 | 3.80 | 0.51 | 0.48 | 6.71 |
| G100 | 15.24 | 10.23 | 32.89 | 29.89 | 27.56 | 7.81 | 0.51 | 0.47 | 7.04 |

Gen genotype, N normal, D drought, R% reduction percentage, RL root length, SL shoot length, RS root shoot ratio

**Table 3-A: showed the mean reduction percentage of relative water content and excised leaf water loss of the given 100 bread wheat genotypes under normal and drought conditions.**

| Gen | RWC | | | ELWL | | | Gen | RWC | | | ELWL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | R% | N | D | R% | | N | D | R% | N | D | R% |
| G1 | 73.63 | 70.71 | 3.97 | 3.07 | 3.00 | 2.35 | G51 | 74.96 | 71.97 | 4.00 | 3.57 | 3.50 | 2.02 |
| G2 | 73.63 | 70.71 | 3.97 | 2.97 | 2.90 | 2.42 | G52 | 74.45 | 71.45 | 4.03 | 4.17 | 4.10 | 1.73 |
| G3 | 74.96 | 72.04 | 3.90 | 3.17 | 3.10 | 2.27 | G53 | 73.63 | 70.63 | 4.07 | 4.17 | 4.11 | 1.41 |
| G4 | 73.63 | 70.71 | 3.97 | 3.27 | 3.20 | 2.20 | G54 | 74.96 | 71.97 | 4.00 | 3.07 | 3.01 | 1.91 |
| G5 | 74.96 | 72.04 | 3.90 | 4.07 | 4.00 | 1.77 | G55 | 72.95 | 69.95 | 4.11 | 4.07 | 4.01 | 1.44 |
| G6 | 73.63 | 70.63 | 4.07 | 4.17 | 4.10 | 1.73 | G56 | 73.63 | 70.63 | 4.07 | 3.87 | 3.81 | 1.52 |
| G7 | 74.96 | 71.97 | 4.00 | 3.57 | 3.50 | 2.02 | G57 | 74.96 | 71.97 | 4.00 | 3.87 | 3.80 | 1.86 |
| G8 | 74.45 | 71.45 | 4.03 | 4.17 | 4.10 | 1.73 | G58 | 73.63 | 70.63 | 4.07 | 4.07 | 4.00 | 1.77 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G9 | 73.63 | 70.63 | 4.07 | 4.17 | 4.11 | 1.41 | G59 | 74.96 | 71.97 | 4.00 | 3.87 | 3.91 | -1.07 |
| G10 | 74.96 | 71.97 | 4.00 | 3.07 | 3.01 | 1.91 | G60 | 73.62 | 71.23 | 3.25 | 4.07 | 4.00 | 1.77 |
| G11 | 71.89 | 68.89 | 4.17 | 4.17 | 4.10 | 1.73 | G61 | 70.96 | 67.97 | 4.23 | 3.87 | 3.80 | 1.86 |
| G12 | 71.89 | 68.89 | 4.17 | 4.17 | 4.10 | 1.73 | G62 | 70.96 | 67.97 | 4.23 | 4.07 | 4.00 | 1.77 |
| G13 | 71.89 | 68.89 | 4.17 | 3.07 | 3.00 | 2.35 | G63 | 71.25 | 68.25 | 4.21 | 3.57 | 3.50 | 2.02 |
| G14 | 71.89 | 68.89 | 4.17 | 4.07 | 4.00 | 1.77 | G64 | 73.63 | 70.63 | 4.07 | 3.37 | 3.30 | 2.14 |
| G15 | 73.63 | 73.01 | 0.84 | 2.96 | 2.76 | 6.70 | G65 | 74.96 | 71.97 | 4.00 | 3.67 | 3.60 | 1.96 |
| G16 | 74.96 | 72.04 | 3.90 | 3.17 | 3.10 | 2.27 | G66 | 71.30 | 68.30 | 4.21 | 3.07 | 3.00 | 2.35 |
| G17 | 73.63 | 70.71 | 3.97 | 3.37 | 3.30 | 2.14 | G67 | 71.30 | 68.30 | 4.21 | 3.37 | 3.30 | 2.14 |
| G18 | 74.96 | 72.04 | 3.90 | 3.67 | 3.60 | 1.96 | G68 | 71.58 | 68.58 | 4.19 | 4.17 | 4.10 | 1.73 |
| G19 | 75.28 | 72.36 | 3.89 | 3.87 | 3.80 | 1.86 | G69 | 71.89 | 68.89 | 4.17 | 4.17 | 4.10 | 1.73 |
| G20 | 82.96 | 81.23 | 2.09 | 2.27 | 2.11 | 6.98 | G70 | 71.89 | 68.89 | 4.17 | 3.57 | 3.50 | 2.02 |
| G21 | 74.95 | 72.02 | 3.90 | 3.07 | 3.00 | 2.35 | G71 | 71.89 | 68.89 | 4.17 | 4.17 | 4.10 | 1.73 |
| G22 | 74.28 | 71.36 | 3.94 | 3.67 | 3.60 | 1.96 | G72 | 71.89 | 68.89 | 4.17 | 4.17 | 4.10 | 1.73 |
| G23 | 73.62 | 70.69 | 3.97 | 3.57 | 3.50 | 2.02 | G73 | 71.89 | 68.89 | 4.17 | 3.07 | 3.00 | 2.35 |
| G24 | 71.64 | 68.72 | 4.08 | 3.67 | 3.60 | 1.96 | G74 | 71.89 | 68.89 | 4.17 | 4.07 | 4.00 | 1.77 |
| G25 | 81.96 | 80.45 | 1.85 | 2.37 | 2.26 | 4.57 | G75 | 71.89 | 68.89 | 4.17 | 3.87 | 3.80 | 1.86 |
| G26 | 72.30 | 68.76 | 4.89 | 3.47 | 3.40 | 2.07 | G76 | 70.60 | 66.76 | 5.44 | 4.27 | 4.34 | -1.68 |
| G27 | 73.63 | 70.71 | 3.97 | 3.67 | 3.60 | 1.96 | G77 | 72.56 | 69.56 | 4.13 | 4.17 | 4.10 | 1.73 |
| G28 | 74.96 | 72.04 | 3.90 | 3.87 | 3.80 | 1.86 | G78 | 72.89 | 69.89 | 4.11 | 3.57 | 3.50 | 2.02 |
| G29 | 73.63 | 70.71 | 3.97 | 3.07 | 3.00 | 2.35 | G79 | 72.91 | 69.45 | 4.75 | 3.07 | 2.97 | 3.20 |
| G30 | 74.96 | 72.04 | 3.90 | 3.37 | 3.30 | 2.14 | G80 | 73.25 | 70.25 | 4.09 | 3.07 | 3.00 | 2.35 |
| G31 | 71.25 | 68.74 | 3.52 | 3.77 | 3.70 | 1.91 | G81 | 73.27 | 70.27 | 4.09 | 3.77 | 3.70 | 1.91 |
| G32 | 73.63 | 70.71 | 3.97 | 3.57 | 3.50 | 1.91 | G82 | 69.95 | 65.88 | 5.81 | 4.47 | 4.56 | -2.05 |
| G33 | 71.61 | 68.69 | 4.08 | 3.37 | 3.30 | 2.14 | G83 | 73.27 | 70.27 | 4.09 | 3.97 | 3.90 | 1.81 |
| G34 | 72.45 | 69.52 | 4.04 | 3.07 | 3.00 | 2.35 | G84 | 73.27 | 70.27 | 4.09 | 3.57 | 3.50 | 2.02 |
| G35 | 79.96 | 78.56 | 1.76 | 2.47 | 2.32 | 6.01 | G85 | 73.30 | 70.30 | 4.09 | 3.67 | 3.60 | 1.96 |
| G36 | 73.63 | 70.71 | 3.97 | 3.47 | 3.40 | 2.07 | G86 | 68.95 | 65.12 | 5.55 | 4.67 | 4.73 | -1.32 |
| G37 | 74.96 | 72.04 | 3.90 | 3.47 | 3.40 | 2.07 | G87 | 73.58 | 70.58 | 4.08 | 3.07 | 3.00 | 2.35 |
| G38 | 71.25 | 68.32 | 4.11 | 3.57 | 3.50 | 2.02 | G88 | 73.96 | 70.97 | 4.05 | 4.07 | 4.00 | 1.77 |
| G39 | 73.63 | 70.23 | 4.62 | 3.07 | 2.99 | 2.55 | G89 | 74.22 | 71.22 | 4.04 | 3.97 | 3.90 | 1.81 |
| G40 | 73.63 | 70.71 | 3.97 | 3.67 | 3.60 | 1.96 | G90 | 76.96 | 75.11 | 2.41 | 2.77 | 2.59 | 6.44 |
| G41 | 74.96 | 72.04 | 3.90 | 3.77 | 3.70 | 1.91 | G91 | 73.63 | 71.45 | 2.96 | 2.97 | 2.90 | 2.30 |
| G42 | 73.45 | 69.65 | 5.17 | 3.87 | 3.94 | -1.85 | G92 | 74.96 | 70.63 | 5.78 | 3.17 | 3.02 | 4.68 |
| G43 | 78.96 | 77.87 | 1.39 | 2.57 | 2.45 | 4.61 | G93 | 73.63 | 71.97 | 2.26 | 3.27 | 3.20 | 2.09 |
| G44 | 77.96 | 76.89 | 1.38 | 2.67 | 2.55 | 4.43 | G94 | 74.96 | 69.95 | 6.69 | 4.07 | 4.01 | 1.44 |
| G45 | 74.95 | 73.45 | 2.00 | 4.17 | 3.99 | 4.28 | G95 | 73.63 | 70.63 | 4.07 | 4.17 | 4.03 | 3.22 |
| G46 | 73.63 | 70.71 | 3.97 | 4.17 | 4.10 | 1.73 | G96 | 71.58 | 68.56 | 4.22 | 4.17 | 4.12 | 1.11 |
| G47 | 74.96 | 72.04 | 3.90 | 3.87 | 3.80 | 1.86 | G97 | 71.89 | 68.34 | 4.94 | 4.17 | 4.12 | 1.09 |
| G48 | 71.25 | 68.32 | 4.11 | 3.07 | 3.00 | 2.35 | G98 | 71.89 | 66.76 | 7.13 | 3.57 | 3.45 | 3.20 |
| G49 | 73.63 | 70.67 | 4.02 | 4.17 | 4.10 | 1.73 | G99 | 71.89 | 65.43 | 8.98 | 4.17 | 4.10 | 1.64 |
| G50 | 73.63 | 70.63 | 4.07 | 4.17 | 4.10 | 1.73 | G100 | 71.89 | 67.97 | 5.46 | 4.17 | 4.10 | 1.64 |

Gen genotype, N normal, D drought, R% reduction percentage, RWC relative water content, ELWL excised leaf water loss

The best and worst performance of the given wheat genotypes under the studied traits root length, shoot length, root shoot ratio, relative water content and excise leaf water loss with their mean performance are given in Table No. 4. The radar analysis of the given attributes like root length, shoot length and relative water content of the 100 bread wheat genotypes with their mean performance were given in the Figure No.1 and the mean performance of the traits like root shoot ratio and excise leaf water loss were given in the Figure No.2.

**Table No.4: showed the best and the worst performance of the given bread wheat 100 genotypes under normal and drought conditions.**

| Trait | Genotype with the best performance | Genotype with the worst performance |
|---|---|---|
| Root Length | G20(18.72),G25(18.94),G35(19.44),G43(19.6),G44(20.05), G90(20.42),G45(22.69),G15(22.6) | G82 (37.51),G42 (36.77),G76 (36.73),G86 (36.70) |
| Shoot length | G15(27.26),G90(27.44),G45(25.86),G25(25.6), G44(25.59),G43(25.29),G20(24.58),G35(24.57) | G76 (12.98),G42 (12.89),G82 (14.31),G86 (14.64) |
| Root shoot ratio | G25(-0.97),G90(-0.95),G44(-0.66),G20(0.21), G45(0.38),G15(1.45),G43(1.73),G35(1.98) | G82(22.83),G42 (21.66),G86 (21.44),G76 (21.36) |
| Relative water content | G15(0.84),G44(1.38),G43(1.39),G35(1.76), G25(1.85),G45(2.00),G20(2.09),G90(2.41) | G82 (5.81),G86 (5.55),G76 (5.44),G42 (5.17) |
| Excise leaf water loss | G20(6.98),G15(6.70),G90(6.44),G35(6.01), G43(4.61), G25(4.57), G44(4.43), G45(4.28) | G82 (-2.05),G42 (-1.85),G76(-1.68),G86 (-1.32) |

## Genotypic and Phenotypic correlation

Genotypic and phenotypic correlation for all possible traits is given in table No.1. A positive value of r shows that the changes of two variables are in the same direction, that is, a high variable of one variable is associated with high values of other and vice versa. In general, the magnitude of the genotypic correlation (rg) was higher than those of the phenotypic correlation (rP). This revealed that association among these characters was under genetic control and indicated the preponderance of genetic variance in the expression of characters. It might be due to the depressing effect of the environment on the character. When the value of "rp" was greater than "rg", it showed that the apparent association of the two traits was not only due to the genes but also due to the favorable influence of the environment. By contrast, if the value of r was zero or insignificant this showed that the two traits were independent.

**Table No. 5-A: showed the genotypic and phenotypic correlation analysis of 100 bread wheat genotypes under normal conditions.**

| | RL | SL | RS | RWC | ELWL |
|---|---|---|---|---|---|
| RL | 1 ** | -0.1304 * | 0.9333 ** | 0.7241 ** | -0.602 ** |
| SL | -0.165 NS | 1 ** | -0.4683 ** | -0.0999 NS | 0.0672 NS |
| RS | 0.9474 ** | -0.4706 ** | 1 ** | 0.6558 ** | -0.5464 ** |
| RWC | 0.7549 ** | -0.1196 NS | 0.6898 ** | 1 ** | -0.5553 ** |
| ELWL | -0.6132 ** | 0.0751 NS | -0.5613 ** | -0.5736 ** | 1 ** |

**Table No. 5-B: showed the genotypic and phenotypic correlation analysis of 100 bread wheat genotypes under Drought conditions.**

| | RL | SL | RS | RWC | ELWL |
|---|---|---|---|---|---|
| RL | 1 ** | -0.3293 ** | 0.9464 ** | 0.765 ** | -0.6137 ** |
| SL | -0.3341 ** | 1 ** | -0.5927 ** | -0.3004 ** | 0.2516 ** |
| RS | 0.9493 ** | -0.599 ** | 1 ** | 0.6984 ** | -0.5682 ** |
| RWC | 0.7867 ** | -0.3288 ** | 0.7255 ** | 1 ** | -0.5722 ** |
| ELWL | -0.6281 ** | 0.2397 * | -0.5763 ** | -0.6348 ** | 1 ** |

**Root length**

The root length in the non-stressed condition showed positive and highly significant correlation with the trait like root shoot ratio and relative water content with the values 0.93** and 0.72** respectively while the significant and negative correlation with shoot length and highly significant negative correlation with excised leaf water loss with the value of -0.6** in the phenotypic correlation as showed in the table No. 5-A. In the genotypic correlation, the root length showed a positive highly significant correlation with the root shoot ratio and relative water content with the values of 0.94** and 0.75** respectively while showed a highly significant negative association with the excised leaf water loss with the value of -0.61**, the only trait that was negative and non-significant with the value of -0.16ns as showed in the table No. 5-A. Our correlation results contradict the study of Ahmed, et al. (2019). He observed the root length had a negative association with the shoot length and relative water content. In our experiment, root length showed a positive correlation with the root shoot ratio. This result in a similar finding (Ahmed, et al. 2013). In drought, the root length in the stressed condition showed positive and highly significant correlation with the trait like root shoot ratio and relative water content with the values 0.94** and 0.76** respectively while the highly significant negative correlation with shoot length and excised leaf water loss with the value of -0.32** and -0.61** respectively in the phenotypic correlation as showed in the table No. 5-B. In the genotypic correlation, the root length showed a positive highly significant correlation with the root shoot ratio and relative water content with the values of 0.94** and 0.78** respectively while showing a highly significant negative association with the trait like shoot length and excised leaf water loss with the value of -0.33** -0.62** respectively as shown in the table No. 5-B.

**Shoot length**

The shoot length in the non-stressed condition showed a highly significant negative association with the root shoot ratio with the value of -0.46** and the trait root length showed a negative significant association with SL with the value of -0.13* while a positive non-significant correlation with the excise leaf water loss with the value of 0.06ns and the only trait that showed negative non-significant association with shoot length was relative water content with the value of -0.09ns in the phenotypic correlation as showed in the table No. 5-A. In the genotypic correlation, the trait shoot length showed a negative highly significant association with root shoot ratio while the positive and non-significant association with excise leaf water loss with the value of 0.07ns and negative non-significant association with the traits root length and relative water content with the value of -0.15ns and -0.11 ns respectively as showed in the table No. 5-A. By increase in the drought concentration, there is a decrease in the length of the shoot in plants (Nezhadahmadi, et al. 2013). Under drought stress, the phenotypic correlation of the trait shoot length showed a negative highly significant association with root length, root shoot ratio and relative water content with the values of -0.32**, -0.59**, and -0.30** respectively while the positive and significant association with excise leaf water loss with the value of 0.25** as shown in the table No. 5-B. The shoot length in the stressed condition showed a highly significant negative association with the root length, root shoot ratio and relative water content with the value of -0.33**, -0.59**, and -0.32** respectively while a positive significant correlation with the excised leaf water loss with the value of 0.23* in the genotypic correlation as shown in the table No. 5-B.

**Root shoot ratio**

The trait root shoot ratio showed a positive highly significant association with a trait like a root length relative to water content with the value of 0.93** and 0.65 ** respectively while a highly significant negative correlation with the trait like shoot length and excised leaf water loss with the value of -0.46** and -0.54** respectively in the phenotypic correlation as showed in the table No. 5-A while it showed positive highly significant association with the traits like root length and relative water content with the value of 0.94** and 0.68 ** respectively while the highly significant negative correlation with the traits like shoot length and excised leaf water loss with the value of -0.47** and -0.56** respectively in the genotypic correlation as showed in the table No. 5-A. The different behavior of the indices in various conditions and their association may be due to an altered behavior of varieties under different environments. Under water stress, the trait root shoot ratio showed a positive highly significant association with a trait like a root length and relative water content with the value of 0.94** and 0.69** respectively while a highly significant negative correlation with the trait like shoot length and excised leaf water loss with the value of -0.59** and -0.56** respectively in the phenotypic correlation as shown in the table No. 5-B. The trait root shoot ratio showed a positive highly significant association with the traits like root length and relative water content with the value of 0.94** and 0.72 ** respectively while a highly significant negative correlation with the traits like shoot length and excised leaf water loss with the value of -0.59** and -0.57** respectively in the genotypic correlation as shown in the table No. 5-B. The traits that were negatively correlated can affect the performance of other traits during the selection process. Some of the findings (Dhanda, et al. 2004) that were related to the current study in relation to the shoot length revealed that it was negatively associated with root shoot ratio and root length.

**Relative water content**

The relative water content showed a highly significant positive correlation with the traits like RL and RS with the values of 0.72** and 0.65** respectively while it showed a highly significant negative association with the ELWL with values -0.55** and the only trait that showed negative non-significant association with RWC was SL with the value of -0.09ns in the phenotypic correlation as showed in the table No. 5-A. In the genotypic correlation relative water content showed a highly significant positive correlation with the traits like RL and RS with the values of 0.75** and 0.68** respectively while it showed a highly significant negative association with the ELWL with values -0.57** and the only trait that showed negative non-significant association with RWC was SL with the value of -0.11ns as showed in the table No. 5-A. Six wheat genotypes were investigated for their capacity to stand in the water deficit conditions by (Kalaji, et al. 2016). Under the stressed condition, the relative water content showed a highly significant positive correlation with the traits like RL and RS with the values of 0.76** and 0.69** respectively while it showed highly significant negative association with the traits like SL and ELWL with values -0.30** and -0.56** respectively in the phenotypic correlation as shown in the table No. 5-B. In the genotypic correlation relative water content showed highly significant positive correlation with the traits like RL and RS with the values of 0.78** and 0.72** respectively while it showed highly significant negative association with the traits like SL and ELWL with values -0.32** and -0.57** as showed in the table No. 5-B. Many genotypes were screened that can perform well in drought and can withstand well water deficit conditions (Soleimani, et al. 2014). The relative water content is an essential sign of the water present in the plants, it revealed the supply to the leaf and transpiration rate and revealed the stability of the plant.

**Excise leaf water loss**

The excise leaf water loss showed a negative highly significant association with the RL, RS and RWC with the value of -0.60**, -0.54** and 0.55** respectively while a positive non-significant correlation with the trait SL with the value of 0.06ns in the phenotypic correlation as showed in the table No. 5-A. In the genotypic correlation, the excise leaf water loss showed a negative highly significant association with the RL, RS and RWC with the value of -0.61**, -0.56** and -0.57** respectively while a positive non-significant correlation with the trait SL with the value of 0.07 ns as shown in the table No. 5-A. Under drought environment, the excise leaf water loss showed negative highly significant association with the RL, RS and RWC with the value of -0.61**, -0.56** and 0.57** respectively while positive highly significant correlation with the trait SL with the value of 0.25** in the phenotypic correlation as showed in the table No. 5-B. In the genotypic correlation, the excise leaf water loss showed a negative highly significant association with the RL, RS and RWC with the value of -0.62**, -0.57** and -0.63** respectively while positive significant correlation with the trait SL with the value of 0.23* ns as shown in the table No. 5-B.

## Heritability and Genetic Advance

Heritability is the estimation of phenotypic variance in plant breeding. It indicates the transfer of traits from parents to their progeny. It provides information about the degree of genetic control in particular traits expression and phenotypic reliability in predicting its breeding value.

**Table No. 6: shows the calculated genetic advance and heritability values of the 100 wheat genotypes under normal and drought conditions.**

| Traits | RL | | SL | | RS | | RWC | | ELWL | |
|---|---|---|---|---|---|---|---|---|---|---|
| Environments | N | D | N | D | N | D | N | D | N | D |
| SE m | 0.38 | 0.02 | 0.55 | 0.20 | 0.01 | 0.00 | 0.32 | 0.34 | 0 | 0.06 |
| (CD) 5% | 1.06 | 0.06 | 1.55 | 0.57 | 0.05 | 0.02 | 0.91 | 0.97 | 0 | 0.18 |
| (CD) 1% | 1.40 | 0.092 | 2.04 | 0.75 | 0.06 | 0.02 | 1.20 | 1.26 | 0 | 0.24 |
| Env CV | 3.64 | 0.34 | 3.43 | 1.63 | 4.80 | 2.28 | 0.77 | 0.83 | 0 | 3.29 |
| Gen CV | 18.8 | 27.05 | 6.94 | 9.68 | 20.44 | 28.02 | 2.99 | 3.55 | 13.57 | 14.8 |
| P CV | 19.24 | 27.05 | 7.74 | 9.82 | 21.00 | 28.13 | 3.08 | 3.64 | 13.57 | 15.2 |
| H (Broad Sense) | 0.96 | 0.99 | 0.80 | 0.97 | 0.94 | 0.99 | 0.93 | 0.94 | 1 | 0.95 |
| Genetic Advance | 6.92 | 7.03 | 3.58 | 4.27 | 0.26 | 0.33 | 4.37 | 5.03 | 1.04 | 1.06 |
| Genetic Advance % | 38.19 | 55.73 | 12.81 | 19.68 | 40.97 | 57.51 | 5.96 | 7.12 | 27.95 | 29.93 |

Heritability indicates the transfer of the traits from its parent to progeny and estimates the phenotypic variance in plant breeding. It provides information on phenotypic reliability to know its breeding value for selection and the degree of genetic control in specific trait expressions. Heritability is the significant parameter that regulates the expression of the trait considering the role of heredity and environment. The genetic advance is significant for the selection based on the phenotypic appearance in heritability (Johnson, et al. 1955) Heritability is affected by the degree of dominance which may be increased or decreased by the epistasis according to the report Hayman (1954a; 1954b; 1958)

The trait root length showed high values for heritability under both normal and drought conditions with the values of 96% and 99% respectively. The genetic advance is the significant parameter for selection to enhance the degree of targeted traits. The genetic advance percentage exhibited for the trait root length is very high under both normal and drought conditions with the value of 38.19% and 55.73% respectively. The trait root length observed the high heritability accompanied by the high genetic advance in both normal and drought conditions which indicates that the heritability is due to the additive genetic effects and selection of this trait is effective. These results are contradicted by the report by Dhanda, et al. (2004); Khan, et al. (2010) in bread wheat.

The trait shoot length showed a high heritability value in both the environments with values of 80% and 97% respectively. The genetic advance percentage observed for the trait shoot length is moderate in both normal and drought environments with the value of 12.81% and 19.6% respectively. The trait shoot length showed high heritability with the moderate genetic advance percentage which means that heritability is due to the additive gene effects and selection may be effective.

The trait root shoot ratio exhibited a high heritability value in both normal and drought conditions with the values of 94% and 99% respectively. The trait root shoot ratio showed a high genetic advance percentage in both normal and drought conditions having the value of 40.9% and 57.51% respectively. The heritability found for the trait root shoot ratio is high accompanied by the high value of genetic advance percentage which also indicates that the effect is due to the additive genes and selection is effective for this trait.

The heritability value found for the trait relative water content is high in both the normal and drought environment with the high value of 93% and 94% respectively. The genetic advance percentage observed for the trait relative water content is very low in both the normal and drought environment and revealed the values of 5.9% and 7.1% respectively. High heritability for the trait relative to water content with the low genetic advance percentage indicates that non-additive gene action and selection may not be rewarding. Similar findings were reported in Gulnaz et al. (2012); Hosseini et al. (2012).

The values for the heritability were very high for the trait excised leaf water loss under both the normal and drought environments with the value of 100% and 95% respectively. The trait excise water loss exhibited a high genetic advance percentage with a value of 27.9% and 29.9% in both normal and drought environments. The trait excise water loss observed the high heritability with the high value of genetic advance percentage indicating the effect of the additive gene in heritability and selection may be successful for this trait.

## Conclusion

In this research, 100 wheat genotypes were analyzed at seedling stage against non-stress and water stress under factorial CRD using, root length, shoot length, root shoot ratio, relative water content and excised leaf water loss. The result of ANOVA indicated that there was significant variability present among the studied attributes. The genotypes G20, G15, G90, G35, G43, G25, G44 and G45 performed best in both conditions which means these genotypes were considered drought tolerant genotypes. The correlation of root shoot ratio was strong with the other traits as compared to the other traits. The root shoot ratio showed a positive association with the root length and relative water content. The value of heritability and the genetic advance was high in all the indices except the relative water content due to the non-additive gene effect. Furthermore, these results would be helpful to develop drought tolerance wheat varieties to fulfill the wheat demand and sustainable food security.

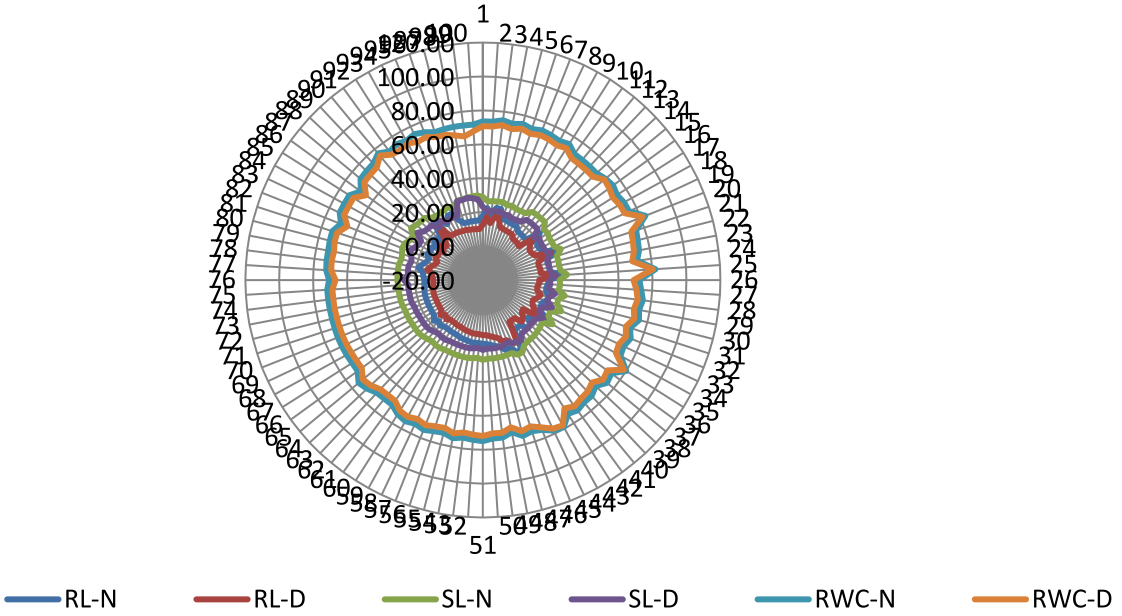


**Figure No.1** showed the mean performance of 100 wheat genotypes under normal and drought (as N and D) of three attributes RL root length, SL shoot length and RWC relative water content.

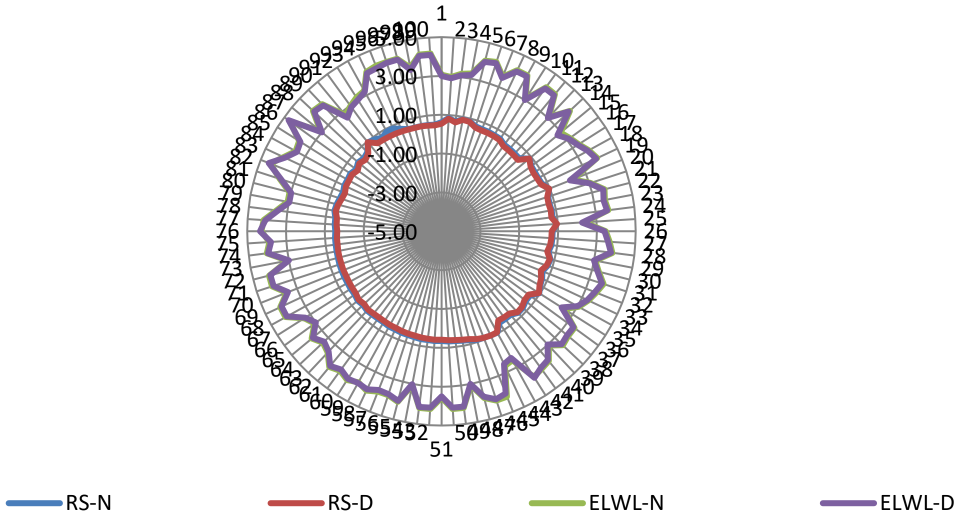


**Figure No.2** showed the mean performance of 100 wheat genotypes under normal and drought (as N and D) of two attributes RS root shoot ratio, ELWL excise leaf water loss

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