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## Research Article

# Evaluating the Impact of Osmotic Stress on Wheat Seedlings for Drought Adaptation

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## ABSTRACT

Wheat stands as the most extensively cultivated staple food crop worldwide, playing a vital role in food security across diverse regions, including Pakistan. Low moisture content during the growing season at various growth stages significantly reduces crop yield. In present study, thirteen (13) local wheat varieties were tested in a factorial completely randomized design (CRD) with three replications under normal and artificial osmotic stressed condition. The experiment was conducted in a growth chamber with optimum growing conditions using petri plates. Two sets of treatments, i.e., normal distilled water (T1) and 15% polyethylene glycol (PEG-8000) simulated stress conditions (T2), were applied for fifteen days and data were recorded for various seedling traits. Results indicated significant variation among the tested varieties for almost all studied seedling traits. However, the PEG Treatment × Varieties interaction was found to be non-significant for root length, shoot length, and seedling length. The mean performance of all seedling traits displayed drastic decrease under osmotic stress condition as compared to normal water. Overall, the varieties Tijaban-10 and K-98 demonstrated stable performance across both environments, whereas variety Anaj-17 and Wadan was recognized most drought-sensitive based on contribution of seedling traits. Conclusively, the seedling traits of Tijaban-10 and K-98 demonstrated stability under osmotic stress conditions. These varieties are recommended for future breeding programs to develop drought-tolerant wheat varieties suited to Balochistan's climate.

**Keywords:** Balochistan, Drought Tolerance, Seedling Traits, Osmotic Stress, Wheat Varieties.



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## INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the world's most important cereal crops, providing a staple food for about one-third of the global population (Wato et al., 2020). It holds a prominent place in the agricultural sector due to its widespread cultivation and ability to grow in various climates, soils, and versatility in making many types of food products (Feldman and Levy, 2023; Khalid et al., 2023). Wheat is cultivated on approximately 220 million hectares globally, yielding over 765 million metric tonnes of grain (FAOSTAT, 2023-24). Wheat production is predominantly concentrated in Asia, contributing approximately 44% to the global output, followed by Europe and the Americas with 34% and 15%, respectively (Streit et al., 2013). Currently, China and India are the world's leading wheat producers, though production trends are shifting in other countries (Igrejas & Branlard, 2020).

Population growth and climate change are raising serious concerns about global wheat production and consumption. By 2050, the world needs to produce an additional 132 million tons of wheat food items to meet the average yearly demand (Erenstein et al., 2022). Globalization, rapid growth, and rising financial resources are all causing notable dietary changes, particularly in Asia, where more wheat-based goods are consumed (Pingali, 2007). Wheat production must rise to satisfy the world's expanding population and demand by the end of this century (Tilman et al., 2011).

Climate change has exacerbated the food security issues by increasing the frequency and intensity of drought episodes (Mansour et al., 2020). Wheat production is significantly hampered by a number of biotic and abiotic stressors, with drought being the most severe. In arid and semi-arid regions where water availability for crop cultivation is severely limited, abiotic stressors, particularly drought, serve as the primary constraint on agricultural productivity (Lehari et al., 2019; Bhandari et al., 2021). Notably, over 65% of the world's cultivable land is located in arid or semi-arid zones, making it highly vulnerable to drought-induced stress. Drought stress retards plant growth, leading to defoliation and stunted development. Numerous studies have documented that drought stress disrupts normal plant growth and development, leading to morphological, physiological, and biochemical abnormalities (Chachar et al., 2016). Water scarcity adversely affects organ development in cereals, particularly wheat—reducing the size of leaves, stems, ears, and the number of spikelets—as well as altering the ratio of spike dry weight to total biomass. These disruptions ultimately result in significant yield reductions (Başer et al., 2024). The adverse effect of drought stress would damage all growth stages of any crop but germination is regarded as most critical stage of plant life which may cause serious setback on upcoming growth stages and final productivity (Seleiman et al., 2021). Thus, the primary objective of wheat breeders is to develop such varieties that achieve maximum and uniform germination under water-limited conditions to enhance early plant growth.

Polyethylene glycol (PEG) has been widely utilized to simulate *in-vitro* drought stress by inducing artificial osmotic stress, thereby limiting water availability and reducing tissue hydration during the seedling stage (Michel and Kaufmann, 1973). PEG 8000 (MW ~8,000 g/mol) serves as a standard non-penetrating osmolyte to impose controlled water-deficit conditions. This approach physiologically mimics soil moisture deficit by lowering the water potential of the germination medium, thereby inducing osmotic stress without inflicting mechanical tissue damage (Jiang et al., 1995). Robust empirical validation confirms PEG-based screening as a reliable predictor of genotypic drought tolerance, primarily through germination-associated phenotypic markers (Ahmed et al., 2025; Othmani et al., 2025).

In Pakistan, bread wheat is the predominant cereal crop, serving as a staple food for nearly 190.13 million people. The per capita wheat availability stands at approximately 124.88 kg per annum (Shahzad et al., 2022). Globally, Pakistan ranks as the 8<sup>th</sup> largest producer of wheat, producing approximately 31.4 million tons annually by engaging total area of cultivable land is about 9.63 million hectares. The country average wheat yield is about 2,827 kg/ha, with contribution of 9% to the value addition in the agriculture sector and approximately 2.2% to the national GDP (Government of Pakistan, 2023-24). Wheat production in Pakistan is predominantly concentrated in the Punjab province (21 M-tons), which accounts for approximately 72% of the country's total Productivity. Sindh, KPK, and Balochistan follow, contributing approximately 16%, 8%, and 4% to the country's wheat production, respectively (Anwar et al., 2024).

Balochistan is the largest province of the country covering an area of 347,190 square kilometers (44% of Pakistan's total land area). Wheat is one of the major crops of the province with around 1.2 million tons of production from 1.9 million acres during 2023-24 (GoB, 2024). Balochistan is divided into distinct agro-ecological zones, each exhibiting extreme variability in environmental conditions, yet wheat is cultivated across all regions (Durrani et al., 2023). In highland regions of Balochistan, including Quetta and adjoining district posing limited rainfall, un-predictable rain intensity and distribution, extreme temperature events, and frequent desiccating winds during the grain filling are the key limitations for wheat crop productivity (Khan et al., 2014).

Wheat production in Balochistan faces major challenges due to its arid climate, with drought being the most critical limiting factor during early growth stages. The region experiences substantial variability in weather patterns, where the severity, timing, and duration of drought events markedly influence wheat productivity (Rees et al., 1990). These environmental fluctuations adversely affect the performance stability of wheat genotypes—varieties that perform well in one season, and may fail in another due to unpredictable climatic conditions, thereby complicating varietal development in these regions (Khan et al., 2022). Insufficient soil moisture during germination and subsequent growth stages adversely affects wheat productivity and delays crop maturation (Ahmed et al., 2022). Moreover, ideal micro-climatic conditions and high-quality seed are pre-requisite for ensuring successful crop establishment at early

seedling vigor. Therefore, it is necessary to increase wheat productivity by selecting drought tolerant genotypes at seedling stage to ensure the sustainable food security. Thus, the primary objective of this study was to conduct experimental trails at early seedling stage focused on the genomic selection based on quantitative seedling traits that show consistent performance under imposed osmotic stress conditions.

## MATERIALS AND METHODS

### Experiment description and stress treatment

The present study was conducted in the Laboratory of Plant Breeding and Genetics, at Balochistan Agriculture College, Quetta. The experimental site is geographically located at 30.1830° N latitude, 66.9987° E longitude, at an elevation of approximately 5,500 feet above sea level. The experiment was designed with a two-factorial arrangement (Varieties and PEG concentration) in a completely randomized design (CRD) having three replications and was carried out from October 3 to October 18, 2023. A total of thirteen (13) indigenous wheat varieties, obtained from Provincial Research Headquarter (Agriculture Research Institute Quetta) and Balochistan Agricultural Research and Development Center (BARDC), were evaluated under controlled artificial osmotic stress conditions at the seedling stage (Table 1). The studied varieties were tested using two sets of treatments: normal distilled water (-0 bars) and a 15% (w/v) PEG-8000 (Polyethylene Glycol, MW 8000) solution, which creates an osmotic potential of -3.5 bars. Each variety was tested with twenty seeds placed in petri dishes on Whatman's filter paper. All petri dishes were randomly arranged in a growth chamber (model: MLR-352H-P) for 15 days under standardized environmental conditions. The chamber was maintained at a day/night temperature of  $24 \pm 2$  °C with a relative humidity of 70-80%. Optimal photoperiod duration was set to 16 hours of light followed by 8 hours of darkness. In order to compensate for moisture loss due to evaporation, 5 mL of distilled water was added to each petri dish under control conditions every two days, whereas an equal volume (5 mL) of (PEG)-8000 solution was applied to the petri dishes under osmotic stress treatments. Seeds were allowed to grow for 15 days and were considered germinated when the radicle length exceeded 3 mm. Data were recorded for various seedling traits, including shoot length (SL), root length (RL), seedling length (SDL), coleoptile length (CL), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW), root dry weight (RDW), and seedling vigor index (SVI). Five seedlings were selected following the methodology described by Afzal et al. (2017) and Mohi-Ud-Din et al. (2021). Statistical analysis of variance (ANOVA) was conducted separately for varieties and PEG treatments, while interactions (PEG Treatment × Varieties) were analyzed using the general linear model. Mean differences were compared using the Least Significant Difference (LSD) test at  $\alpha=0.05$  to classify homogeneous groups with the software Statistix 8.1 (Steel & Torrie, 1980).

Table 1: Information regarding local wheat varieties used in this study.

S#	Variety Name	Source of Acquisition
1.	Anaj-17	Agriculture Research Institute (ARI) Quetta
2.	Pak-81	Agriculture Research Institute (ARI) Quetta
3.	Saryab-92	Agriculture Research Institute (ARI) Quetta
4.	Shalkot-14	Agriculture Research Institute (ARI) Quetta
5.	AZRI Dera	Balochistan Agricultural Research and Development Center (BARDC), Quetta
6.	Bagba Dush	Balochistan Agricultural Research and Development Center (BARDC), Quetta
7.	Chamman -16	Balochistan Agricultural Research and Development Center (BARDC), Quetta
8.	Entray A	Balochistan Agricultural Research and Development Center (BARDC), Quetta
9.	Faisalabad	Agriculture Research Institute (ARI) Quetta
10.	K-98	Balochistan Agricultural Research and Development Center (BARDC), Quetta
11.	Morco	Balochistan Agricultural Research and Development Center (BARDC), Quetta
12.	Tijaban-10	Balochistan Agricultural Research and Development Center (BARDC), Quetta
13.	Wadan	Balochistan Agricultural Research and Development Center (BARDC), Quetta

## RESULTS AND DISCUSSION

### Analysis of variance (ANOVA) for seedling traits

Analysis of variance (ANOVA) revealed highly significant differences ( $p < 0.01$ ) among tested wheat Varieties and for PEG-induced drought stress treatments across all measured traits. However, interaction (Varieties × PEG Treatment) was highly significant ( $p < 0.01$ ) for coleoptile length (CL), root fresh weight (RFW), shoot fresh weight (SFW), root dry weight (RDW), shoot dry weight (SDW), seedling vigor index (SVI). On the other hand, the interaction was found

to be non-significant for shoot length (SL), root length (RL), and seedling length (SDL) (Table 2). The considerable genetic variability among tested wheat varieties highlights their potential in responding to osmotic stress. Moreover, PEG treatment exerted significant effects on seedling traits compared to the control, underscoring their impact on early seedling development. The significant interaction of Varieties × PEG Treatment for most seedling traits suggests that varietal responses to drought stress are treatment-specific, emphasizing the potential for trait-based selection in breeding programs. Various researchers have confirmed similar outcomes on wheat and other crops by evaluating the impact of PEG induced drought stress on seedling traits at the early growth stage (Ahmed et al., 2025; Belay et al., 2021; Khan et al., 2019; Mohi-Ud-Din et al., 2021). These traits serve as reliable indicators for screening large wheat germplasm collections for drought tolerance at early growth stages, improving selection efficiency while reducing labor and time requirements (Ahmed et al., 2025). The Coefficient of Variation (CV%) is a crucial statistical indicator in agricultural research for assessing experimental precision and reliability. In this study, it ranged from 7.49% (SL) to 18.09% (CL), indicating that all traits were measured accurately (Table 2). In agricultural experiments, a lower CV% is generally interpreted as a sign of high experimental accuracy and uniformity, indicating minimal environmental or experimental error (Gomez and Gomez, 1984). Thus, CV% is commonly used to evaluate the reproducibility and robustness of agronomic trials, especially in multi-genotype or multi-treatment comparisons (Bowman, 2001).

Table 2: Mean Square variances from ANOVA for seedling traits of wheat varieties.

Seedling traits	Varieties <i>d.f</i> = 12	PEG Treatment <i>d.f</i> = 1	Varieties × PEG <i>d.f</i> = 12	Error <i>d.f</i> = 50	Coefficient of Variation C. V (%)
Shoot Length (cm)	22.91**	808.99**	2.548 NS	2.116	7.49
Root Length (cm)	8.58**	261.06**	1.27 NS	1.26	11.05
Seedling Length (cm)	22.91**	808.99**	2.54 NS	2.11	7.49
Coleoptile Length (cm)	7.49*	4.34**	0.27**	0.24	18.09
Shoot Fresh Weight (mg)	6987**	144480**	705**	1362	17.45
Shoot Dry Weight (mg)	323.4**	27640.9**	31.0**	55.4	11.42
Root Fresh Weight (mg)	3217.8**	37691.7**	102.3 **	113.9	9.20
Root Dry Weight (mg)	32.36 **	1185.68**	7.80**	1.780	11.58
Seedling Vigour Index	351373**	1.40807**	3801.4**	29016.5	10.68

\*\* = Highly significant ( $P < 0.01$ ); \* = Significant ( $P < 0.05$ ); NS = Non-significant ( $P > 0.05$ )

### Mean variability of seedling traits

#### Shoot length (cm)

Data on the mean shoot length (SL) performance revealed that the varieties K-98 and Tijaban-10 demonstrated superior growth under both normal (T1) and drought stress (T2) conditions. Conversely, Bagba Dush and Anaj-17 displayed significantly shorter shoot lengths under both conditions (Figure 1). Shoot length (SL) is a critical morphological trait influencing the early development of wheat seedlings (Ahmed et al., 2019). In the current study, a significant decrease in shoot length was observed with increasing levels of osmotic stress in the wheat genotypes under investigation. These findings align with Ahmed et al. (2019), who reported that shoot growth is typically more affected by moisture stress than root development. Similarly, Ahmadi et al. (2012) and Mohi-Ud-Din et al. (2021) demonstrated that water stress significantly impairs shoot development in wheat.

#### Root length (cm)

The mean root length (RL) values indicate that Tijaban-10 exhibited superior performance under both normal and drought conditions, followed by Saryab-92. In contrast, variety Wadan and Anaj-17 demonstrated reduced root length under drought stress. Additionally, AZRI Dera exhibited a comparatively lower mean RL under controlled conditions (Figure 2). Root development is a critical trait, contributing to plant resilience under drought-prone conditions (Eweda et al., 2025). As the primary organ responsible for water uptake, roots play a fundamental role in meeting the plant's transpirational demand and ensuring moisture availability (Ehlers and Goss, 2003). Osmotic stress significantly reduced root length in the bread wheat varieties evaluated in this study, aligning with the findings of Ahmed et al. (2025). Furthermore, under drought conditions, genotypes with longer roots may exhibit adaptive responses such as extending root systems to access deeper soil moisture (Kalra et al., 2024).

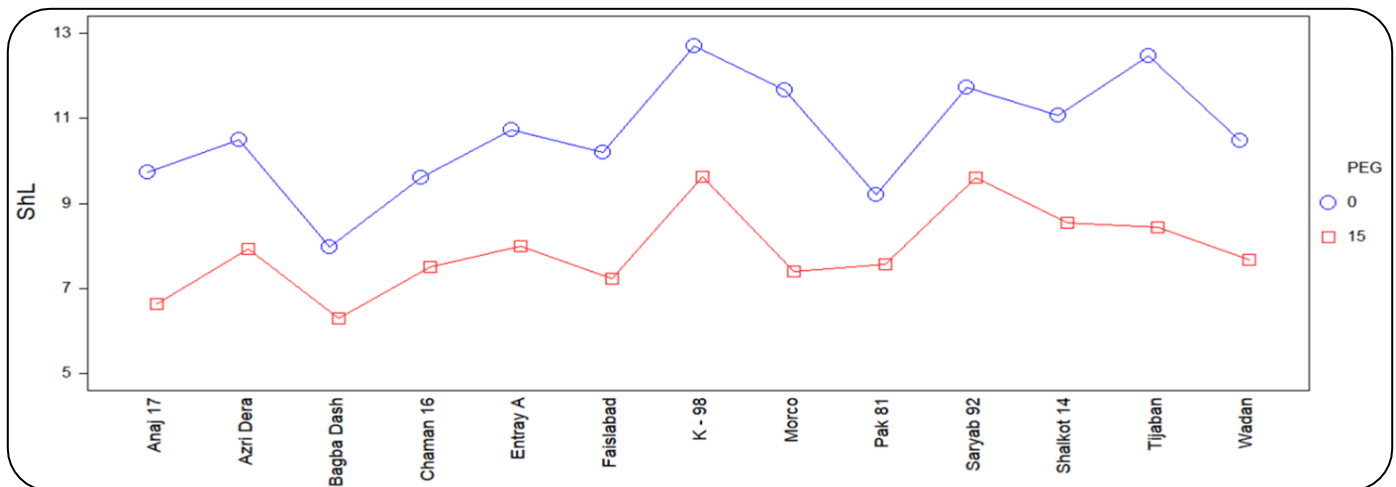


Figure 1. Means of thirteen wheat varieties for shoot length under normal and drought stress conditions.

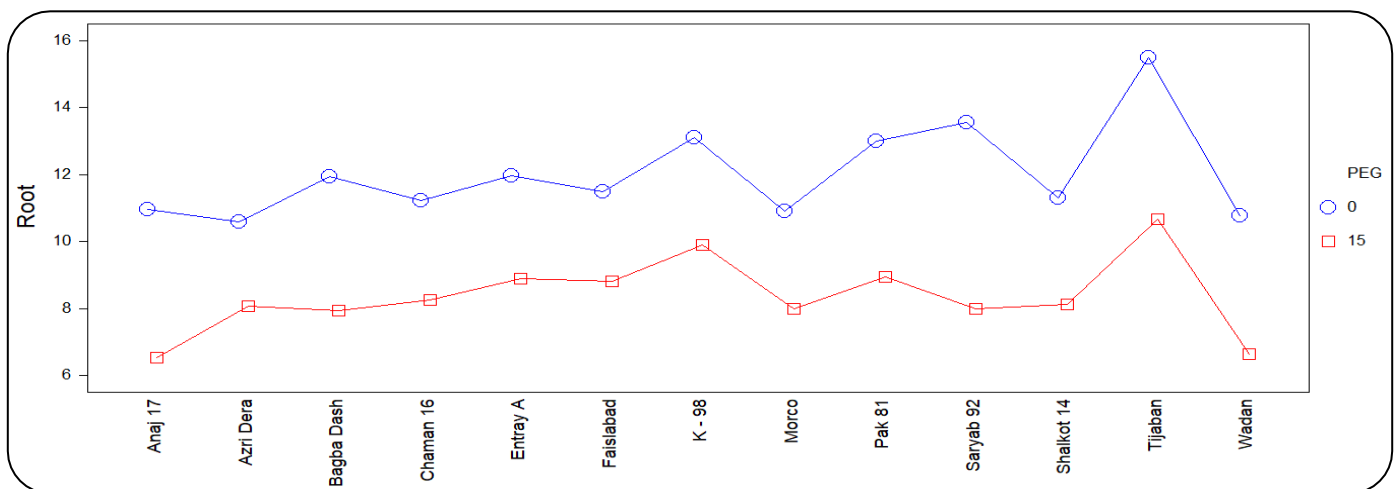


Figure 2: Means of thirteen wheat varieties for root length under normal and drought stress conditions.

### Seedling length (cm)

Seedling development under controlled laboratory conditions is widely recognized as an appropriate stage for evaluating drought tolerance. Seedling length (SDL) data showed that Tijaban-10 had the highest mean SDL under both environmental conditions (T1 and T2), followed closely by K-98 (Figure 3). In contrast, variety Anaj-17 and Wadan demonstrated the lowest seedling length under both conditions. This suggests that stable varieties performing well at the seedling stage may also exhibit similar performance at maturity. Seedling vigour under low-moisture conditions depends on the ability of a plant to mitigate the adverse effects of reduced soil and atmospheric water potential by modulating physiological and morphological responses in both shoots and roots (Morgan, 1984). These findings are consistent with those of Ahmed et al. (2025), Ahmadi et al. (2012) and Ahmed et al. (2019), who reported that low water availability negatively affects wheat seedling emergence and development.

### Coleoptile length (cm)

The coleoptile in wheat serves as a crucial protective sheath that safeguards the emerging shoot tissues in seedlings (Farhad et al., 2014). Exposure to osmotic stress resulted in a significant reduction in coleoptile length (CL) across all evaluated wheat varieties. Analysis of variance revealed that all sources of variation—Varieties, PEG treatment, and their interaction (Varieties × PEG Treatment) showed highly significant variations for this trait (Table 2). Mean values of CL were highest in the variety Tijaban-10 under both drought-stressed (T1) and well-watered (T2) conditions, followed by genotype K-98. In contrast, Bagba Dash and Morco exhibited the lowest CL values across both environments (Figure 4). Our findings confirm that coleoptile length declines under water-deficit conditions, consistent with Ahmed et al. (2019), who identified drought stress as a significant factor reducing this trait in wheat.

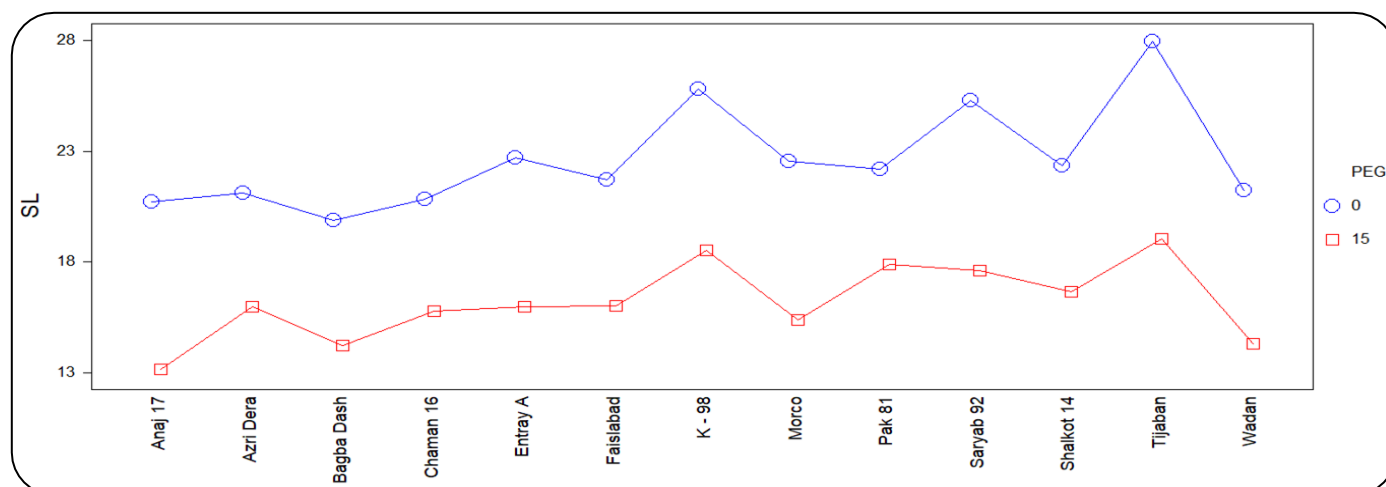


Figure 3. Means of thirteen wheat varieties for seedling length under normal and drought stress conditions.

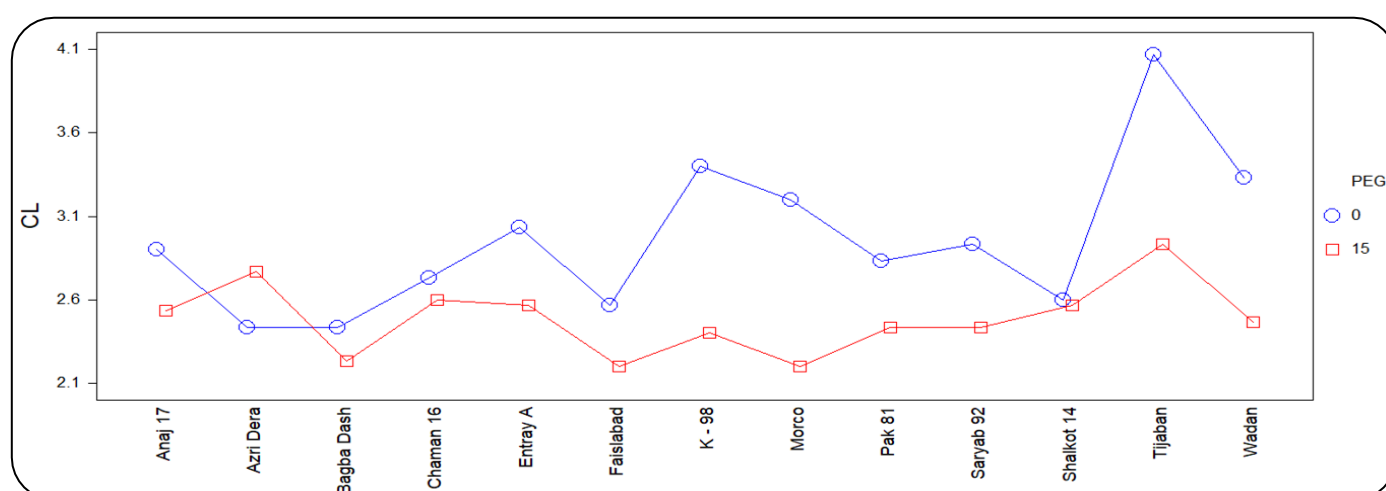


Figure 4. Means of thirteen wheat varieties for coleoptile length under normal and drought stress conditions.

### Shoot fresh weight (mg)

Shoot fresh weight (SFW) is a dynamic seedling trait for assessing drought tolerance in wheat varieties. Data regarding SFW revealed that variety Tijaban-10 exhibited the highest mean value under both well-watered (control) and drought-stressed conditions, closely trailed by variety K-98 (Figure 5). Under induced osmotic stress, varieties Bagba Dash, Faisalabad, and Wadan consistently demonstrated the lowest SFW values among the tested varieties. Conversely, under control condition, the lowest SFW values were recorded for variety Anaj-17, Bagba Dash, and Faisalabad. However, it is worth mentioning that artificially induced osmotic stress significantly reduced SFW across all varieties. These results are aligned with established findings reported by Ahmed et al. (2024), and Ahmed et al. (2025), confirming that drought stress adversely affects shoot fresh biomass accumulation.

### Shoot dry weight (mg)

Shoot dry weight (SDW) is considered to be most reliable indicator for assessing individual plant biomass and is also widely used to estimate seedling biomass (Ahmed et al., 2025). In the present study, the effects of Varieties, PEG-Treatment, and their interaction (Varieties × PEG treatment) were found to be highly significant for SDW trait (Table 2). Under both environmental conditions (T1: well-watered and T2: drought stress), Tijaban-10 exhibited the highest mean for SDW, followed by variety K-98, indicating superior biomass accumulation (Figure 6). Conversely, Chaman-16 and Morocco consistently recorded the lowest SDW values across both treatments, reflecting their comparatively poor biomass performance under both optimal and stress conditions. Varieties displayed genetic variation in terms of shoot dry weight (SDW) when subjected to osmotic stress conditions, and shoot biomass decreased significantly as a result of moisture stress. The obtained findings are in accordance with the outcomes of Faisal et al. (2019), and Ahmed et al. (2022), they declared that dry shoot weight is negatively influenced by moisture deficit.

### Root fresh weight (mg)

Root fresh weight (RFW) is a key seedling trait that directly contributes to overall biomass accumulation. In this

study, all bread wheat varieties exhibited differential responses in RFW when subjected to varying levels of osmotic stress, indicating genotype-specific variability in root biomass accumulation under drought conditions. Analysis of variance revealed highly significant differences for all sources, including Varieties, PEG-Treatment, and Varieties × PEG-Treatment of this trait (Table 2). Data concerning to mean values of FRW showed that variety Tijaban-10 supersede in performance, followed by Pak-81 and K-89 (Figure 7). Conversely, it was noted that under induced osmotic stress, variety Faisalabad, Wadan and Chaman-16 showed low FRW values as compared to other tested varieties. Root fresh weight (RFW) is an important seedling characteristic that directly determines seedling biomass. Intensive drought stress considerably reduces the fresh root weight of wheat seedlings (Kiran et al., 2023). These findings are consistent with the previous reports of Baloch et al. (2012), Faisal et al. (2019), and Ahmed et al. (2019)' all researchers revealed that induced osmotic pressure caused a significant loss in fresh root weight in wheat crop.

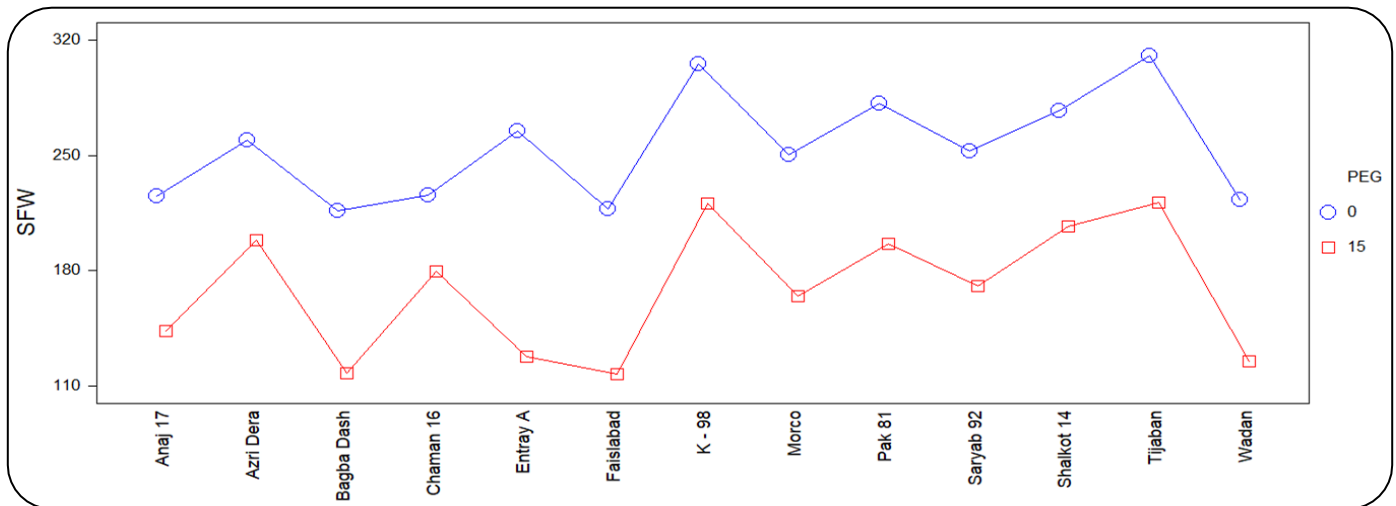


Figure 5. Means of thirteen wheat varieties for shoot fresh weight under normal and drought stress conditions.

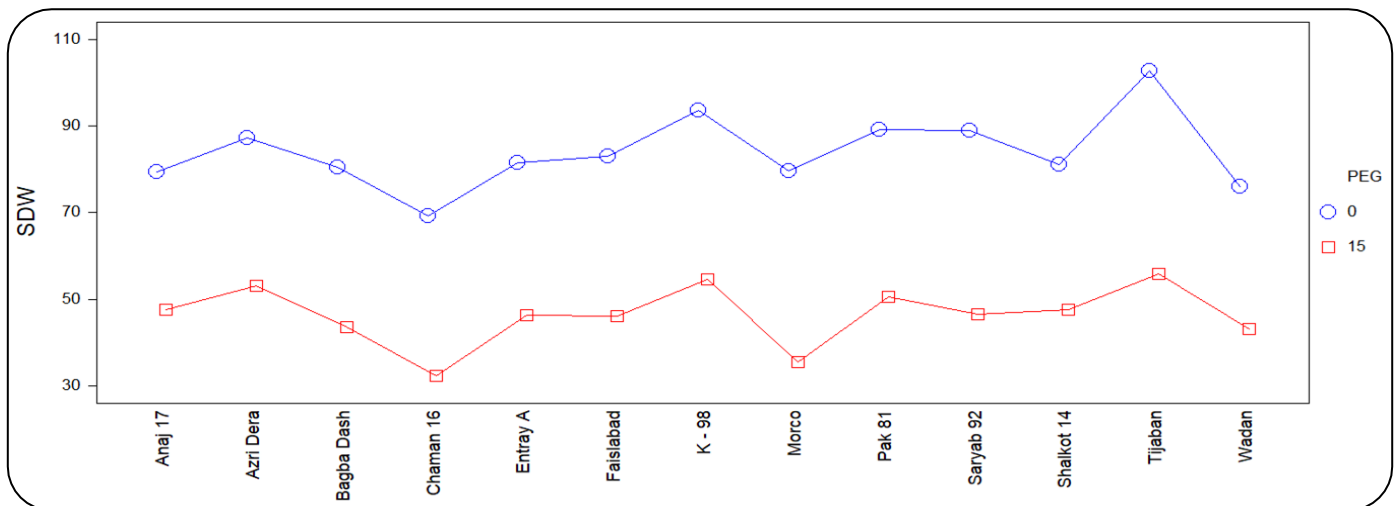


Figure 6. Means of thirteen wheat varieties for shoot dry weight under normal and drought stress conditions.

### Root dry weight (mg)

All of the studied wheat varieties responded differently under the osmotic stress as well as under normal water condition. As per ANOVA, Varieties, PEG-Treatment and interaction of Varieties × PEG-Treatment noticed highly significant differences for RDW (Table 2). Under both, controlled normal water condition and artificial drought stress, variety Tijaban-10 and K-98 showed stable performance as compared to other tested varieties. While variety Morocco found to be less stable than other varieties and showed poor performance under both environments (Figure 8). Dry root weight (DRW) represents the mass of root tissue after complete removal of moisture and serves as a key indicator of root biomass allocation (Ahmed et al., 2022). In the present study, osmotic stress induced a significant reduction in DRW across all evaluated wheat varieties, highlighting the adverse impact of drought conditions on root

development. This study's findings revealed that moisture stress had a greater influence on dry mass. These findings are consistent with those of Mujtaba et al. (2016), Faisal et al. (2019) and Baloch et al. (2012), who found that osmotic stress significantly reduced the root dry weight of wheat cultivars.

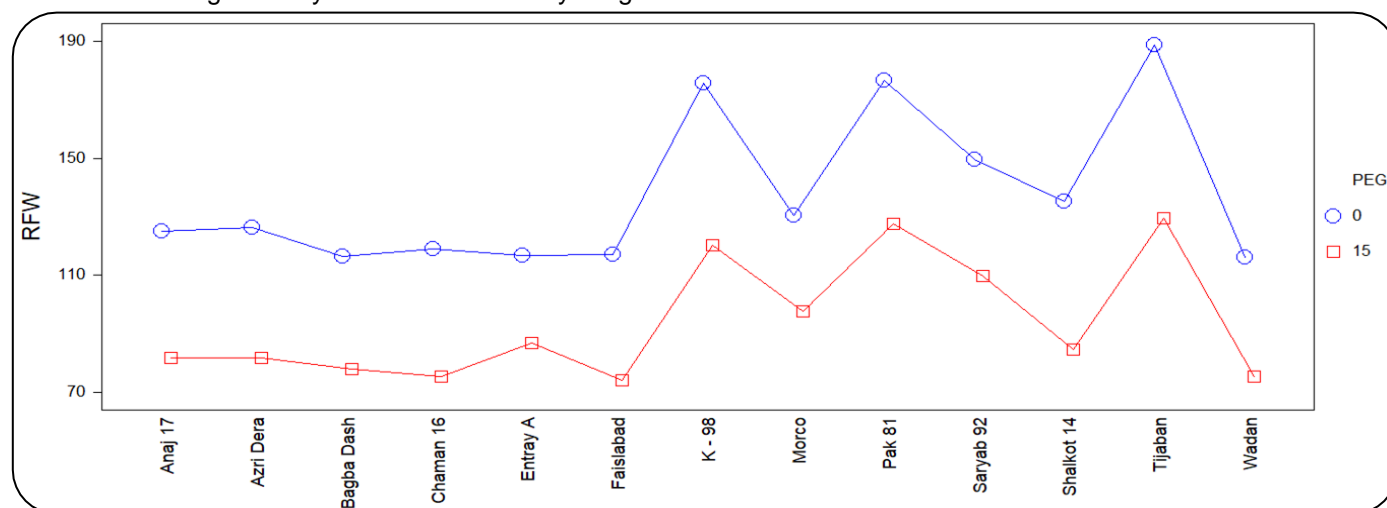


Figure 7: Means of thirteen wheat varieties for root fresh weight under normal and drought stress conditions.

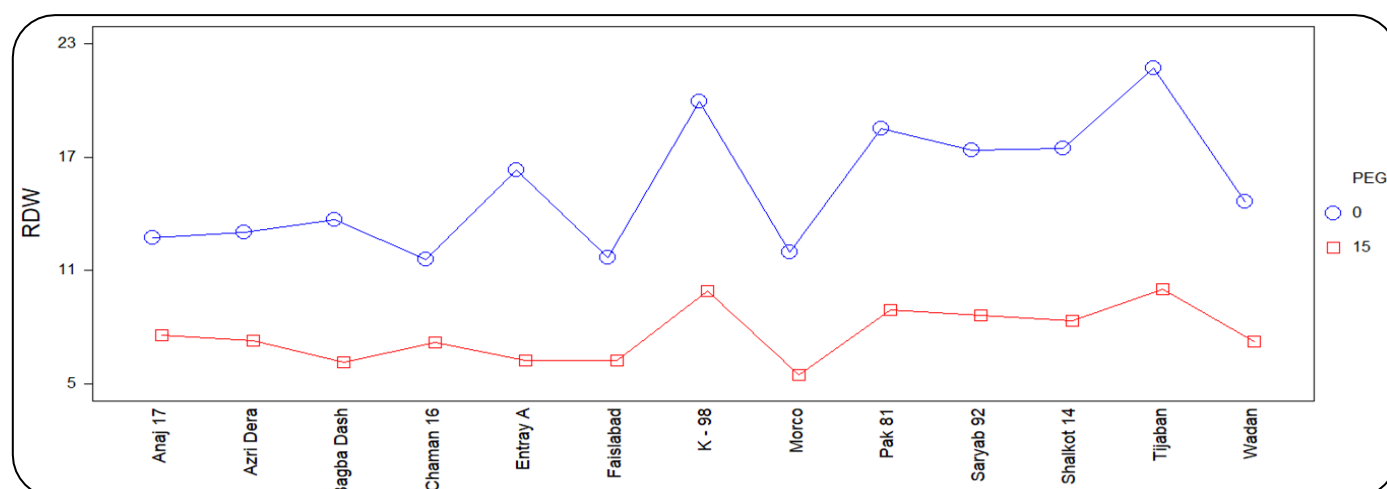


Figure 8. Means of thirteen wheat varieties for root dry weight under normal and drought stress conditions.

### Seedling vigour index

The seedling vigor index (SVI) emerged as the most sensitive seedling trait in response to drought stress, as evidenced by its variable expression across different moisture regimes. The application of polyethylene glycol (PEG) to simulate drought stress significantly inhibited key growth parameters during the seedling stage. Thus, PEG-induced osmotic stress led to a significant reduction in SVI across all evaluated wheat varieties. Analysis of variance revealed highly significant variation for all sources, including Varieties, PEG Treatment, and their interaction (varieties  $\times$  PEG treatment), indicating substantial genetic variability within the studied material (Table 2). Under both well-watered (T1) and drought-stressed (T2) conditions, variety Tijaban-10 and K-98 demonstrated superior seedling vigor, while Wadan, Maroco, and Ajan-17 consistently exhibited the lowest SVI values (Figure 9), reflecting their reduced early growth potential under stress. The findings of the present study are in agreement with previous researchers (Ahmed et al., 2019, Ahmed et al., 2022, Ahmed et al., 2023, Faisal et al., 2019), who have reported similar results that wheat genotypes exhibiting higher germination percentages and enhanced root and shoot lengths also tend to demonstrate a greater Seedling Vigor Index (SVI). These observations are further supported by the findings of Ahmed et al. (2025), who observed decline in shoot and root growth may be attributed to suppressed cell division and elongation, potentially triggering premature tuberization and lignification of the radicle system. Such physiological responses are likely adaptive mechanisms that enable the plant to minimize metabolic activity under prolonged drought conditions.

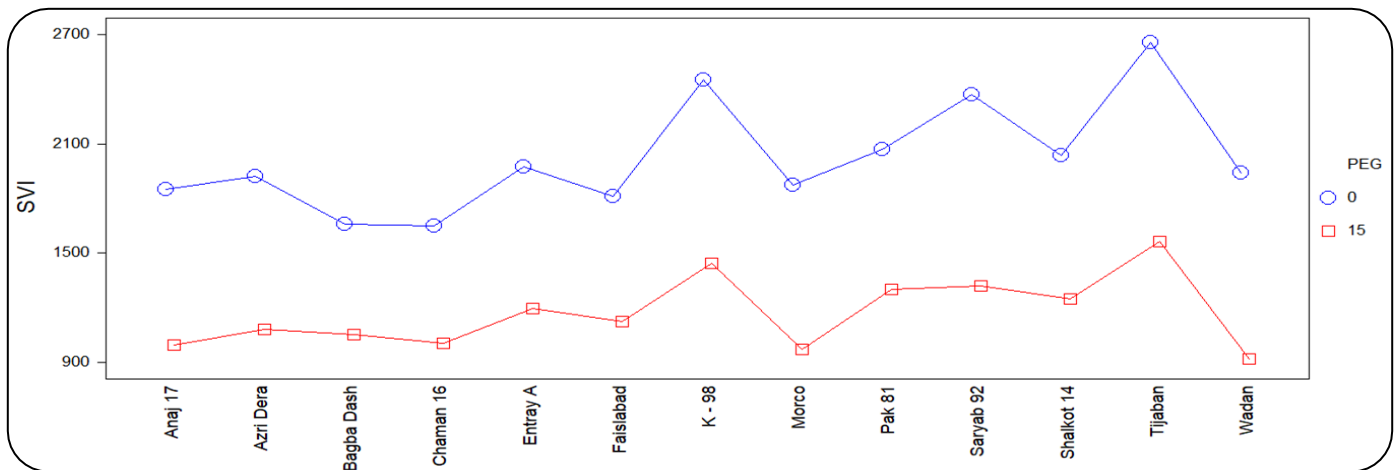


Figure 9. Means of thirteen wheat varieties for seedling vigour index under normal and drought stress conditions.

## CONCLUSION

Drought tolerance is a multifaceted trait that plays a pivotal role in ensuring stable wheat yield under water-limited conditions. This study evaluated the impact of drought stress on key seedling traits—including shoot and root length, coleoptile length, seedling length, biomass parameters, and seedling vigor index—which serve as reliable indicators for early-stage drought screening. The results of this study provided valuable insights into the genetic variability and drought response among wheat varieties, enabling their classification into three distinct tolerance groups: drought-tolerant, moderately drought-tolerant, and drought-sensitive. Among the studied varieties, Tijaban-10 and K-98 consistently outperformed under both control and stress conditions, and were identified as drought-tolerant. Two varieties Pak-81 and Saryab-92 were classified as moderately drought-tolerant due to their intermediate responses. In contrast, Wadan, Ajan-17, Morocco, and Faisalabad exhibited high susceptibility to drought stress and recognized as drought-sensitive. These findings underscore the significance of integrating drought-tolerant varieties into breeding programs to enhance drought resilience in local wheat cultivars tailored to the agro-climatic conditions of Balochistan and similar regions.

## AUTHOR CONTRIBUTIONS

B. Ali: Conducted experiment, G. Rasool: Conceptualization and Supervision, A. Ullah: Analyzed Data and Draft Manuscript, M. Shoaib: Managed Data, N. Khan: Editing, M. Waris: Review Article, A. Ali: Investigation guidance, K. Asghar: Managed Citation, K. Hashim: Data Curation, A. Azeem: Financial assistance

## COMPETING OF INTEREST

The authors declare no competing interests.

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