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Original Article

Assessment of Drought Tolerance in Bread Wheat During Germination and Seedling Stages

Shano Abdulrahman Omer[1], Shwan Muhammad Salih Hama Rash*[1], Sayran Sardar Hasan[1]

[1]*Biotechnology and Crop Science Department, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaymaniyah 40061, Kurdistan Region, Iraq.*

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ABSTRACT

Plant growth globally faces different limitations, including abiotic limitations. Drought conditions are increasingly turning out to be a common abiotic challenge. The current study attempts to show how germination and early growth stages of wheat varieties can be influenced by drought stress. The laboratory experiment was carried out using a factorial complete randomized design (CRD). Seven common wheat varieties in the Kurdistan region of Iraq (Aras, Adana, Slemani 2, Hawler 2, Hasad, Jehan 99, and Maroof) were tested under five levels of polyethylene glycol (PEG-6000) (0, 5%, 10%, 15%, and 20%). The studied traits were considerably affected by both individual and interactive cultivars and PEG levels. Reductions of 10.6%, 54%, 39.5%, 43.2%, 30.8%, and 37.3% were recorded in seed germination, seedling vigour, root length, shoot length, root weight and shoot weight, respectively at PEG level of 20%. Variety Hasad demonstrated remarkable resilience under intense levels of drought conditions during germination its associated traits. Additionally, it exhibited impressive seedling growth performance under water stress conditions. Among the varieties, Aras stood out for its strong seedling vigour, a crucial trait for surviving drought stress that occurs later in the development cycle. However, Hawler 2 emerged as the variety most significantly impacted by drought stress. Principal component analysis confirmed the results from the analysis of variance and segregated the varieties according to their strength of drought resistance into three groups: resistant varieties (Hasad, Slemani 2, Aras); moderately susceptible varieties (Adana, Jihan 99); and susceptible varieties (Hawler 2, Maroof). The findings of this study can guide breeders in selecting and enhancing resistant varieties within any breeding program, ultimately leading to the development of more resilient wheat varieties to drought stress condition.

Keywords: Wheat varieties, Germination, Seedling vigour, Drought stress, Polyethylene glycol.

1 Introduction

One of the most significant environmental variables that reduce crop yield is drought. As a result of numerous climatic changes, rainfall patterns have changed, and there are fewer water resources available to meet the water requirements of crops [1, 2]. Adverse environmental conditions expose plants to stresses, i.e., drought, which affect growth, metabolism, and yield [3]. Water shortage is one of the major abiotic factors that lowers crop production globally, limiting crop species productivity, particulary in arid and semiarid regions [4]. In general, drought and high temperatures reduce crop yields by 9-10 per cent globally [5]. Studies have reported a 20-60% reduction in yield, depending on the severity and time of the drought [6-8].

* Corresponding author
E-mail address shwan.salih@univsul.edu.iq(Instructor).
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Water deficiency in rain-fed conditions severely restricts seed germination and establishment of seedlings. These stages are crucial for determining the crop's growing period and yield [9]. Plant development begins with seed germination, which has an impact on yield [10]. Given that the length of seed germination influences the establishment of seedlings and their subsequent growth, this phase can be characterized as a crucial and vulnerable period of plant development [11,12]. The most crucial growth stages are seed germination and the establishment of seedlings, occurring during drought stress which significanlty constrains crop yield [13]. Drought tolerance during germination stabilizes the plant. Nevertheless, the assessment of drought resilience in the initial seedling stages is frequently conducted utilizing chemical desiccants such as polyethylene glycol (PEG) media [14]. Polyethylene glycol is commonly used in many studies to examine the drought tolerance of different crops during germination and early growth stage [14-17]. It is well known that polyethylene glycol is utilized as an osmotic substance of high molecular weight to evaluate the drought tolerance of crops [18].

Bread wheat is one of the world's most significant staple crops and is a main source of carbohydrates, which accounts for 40% of the food worldwide production [19]. The yield losses of wheat are still common due to variable and unpredictable drought incidence in the rain-fed wheat-growing areas [20]. Thus, it appears that studying plant responses to drought resilience during the germination stage and growth of seedlings is required to develop drought stress-tolerant plants and produce suitable yields of crops under drought stress conditions. Consequently, this study investigated the response of seven wheat varieties to different drought stress levels during germination and seedling stages in order to evaluate their potential for tolerance to drought conditions. The current study aimed to examine drought stress tolerance for some wheat varieties and determine the most tolerant variety (s) to drought stress. Additionally, to identify the critical growth stage most susceptible to drought stress.

2 Methods and Materials

The current study was carried out in the laboratory at the Department of Biotechnology and Crop sciences at the Collecge of Agricultural Engineering Sciences at the University of Sulaimani. To evaluate resistance of drought, seven wheat varieties (*Triticum aestivum* L.) were examined. The wheat varieties were Aras, Adana, Slemani 2, Hawler 2, Hasad, Jehan 99, and Maroof. All varieties were provided by the general directory of agricultural research in Sulaymaniyah Governorate.

2.1 Laboratory Experiment

In this study, five different osmotic potentials were examined by using polyethylene glycol (PEG) 6000. The PEG 6000 solutions were prepared at four levels (5%, 10%, 15%, and 20%) and prepared according to weight by volume (Bayoumi et al., 2008). The PEG solution of 5% was prepared by dissolving 50 g of PEG in 200 ml of distilled water; the total volume was completed to one litre. Similarly, PEG solutions of 10%, 15%, and 20% were prepared by dissolving 100, 150, and 200 g of PEG in 200 ml of distilled water, respectively, and the total volume was completed to one litre each. Twenty-five seeds from each variety were sterilized (ethanol 70%, for one minute); afterward, immediately the ethanol was removed by washing the seeds using sterilized distilled water. Petri dishes (90 x 15 mm) and Whatman filter papers were used for seed germination, in which sterilized seeds were settled on filter papers inside the petri dishes. An incubator (M 7040 R Electro.mag) was used to keep the petri dishes under laboratory conditions at 25±2°C for 14 days.

Every three days for two weeks, the seeds were washed and the remaining solution was drained. Then, 5 ml of PEG solution for each concentration was applied.

2.2 Observation on Morpho-Physiological Traits Measurements

To observe germination percentage, the numbers of germinated seeds were accounted for (each petri dishes) from the fourth day of germination for the duration of the experiment. Germination and seedling traits were assessed according to the rules of the International Seed Association Test (ISTA). When the radical showed an extension greater than 2 mm, the seeds were treated as germinated. The following traits were measured:

- Germination % = Ng/Nt × 100 Where Ng is the number of germinated seeds until the i day and Nt is the total number of seeds [21].
- Mean Daily Germination (MDG) = FGP/d. Where FGP: final germination percentage (viability), d: day(s) spent from the first to final germination [22].
- Mean Germination Time (MGT) (d) = Σ (NiTi)/(ΣNi). Where N is the percentage of germinated seed in day i, and Ti is the sequence of days from sowing [23].
- Seedling Vigour (SV) (mm): The plumule lengths were measured on the 14th after sowing by ruler for each seedling from the centre line up to the plumule tip. The mean length of each replicate was calculated by the following formula: L=(L1+L2…Ln)/n, where L is the mean plumule length from each replicate, "L1, L2 …Ln" are the individual seedling plumule lengths, and n is germinated seeds in each replicate [24].
- Seedling growth traits such as root length (RL) (mm); shoot length (SHL) (mm); root weight (RW) (mg plant^{-1}); shoot weight (SHW) (mg plant^{-1}) were measured at the 14th day after sowing. The ratio between root and shoot (length ratio RL/SHL, weight ratio RW/SHW) were calculated by dividing root length and weight by shoot length and weight, respectively.

2.3 Statistical analysis

The experiment design was a completely randomized design (CRD) with two factors: varieties and water stresses, with three replications. By employing XLSTAT 2022 software, the dataset underwent an analysis of variance (ANOVA), and the means of traits for both factors and their interactions were compared via LSD at the 5% level of probability. The analysis of principal components was conducted by using Cnoco5 to better visualize the relationships between the studied traits and to compare and segregate varieties based on their relationships with the studied traits.The data were normalized before conducting the analysis of principal components.

3 Results and Discussions

The analysis findings showed significant ($p<0.05$) distinctions in the varieties and PEG concentrations, as well as the interaction between these variables across all analysed traits (seed germination percentage, mean germination time (MGT), mean daily germination (MDG), seedling vigour (SV), shoot and root length (SHL and RL), weights of shoot and root (SHW and RW), root/shoot weight ratio (RW/SHW) and root/shoot length ratio (RL/SHL) (Table1).

3.1 Germination characteristics response under PEG-induced drought stress

The variability in germination, mean germination time, and mean daily germination explains the highly significant impact of different varieties, different PEG concentration levels, and the interaction between varieties and PEG concentrations (Table 1). This suggests that the effect of PEG concentration on germination, mean germination time, and mean daily germination varies depending on the variety, or vice versa. The result suggests that, on average, germination rates are high and relatively consistent across the experimental conditions.

The results of this study exhibit significant variability ($p<0.05$) in germination percentages among studied varieties underneath various PEG concentration levels. The variety Hasad exhibits the highest germination percentage (99.20%), whereas the variety Adana shows the lowest (91.60%). Different studies observed significant differences among wheat varieties under stress conditions[25,26]. Other varieties fall between these extremes, with varying degrees of significance denoted by the letters "b" and "c" (Table 2). The impact of PEG concentration on germination percentages is notable, with 0% PEG showing the highest germination percentage (100%). However, as PEG concentration increases from 5% to 15%, germination percentages remain relatively consistent around 96-97%. A significant decline is observed at 20% PEG concentration, with germination dropping to 89.43%. Adana is particularly affected with drought stress induced by PEG, showing germination percentages of 88% and 76% at 15% and 20% PEG levels, respectively. Similarly, variety Jihan 99 exhibits low germination (82%) at 20% PEG concentration (Figure 1 (A)).

Mean germination time (MGT) and mean daily germination (MDG) afford additional insights into germination dynamics. The mean square of varieties Slemani2 and Hawler 2 have the lowest MDG values (3.329 and 3.286 days, respectively), indicating faster germination. At 0% PEG level, MDG is the lowest (3.571 days), indicating faster germination without PEG (Table 2). Varieties Aras and Jihan 99 have slightly longer germination times (Figure 1. B). It is found that germination can be delayed under drought stress [27].

Regarding MGT, variety Hasad exhibits the lowest value, indicating faster germination. Variety Hasad has the lowest MGT (4.399 days), indicating faster germination. This aligns with findings from other study [26] , who showed that drought stress (simulated by PEG) can slow down germination. At 0% PEG level, MGT is lowest (4.284 days), indicating faster germination without PEG (Table 2). Elevated concentrations of PEG had a significant and negative influence on MGT for the Adana variety, indicating an increased and notable value of 4.756 days (Figure 1 (C)). Again, at 0% PEG level, MGT is lowest, implying faster germination without PEG. However, increased PEG concentration negatively impacts MGT, as evidenced by the higher value for the Adana variety. The inhibitory effect of PEG on seed germination demonstrated in various varieties of the same species [16].

3.2 Seedling vigour under PEG-induced drought stress

Seedling vigour refers to the general health and toughness of seedlings. Higher seedling vigour suggests that the seedlings will survive and thrive in different environments. The variety Aras shows the highest SV at 116.6 mm, emphasizing it as the most vigorous and thriving of the varieties. At 0% PEG level, SV is highest (125.0 mm), indicating the strongest seedlings without PEG. However, as PEG concentration increases, seedling vigour tends to decrease (Table 2). There variation was notable among the varieties in seedling vigour. The varieties Aras and Hasad exhibit relatively higher SV at different levels of PEG (Figure 1 (D)). The varieties Hawler 2, Jihan99, and Maroof, however, show the relatively lowest SV at 20% concentration of PEG (Figure 1 (D)). The negative effect of drought stress on seedling vigour observed by others [16], as the raise of PEG level occurred with a decrease of seedling vigour. This decline in seedling vigour is probably because of redirecting the energy from growth processes by the effect of stress triggered by PEG on physiological reactions [16].

3.3 Early growth stage performance under PEG-induced

The studied factors, varieties and different levels of PEG concentrations, and the interactions between these two factors showed significant ($p<0.05$) differences for all measured traits of seedling growth: RW (Root Weight), SHW (Shoot Weight), RL (Root Length), SHL (Shoot Length), RL/SHL (Root Length to Shoot Length ratio), and RW/SHW (Root Weight to Shoot Weight ratio) (Table 2). These results afford an outline of the distribution of each parameter throughout the studied varieties and PEG concentrations. The varieties and PEG concentrations, generally, affect significantly various growth parameters, and the significant effect of the interactions between them is detected properly (Table 2). The seedling shoot length and root length were negatively impacted by way of water stress, leading to reduced overall plant size and development. The maximum affected variety via drought stress was Hawler 2 with a value of 6.86 cm root length, while variety Hasad with a value of 11.91 cm indicates longest root (Table 2). Increasing PEG concentration adversely affected root length, as at 0% it was recorded 12.53 cm while decreasing to 6.92 cm at 20% of PEG (Table 2).

Seedling shoot length was also adversely affected by water stress, leading to decreased plant size and development (Figure 2 (A) and (B)). All varieties show decreased shoot length as PEG concentration increases. Aras maintains relatively longer shoots across all stress levels. Shorter shoots may indicate water scarcity and stress adaptation. Similar trends in root length (RL) and shoot length (SHL) under PEG stress were found by others [28]. They observed decreased RL and SHL with increasing PEG concentration.

Table 1: Analysis of variance for the studied characters of seven wheat varieties during in vitro drought stress, induced by five levels (0% to 20%) of polyethylene glycol 6000.

Source of Variance	d.f	Mean Square									
		Germination (%)	MDG (d)	MGT (d)	SV (mm)	RL (cm)	SHL (cm)	RW (mg.plant-1)	SHW (mg.plant-1)	RL/SHL	RW/SHW
Varieties	6	118.17**	0.188**	0.132**	1880.44**	20.385**	26.755**	477.37**	541.53**	0.720**	0.089**
PEG conc.	4	312**	0.396**	0.480**	14736.73**	92.569**	94.489**	551.36**	1805.37**	1.000**	0.035*
Varieties x PEG conc.	24	58.60**	0.094**	0.029**	230.60**	8.648**	2.235**	69.12**	90.97**	0.125**	0.046**
Residual	70	15.66	0.031	0.004	70.02	1.534	1.389	12.78	45.82	0.022	0.008
Minimum		72	2.29	4.000	19.5	3.58	3.40	6.60	1.80	0.577	0.128
Maximum		100	3.57	4.96	140.5	16.16	15.10	47.20	68.70	2.324	1.231
Mean		95.7	3.40	4.49	100.5	10.64	10.26	29.6	48.13	1.075	0.627
Standard deviation		6.54	0.26	0.18	27.85	2.78	2.57	8.56	12.35	0.299	0.152

MDG, MGT, SV, RL, SHL, RW, SHW, RL/SHL and RW/SHW are denote Mean Daily Germination, Mean Germination Time, Seedling Vigour, Root Length, Shoot Length, Root to Shoot Length ratio, and Root to Shoot Weight ratio, respectively.
*, ** Denote Significant at 5% ($p<0.05$) and 1% ($p<0.01$) probability level, respectively.

Table 2: The impact of varieties and different osmotic potentials by PEG 6000 on the studied traits for seven wheat varieties.

Factor		Germination (%)	MDG (d)	MGT (d)	SV (mm)	RL (cm)	SHL (cm)	RW (mg.plant-1)	SHW (mg.plant-1)	RL/SHL	RW/SHW
Varieties	Slemani 2	93.20 ab	3.329 a	4.445 a	104.2 c	10.61 c	10.97 de	26.65 b	49.58 cd	0.950 ab	0.540 a
	Hawler 2	94.80 ac	3.286 a	4.599 b	94.3 b	6.86 a	10.03 c	19.93 a	38.71 a	0.883 a	0.584 a
	Adana	91.60 a	3.271 a	4.416 b	90.1 ab	11.93 d	9.03 b	34.26 d	48.42 bc	1.385 c	0.710 cd
	Hasad	99.20 d	3.543 c	4.399 a	112.4 d	11.91 d	11.55 e	35.74 d	54.36 de	1.045 b	0.656 bc
	Aras	98.40 d	3.514 bc	4.416 a	116.6 d	9.67 b	11.87 e	30.49 c	56.13 e	0.843 a	0.546 a
	Jihan 99	95.20 bc	3.400 ab	4.581 b	86.5 a	10.84 c	8.17 a	26.23 b	44.00 b	1.366 c	0.613 ab
	Maroof	97.60 cd	3.486 bc	4.442 a	101.5 c	10.81 c	10.17 cd	33.73 d	45.69 bc	1.055 b	0.736 d
PEG levels	0%	100 c	3.571 c	4.284 a	125.0 e	12.53 c	12.20 d	32.95 d	54.45 c	1.054 ab	0.613 a
	5%	96.00 b	3.429 b	4.396 b	117.0 d	11.94 c	11.7 d	35.49 e	55.96 c	1.030 ab	0.638 ab
	10%	96.57 b	3.378 b	4.592 c	108.0 c	11.78 c	10.84 c	30.48 c	52.85 c	1.113 bc	0.582 a
	15%	96.57 b	3.449 b	4.604 c	95.1 b	9.36 b	9.56 b	26.19 b	43.27 b	1.004 a	0.608 a
	20%	89.43 a	3.194 a	4.622 c	57.5 a	7.57 a	6.92 a	22.77 a	34.10 a	1.176 c	0.691 b

MDG, MGT, SV, RL, SHL, RW, SHW, RL/SHL and RW/SHW are denote Mean Daily Germination, Mean Germination Time, Seedling Vigour, Root Length, Shoot Length, Root to Shoot Length ratio, and Root to Shoot Weight ratio, respectively.
The mean sharing same letters within a same column are statistically non-significant ($p < 0.05$).

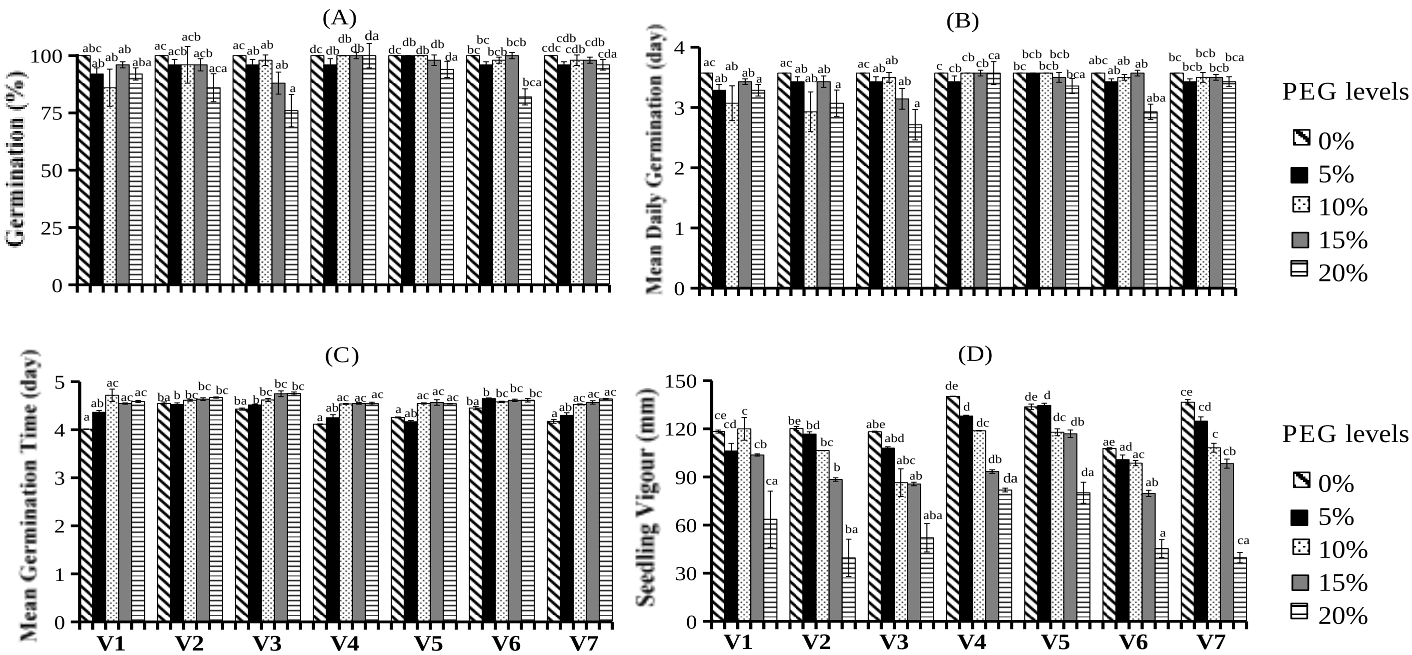

Figure 1: Effect of water stress on the; A) germination %; B) mean daily germination (day); C) mean germination time (day); and D) seedling vigour (mm) of seven wheat varieties. The letters on the bars signify the significance of the combine effect of varieties and PEG levels (as in the table 2).The letters V1 to V7 in the X axis represent the wheat varieties Slemani2, Hawler2, Adana, Hasad, Aras, Jihan99 and Maroof, respectively. The X axis of (A) and (B) is the same as in (C) and (D).

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A study observed variations in the ratio of root/shoot among varieties subjected to diverse drought stress conditions, with some showing increased ratios with higher PEG concentrations[26]. Less difference in the root/shoot length ratio for the drought stress levels was for Hasad, followed by Slemani 2. In the other varieties, generally, there was a general trend of increasing root/shoot ratios correlating with heightened PEG concentrations (Figure 2 (E) and (F)). Generally, water stress led to decreased growth parameters and altered root-to-shoot ratios in the wheat varieties, highlighting the plants' adaptive responses to water scarcity. Water stress negatively impacted the growth parameters of the wheat varieties studied. Variety Hasad exhibits relatively higher shoot and root weights at lower PEG concentrations. In general, shoot and root declined in all varieties as PEG concentration increased.

Furthermore, the coefficient of root/shoot weight ratio also increased, demonstrating a change in the balance between root and shoot biomass accumulation beneath water stress conditions (Figure 2 (F)). The variety slemani 2 showed less difference in root/shoot ratio under different levels of PEG, whereas the ratio of root/shoot decreased by increasing PEG level for variety Maroof. These results are in agreement with those observed by a previous study [29], which found a decrease in root weight (RW) and shoot weight (SHW) as PEG concentration increased. The root/shoot ratio indicates the allocation of energy between roots and shoots. On the other hand, variety Jihan99 shows a significant increase in this ratio under stress. As stress intensifies, this ratio increases, suggesting that more energy is allocated to root growth. A higher root/shoot ratio is an adaptive response to drought found variations in root to shoot length ratio (RL/SHL) and root weight to shoot weight ratio (RW/SHW) among wheat varieties under PEG stress [30]. They found different varieties showing varying degrees of adaptation to PEG stress, leading to inconsistent changes in these ratios. The responses of wheat varieties were inconsistent to PEG stress; some varieties exhibit better tolerance and adaptability, while others are more sensitive, highlighting the complex nature of plant responses to environmental stresses. Overall, water stress altered the growth parameters by reducing biomass accumulation, affecting plant size, and changing the root-to-shoot ratios in the wheat varieties, reflecting their adaptive responses to water stress.

3.4 Principal Component Analysis (PCA)

To determine superior varieties for the drought condition and to investigate relationships between all characteristics, the PCA analysis was executed. This analysis shows that the total counted variation was 96.36% by the first and second components, in which 79.59% and 20.41% were covered by the first and second components, respectively (Table 3). This high percentage demonstrates that the PCA successfully captures the majority of the variance in the data, making it a reliable method for understanding the relationships among traits. The relationships between characteristics that exhibited proximity to each other in the PCA analysis were positively correlated, such as SHW with RW, SV and germination with SV. Positive correlations were observed among MGT, MGD, RL, and RL/SHL, implying that development in this kind of trait may also additionally result in progress inside the others, which is useful for choosing varieties that carry out properly under drought situations. These results coincide with the outcome in other studies [31-33]. Negative correlations, on the other hand, were detected among those traits that were located in opposite directions, which include SHW and SHL; Germination and SV in opposition to RL; RL/SHL; RW/SHW, indicating an inverse dating among these characters. Previous research determined poor correlations among studied characters [34,35].

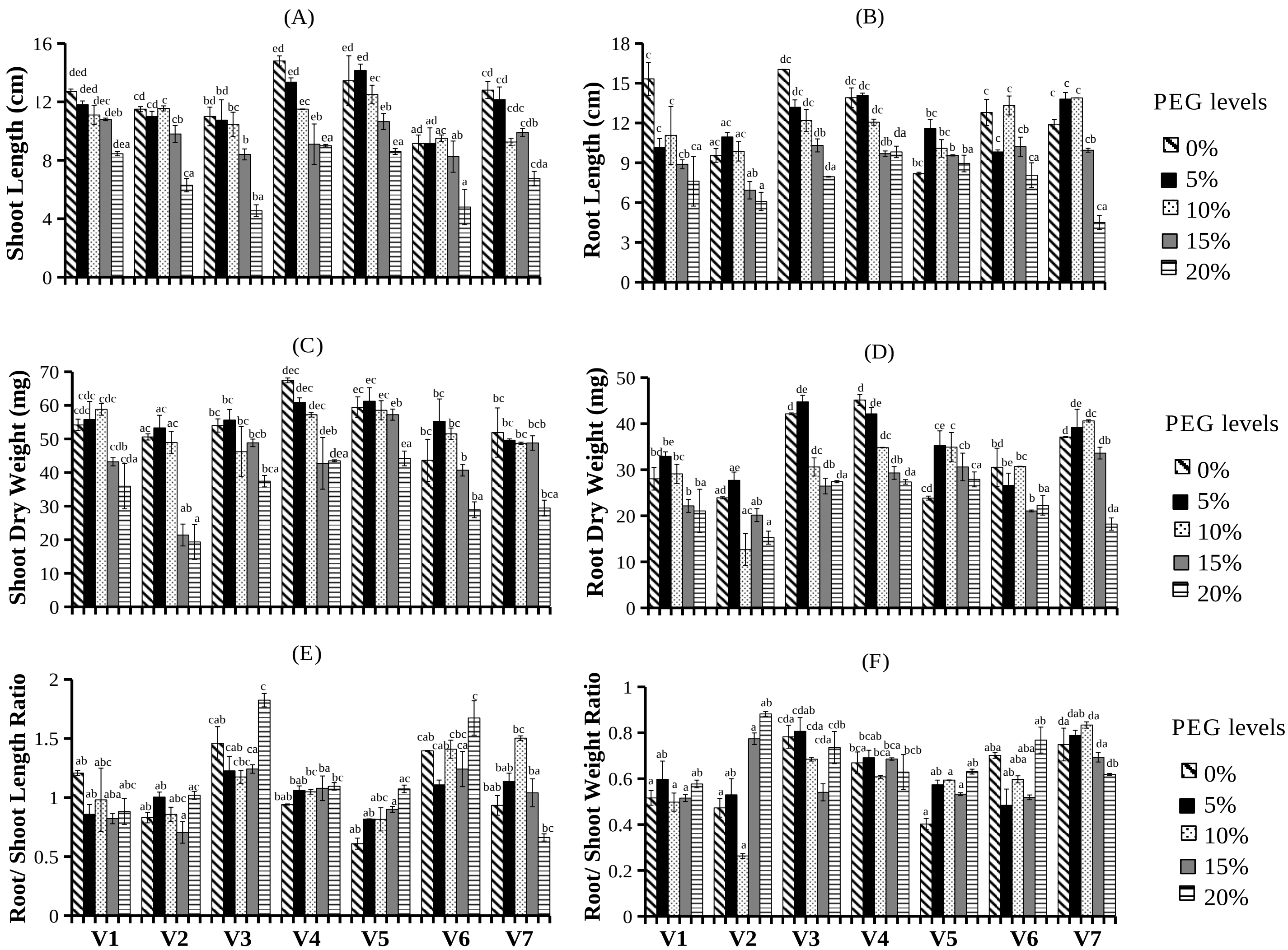

Figure 2: Effect of water stress on the; A) seedling shoot length (cm); B) seedling root length (cm); C) seedling shoot weight (mg); D) seedling root weight (mg); E) coefficient of root/ shoot length ratio; and F) coefficient of root/ shoot weight ratio of seven wheat varieties. The letters on the bars signify the significance of the combine effect of varieties and PEG levels (as in the table 2). The letters V1 to V7 in the X axis represent the wheat varieties Slemani2, Hawler2, Adana, Hasad, Aras, Jihan99 and Maroof, respectively. The X axis of (A),(B) , (C), and (D) is the same as in (E) and (F).

The PCA biplot categorizes wheat varieties into three groups (G1, G2, and G3) based on their correlations with studied traits (Figure 3). First group (G1) varieties (Hasad, Slemani2, Aras) correlated positively and strongly with traits that are critical for drought resistance. Heavier and larger seeds may be produced inside the varieties with high SHW and SV [36], which is useful for survival under drought stress situations. Moreover, a positive correlation with RW shows that those varieties increase robust root systems, improving their ability to obtain right of entry to water and vitamins [37]. The association with germination shows that these varieties can thrive in stressful environments, increasing resilience. While these characteristics are important for seed quality, they do not necessarily indicate drought resistance. However, high germination rates promote quick plant establishment [17], which is advantageous under drought conditions. According to these results, varieties in this group may be considered greater proof against drought stress due to their favourable traits that guide increase under inverse conditions. Second group varieties (G2) (Adana, Jihan99) focus on root improvement and germination efficiency. A longer RL shows a higher capacity to explore the soil for moisture [37], while the RL/SHL ratio suggests a balanced increase among roots and shoots. However, the presence of MGT and MDG suggests that these varieties may take longer to germinate, which may be a drawback beneath severe drought situations. The RW/SHW ratio also suggests that while root weight is important, it may not be as robust as in Group 1. Although these varieties (Adana, Jihan99) have some traits that support drought tolerance, their longer germination times may make them less competitive under stress, suggesting a moderate level of susceptibility compared to Group 1. Varieties in the third group (G3) (Hawler, Maroof) are mainly related to SHL, which suggests a crucial point on seed morphology as opposed to root improvement. The lack of robust correlations with different traits shows that these varieties would not be as properly adapted to drought conditions. The emphasizing on SHL without associated traits such as RW or SHW proposes a potential vulnerability, as they may now not produce sufficient biomass or have effective root systems to cope with water stress.

Table 3: PCA analysis for the studied traits of seven wheat varieties.

Trait	F1	F2
Germination	0.1089	-0.9762
MDG	-0.9905	0.0219
MGT	-0.9812	0.1322
SV	0.9895	0.0031
RL	-0.9042	0.5863
SHL	-0.9578	-0.4941
RW	0.0213	0.8927
SHW	0.8457	0.6022
RL/SHL	-0.9561	0.2605
RW/SHW	-0.9786	0.1274
Eigenvalues %	0.8457	-0.9762
Variability	-0.9905	0.0219
cumulative %	-0.9812	0.1322

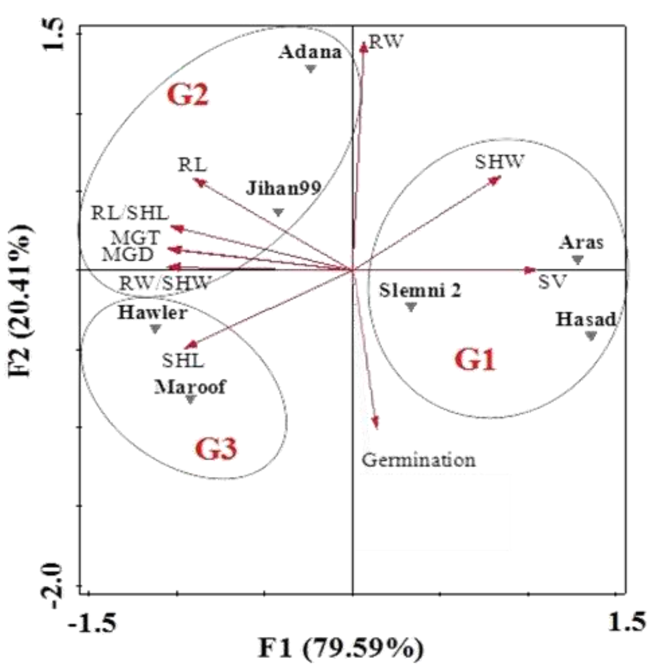

Figure 3: Biplot PCA analysis for seven wheat varieties to assess correlations between studied traits under water stress.

Conclusions

In this study, drought stress significantly impacted germination and the studied seedling characteristics. The most effect of PEG concentration was at 20% on most of the studied traits. According to the results of both variance and principal component analyses, varieties Hasad, Slemani 2, and Aras showed better drought resistance among the studied varieties, especially variety Hasad, which outperformed the majority of the studied attributes under drought stress circumstances. While moderate susceptible varieties were Adana, Jihan99, and susceptible varieties were Hawler and Maroof. Drought- tolerant varieties, hence, may prove their propriety for cultivation in arid and semiarid regions. Further studies are recommended to assess the performance of the varieties under field conditions. The outcome from this study could guide breeders in selecting and enhancing of tolerant genotypes within breeding programs to develop more resilient wheat varieties.

Authors contribution

S.S., conceptualized the project idea, and the other authors conceived and planned the experiments. S.O. and S.S. carried out the experiments, and S.MS. supervised the project and partially contributed to the implemented experiments. SH.O. and S.S. performed data calculations. S.MS. conducted the analysis of data and drafted the initial manuscript. All authors engaged in discussions regarding the results and contributed to the final document.

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References

[1] Al-Ghamdi, A. A. Evaluation of oxidative stress tolerance in two wheat (*Triticum aestivum* L.) varieties in response to drought. *Int J Agr Biol (Pakistan)* **11**(1), 7-12 (2009).

[2] Abedi, T., Pakniyat, H. Antioxidant enzyme changes in response to drought stress in drought stress in ten varieties of oilseed rape (*Brassica napus* L.). *Czech J Gen Plant Breeding* **46**(1).27-34 (2010).

[3] Kumar, R. R., Karajol, K. & Naik ,G. R. Effect of Polyethylene Glycol induced water stress on physiological biochemical responses in pigeonpea (*Cajanus cajan* L. Millsp.). *Res Sci Tech* **3**(1),148-152 (2011).

[4] Chutipaijit, S., Cha-um, S. & Sompornpailin, K. An evaluation of water deficit tolerance screening in pigmented indica rice genotypes. *Pakistan J Botany* **44**(1), 65-72 (2012).

[5] Lesk, C., Rowhani, P., & Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature* **529**(7584), 84-87 (2016).

[6] Zhang, J., Zhang, S., Cheng, M., Jiang, H., Zhang, X., Peng, C. & Jin, J. Effect of drought on agronomic traits of rice and wheat: A meta-analysis. *Int J Environ Res Public Health* **15**(5), 839 (2018).

[7] Zhao, W., Liu, L., Shen, Q., Yang, J., Han, X., Tian, F., & Wu, J. Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. *Water* **12**(8), 2127 (2020).

[8] Xu, Z., Lai, X., Ren, Y., Yang, H., Wang, H., Wang, C. & Zhang, Y. Impact of Drought Stress on Yield-Related Agronomic Traits of Different Genotypes in Spring Wheat. *Agronomy* **13**(12), 2968 (2023).

[9] Khakwani, A. A., Dennett, M. D., & Munir, M. Drought tolerance screening of wheat varieties by inducing water stress conditions. *Songklanakarin J Sci Tech* **33**(2), 135-142 (2011).

[10] Sanchez, P. L., Chen, M. K., Pessarakli, M., Hill, H. J., Gore, M. A. & . Jenks, M. A. Effects of temperature and salinity on germination of non-pelleted and pelleted Guayule (Parthenium argentatum A. Gray) seeds. *Indust Crops Products* **55**, 90-96 (2014).

[11] Abo-Kassem, E. M. Effects of salinity: Calcium interaction of growth and nucleid acid metabolism in five species of Chenopodiaceae. *Turkish J Botany* **31**(2), 125–134 (2007).

[12] Hakim, M. A., Juraimi, A. S., Begum, M., Hanafi, M. M., Ismail, M. R. & Selamat, A. Effect of salt stress on germination and early seedling growth of rice (*Oryza sativa* L.). *African J Biotech* **9**, 1911–1918 (2010).

[13] Faisal, S., Mujtaba, S. M., Asma, W. M. Polyethylene Glycol Mediated osmotic stress impacts on growth and biochemical aspects of wheat (*Triticum aestivum* L.). *J Cro p Sci Biotech* **22**, 213–223 (2019).

[14] Bukhari, M. A., Shah, A. N., Fahad, S., Iqbal, J., Nawaz, F., Manan, A., Baloch M. S. Screening of wheat (*Triticum aestivum* L.) genotypes for drought tolerance using polyethylene glycol. *Arabian J Geosciences* **14,** 2808 (2021).

[15] Awan, S. A., Khan, I., Rizwan, M., Zhang, X., Brestic, M., Khan, A., & Huang, L. Exogenous abscisic acid and jasmonic acid restrain polyethylene glycol-induced drought by improving the growth and antioxidative enzyme activities in pearl millet. *Physiol Plantarum* **172**(2), 809-819 (2021).

[16] Fatima, Z., Awais, M., Waheed, A., Ali, A., Hashmi, Q. A., Abbas, M., & Sufyan, A. Effect of Polyethylene Glycol (PEG) on germination and seedling parameters of maize varieties. *Asian J Res Crop Sci* **8**(4), 410-420 (2023).

[17] Mahpara, S., Zainab, A., Ullah, R., Kausar, S., Bilal, M., Latif, M. I., Arif, M., Akhtar, I., Al-Hashimi, A.,Elshikh, M. S., Zivcak, M., & Zuan, A. T. The impact of PEG-induced drought stress on seed germination and seedling growth of different bread wheat (*Triticum aestivum* L.) genotypes. *PloS one* **17**(2), e0262937 (2022).

[18] Zarei, L., Farshadfar, E., Haghparast, R., Rajabi, R., & Badieh, M.M.S. Evaluation of some in direct traits and indices to identify drought tolerance in bread wheat (*Triticum aestivum* L.). *Asian J Plant Sci* **6**(8),1204–1210 (2007).

[19] Duvnjak, J., Lončarić, A., Brkljačić, L., Šamec, D., Šarčević, H., Salopek-Sondi, B., & Španić, V. Morpho-Physiological and hormonal response of winter wheat varieties to drought stress at stem elongation and anthesis stages. *Plants* **12**(3), 418 (2023).

[20] Mohamed, E. A., Ahmed, A. A., Schierenbeck, M., Hussein, M. Y., Baenziger, P. S., Börner, A. & Sallam, A. Screening spring wheat genotypes for TaDreb-B1 and Fehw3 genes under severe drought stress at the germination stage using KASP technology. *Genes* **14**(2), p.373 (2023).

[21] International Seed Testing Association. Chapter 5: The germination test. *Int Rules Seed Testing*, ISTA, Bassersdorf, Switzerland, (2018).

[22] Shalaby, N. E., & Shahein, A. M. The influence of priming on viability of aged sunflower (*Helianthus annuus* L.) *Seeds. J Plnat Production* **13**(8), 605-610 (2022).

[23] Ellis, R., & Roberts, E. The quantification of ageing and survival in orthodox seeds. *Seed Sci Tech* (Netherlands) **9**(2), 373-409 (1981).

[24] Hampton, J.G. & TeKrony, D.M. *Handbook of Vigour Test Methods*,3rd ed. ISTA, Zurich, (1995).

[25] Chachar, Z., Chachar, N. A., Chachar, Q. I., Mujtaba, S. M., Chachar, G. A. and Chachar, S. Identification of drought tolerant wheat genotypes under water deficit conditions. *Int J Res* **44**(22), 206- 214 (2016).

[26] Ahmad, N. S., Kareem, S. H., Mustafa, K. M. and Ahmad, D. A. Early screening of some Kurdistan wheat (*Triticum aestivum* L.) varieties under drought stress. *J Agri Sci* **9**(2),88-103 (2017).

[27] Liu, M., Li, M., Liu, K., & Sui, N. Effects of drought stress on seed germination and seedling growth of different maize varieties. *J Agri Sci* **7**(5), 231 (2015).

[28] Sarmad, S., Ali, S., Iqbal, N., Khan, M. R., Haider, M. Z., Abbas, G., & Hussain, S. Effect Polyethylene Glycol (PEG) on growth and development of some wheat varieties. *J Soil Sci Plant Nutrition* **19**(4), 797-809 (2019).

[29] Ali, S., Rizwan, M., Hussain, A., Rehman, M. Z. U., Javed, M. R., Bukhari, S. A. H., & Al-Wabel, M. I. Polyethylene glycol 6000 (PEG-6000) mediated drought stress tolerance in common wheat (*Triticum aestivum* L.): Growth, photosynthesis, and antioxidant capacity. *Environ Sci Pollut Res* **24**(31), 24726-24737 (2017).

[30] Khan, M. R., Khan, M. W., Khan, M. A., & Mujeeb, F. Response of wheat varieties to different levels of PEG-induced water stress. *Pure Appl Biol* **7**(3), 891-899 (2018).

[31] Devi, O.R., Verma, O., Pandey, S.T., Laishram, B., Bhatnagar, A. & Chaturvedi, P. Correlation of germination, seedling vigour indices and enzyme activities in response to liquid organic Kunapajala to predict field emergence in late sown wheat. *Environ Ecol* **41**(3B), 1694-1698 (2023).

[32] Chen, Y., Palta, J., Prasad, P. V., & Siddique, K. H. Phenotypic variability in bread wheat root systems at the early vegetative stage. *BMC Plant Biol* **20**, 1-16 (2020).

[33] Figueroa-Bustos, V., Palta, J.A., Chen, Y., Siddique, K. H. M. Characterization of root and shoot traits in wheat cultivars with putative differences in root system size. *Agronomy* **8**(7), 109 (2018).

[34] Othmani, A., Ayed, S., Chamekh, Z., Slama-Ayed, O., Teixeira Da Silva, J. A., Rezgui, M., SLIM-AMARA, H. & Younes, M. B. Screening of seedlings of durum wheat (Triticum durum Desf.) cultivars for tolerance to peg-induced drought stress. *Pakistan J Botany* **53**(3), 823-832 (2021).

[35] Sharma, V., Kumar, A., Chaudhary, A., Mishra, A., Rawat, S., Shami, V., & Kaushik, P. Response of wheat genotypes to drought stress stimulated by PEG. *Stresses* **2**(1), 26-51 (2022).

[36] Zareian, A., Hamidi, A., Sadeghi, H., & Jazaeri, M. R. Effect of seed size on some germination characteristics, seedling emergence percentage and yield of three wheat (*Triticum aestivum* L.) cultivars in laboratory and field. *Middle-East J Sci Res* **13**(8), 1126-1131 (2013).

[37] Wasson, A. P., Richards, R. A., Chatrath, R., Misra, S. C., Prasad, S. S., Rebetzke, G. J. & Watt, M. Traits and selection strategies to improve root systems and water uptake in water-limited wheat crops. *J Exp Botany* **63**(9), 3485-3498 (2012).