

Germination and Tolerance of *Phaseolus vulgaris* Genotypes under PEG 6000 Drought Stress

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Abstract

This study evaluated germination performance and drought tolerance of common bean (*Phaseolus vulgaris* L.) genotypes under PEG 6000-induced osmotic stress. Increasing stress levels significantly reduced plumule and radicle lengths and decreased fresh and dry weights of the hypocotyl, plumule, and radicle. Under severe stress (-5 bar), shoot and root development and biomass accumulation were substantially suppressed across all genotypes. However, significant differences among genotypes revealed differential adaptive strategies. The Berrak genotype maintained the longest radicle length under severe stress, while Karaman-2016 preserved higher radicle fresh weight, indicating better root biomass retention. In contrast, KKF-BY-15-28 showed the most pronounced reductions in fresh and dry biomass, suggesting higher sensitivity. KKF-BY-15-8 displayed intermediate performance. Morphological and biomass-based parameters at germination are reliable, practical indicators for early drought tolerance assessment in common bean and may serve as effective tools for preliminary genotype selection.

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PEG 6000 Kuraklık Stresi Altında *Phaseolus vulgaris* Genotiplerinin Çimlenmesi ve Dayanıklılığı

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ÖZ

Bu çalışma, PEG 6000 ile indüklenen osmotik kuraklık stresi altında farklı fasulye (*Phaseolus vulgaris* L.) genotiplerinin çimlenme performansını ve toleransını değerlendirmiştir. Artan stres seviyeleri plumula ve radikula uzunluklarını ve hipokotil, plumula ile radikulanın taze ve kuru ağırlıklarını önemli ölçüde azaltmıştır. Şiddetli stres altında (-5 bar), tüm genotiplerde sürgün ve kök gelişimi ile biyokütle birikimi baskılanmıştır. Bununla birlikte, genotipler arasında önemli farklılıklar tespit edilmiştir. Berrak genotipi şiddetli stres altında en uzun radikula uzunluğunu korurken, Karaman-2016 daha yüksek radikula taze ağırlığını muhafaza ederek daha iyi kök biyokütlesi tutulumu göstermiştir. KKF-BY-15-28 ise taze ve kuru biyokütle parametrelerinde en belirgin azalmaları sergileyerek daha yüksek duyarlılık göstermiştir. KKF-BY-15-8 orta düzeyde performans sergilemiştir. Çimlenme aşamasında ölçülen morfolojik ve biyokütle bazı parametreler, yaygın fasulyede kuraklık toleransının erken değerlendirmesi için güvenilir ve pratik göstergeler olup ön seleksiyon için etkili araçlardır.

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Introduction

Drought is one of the most significant abiotic stress factors limiting plant growth and productivity. Global climate change and the depletion of water resources are making the effects of drought stress on agricultural production increasingly pronounced (Qian et al., 2025; Wang et al., 2025). In plants, the germination stage is particularly sensitive to environmental stresses (Ghosh et al., 2025). Therefore, the identification of genotypes with high germination capacity under stress conditions is of great importance for sustainable agriculture and breeding programs.

Phaseolus vulgaris L. (common bean) is a widely cultivated legume species worldwide and is of considerable importance for both human nutrition and soil fertility due to its high protein content and nitrogen-fixing ability. However, bean production is highly susceptible to environmental stress factors such as drought (Kumari et al., 2025). Water deficit negatively affects growth and yield in common bean depending on the severity and duration of the stress, as well as the developmental stage of the plant (Asfaw et al., 2017).

Under drought conditions, plants reduce water loss by closing their stomata, thereby limiting transpiration. However, this response also restricts CO₂ uptake and consequently reduces photosynthetic activity. Prolonged water deficiency leads to reductions in plant height, leaf area, and biomass, as well as flower and young pod abortion and decreased root nodule activity (Asfaw et al., 2017).

Drought tolerance in common bean exhibits substantial variation among genotypes and involves numerous morphological and physiological mechanisms (Beebe et al., 2013; Polania et al., 2017). Drought-tolerant genotypes are generally characterized by more efficient water use, a more developed root system, higher relative water content, and the ability to maintain photosynthesis under limited water conditions. Additionally, these genotypes are capable of preferentially allocating photosynthates to reproductive organs, thereby maintaining a higher harvest index under stress conditions (Polania et al., 2017).

The evaluation of early developmental stages provides significant advantages in determining drought tolerance. Osmotic stress induced under laboratory conditions using polyethylene glycol (PEG 6000) is a widely employed and effective method for simulating drought conditions (Michel & Kaufmann, 1973; Emmerich & Hardegree, 1990). PEG 6000 reduces the water potential of the medium without exerting toxic effects on plant tissues, thereby creating controlled water stress. This approach enables comparative assessment of drought tolerance among different common bean genotypes at the germination stage (Emmerich & Hardegree, 1990).

This study aimed to evaluate the germination performance of different common bean genotypes under PEG 6000-induced drought stress and to determine their tolerance levels. The findings are expected to contribute to the early-stage selection of drought-tolerant common bean genotypes and to support breeding programs.

Materials and Methods

The experiment was conducted in 2025 under in vitro controlled conditions in plant growth chambers at the laboratories of the Department of Agricultural Biotechnology, Faculty of Agriculture, Iğdır University. The study was carried out according to a completely randomized design (CRD) with three replications. A total of four different common bean (*Phaseolus vulgaris* L.) genotypes were used as plant material: the cultivars KKF-BY-15-8 and KKF-BY-15-28 obtained from Mardin Artuklu University, and the varieties Karaman-2016 and Berrak.

Before germination, seeds were surface sterilized to eliminate potential contaminants by immersion in 2% (w/v) commercial sodium hypochlorite solution for 1 minute, followed by several rinses with sterile distilled water. The sterilized seeds were placed between folded drying papers, transferred into sealed plastic bags, and allowed to germinate for 10 days in a plant growth chamber set at 25 ± 1 °C.

Three different osmotic conditions were applied to the seeds: control (0 bar), -2.5 bar, and -5 bar osmotic potentials prepared using PEG 6000 solutions. The osmotic potentials of the PEG 6000 solutions used for simulate drought stress were calculated according to the equation developed by Michel and Kaufmann (1973):

$$\psi_s = -(1.18 \times 10^{-2}) C - (1.18 \times 10^{-4}) C^2 + (2.67 \times 10^{-4}) CT + (8.39 \times 10^{-7}) C^2 T \quad (1)$$

where:

ψ_s = osmotic potential (bar),

C = polyethylene glycol concentration (g L^{-1}),

T = ambient temperature (°C).

Five seeds were placed between each layer of drying paper, and 10 mL of the prepared PEG solutions were applied to each sample (Keshtiban, 2015; Mena et al., 2015). At the end of the germination period, on day 10, the samples were removed from the growth chamber, and measurements were conducted.

Shoot (plumule) and root (radicle) lengths (mm), as well as fresh and dry weights (g) of the hypocotyl, radicle, and plumule, were evaluated as assessment criteria. These parameters were measured using millimeter paper and a precision balance. The experiment was established according to a completely randomized design (CRD) with three replications. The experiment was conducted with three replications, and each replication consisted of 5 seeds per genotype–treatment combination.

Common bean seeds consist of two cotyledons attached to the tip of the hypocotyl and a plumule structure of epicotyl origin developing between these cotyledons (Kater, 1927). During germination, the distinction between root and hypocotyl regions was determined based on color differentiation observed in the emerging tissues. Accordingly, light, white-colored portions were classified as roots, whereas relatively darker regions were identified as plumules (Zhu et al., 2006).

All data were subjected to statistical analysis using XLSTAT software. Statistically significant means were grouped using Duncan's multiple range test.

Results

In this study, the responses of four common bean genotypes to varying drought levels (Control (0 bar), -2.5 bar, and -5 bar PEG 6000 treatments) during germination were statistically evaluated. Radicle and plumule lengths, as well as fresh and dry weights of the hypocotyl, radicle, and plumule, were analyzed using analysis of variance (ANOVA). Statistically significant differences were detected (Table 1, Table 2, and Table 3).

Plumule and Radicle Lengths

The responses of different common bean genotypes to PEG 6000-induced drought stress during germination exhibited significant differences in terms of plumule and radicle lengths (Table 1).

Genotype ($p < 0.05$), treatment dose ($p < 0.001$), and the genotype $\times$ dose interaction ($p < 0.05$) were found to have statistically significant effects on both plumule and radicle length. Regarding plumule length, significant differences were observed among genotypes and PEG doses (Table 1). The highest plumule length (34.467 mm) was obtained in the KKF-BY-15-28 genotype under control (0 bar) conditions. In contrast, the lowest plumule length (0.667 mm) was observed in the Karaman-2016 genotype under -5 bar PEG treatment. In all genotypes, increasing PEG concentrations resulted in a marked reduction in plumule length, with severe suppression of plumule development, particularly under -5 bar PEG treatment. Radicle length values also varied significantly depending on genotype and treatment dose (Table 1). The longest radicle development (95.833 mm) was determined in the Berrak genotype under control conditions. Conversely, the shortest radicle length (6.667 mm) was determined in the Karaman-2016 genotype under -5 bar PEG treatment. Overall, PEG treatments restricted root elongation, and at higher doses, root growth was substantially inhibited.

Table 1. Plumule and radicle lengths (mm) of different genotypes under PEG 6000 treatment.

Genotype	Dose (bar)	Plumule Lenght (mm)	Radicle Lenght (mm)
KKF-BY-15-8	0	30.200 ^a	55.300 ^{bc}
	2.5	2.000 ^{bc}	20.500 ^d
	5	2.667 ^{bc}	16.000 ^d
	Mean	11.622 ^a	30.600 ^{bc}
KKF-BY-15-28	0	34.467 ^a	73.200 ^{ab}
	2.5	5.833 ^{bc}	64.000 ^{ab}
	5	1.000 ^c	20.333 ^d
	Mean	13.767 ^a	52.511 ^a
Karaman-2016	0	19.750 ^{abc}	26.000 ^{cd}
	2.5	3.375 ^{bc}	18.125 ^d
	5	0.667 ^c	6.667 ^d
	Mean	10.450 ^a	49.078 ^{ab}
Berrak	0	21.750 ^{ab}	95.833 ^a
	2.5	6.000 ^{bc}	28.400 ^{cd}
	5	3.600 ^{bc}	23.000 ^{cd}
	Mean	7.931 ^a	16.931 ^c
Mean PEG Concentrations	0	26.542 ^a	62.583 ^a
	2.5	4.302 ^b	32.756 ^b
	5	1.983 ^b	16.500 ^b
Mean squares	Genotype	0.365 [*]	5.735 ^{**}
	Dose	20.698 ^{***}	17.816 ^{***}
	GxD	0.525 [*]	2.383 [*]

Values represent replication means. Means within the same column followed by different lowercase letters differ significantly at $p \leq 0.05$ according to Duncan's multiple range test. Differences among genotype means are indicated by uppercase letters. ANOVA was used to evaluate the effects of Genotype (G), Dose (D), and $G \times D$ interaction. Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Fresh Weight Parameters

PEG 6000 treatment caused statistically significant effects on plumule fresh weight and radicle fresh weight (Table 2). For plumule fresh weight, genotype ($p < 0.001$), dose ($p < 0.01$), and the genotype $\times$

dose interaction ($p < 0.001$) were found to be significant. Similarly, for radicle fresh weight, both genotype and the genotype $\times$ dose interaction were statistically significant ($p < 0.001$). For hypocotyl fresh weight, the genotype $\times$ dose interaction was significant ($p < 0.05$).

Significant differences were observed among genotypes in terms of hypocotyl fresh weight (Table 2). The highest hypocotyl fresh weight (0.926 g) was reached in the KKF-BY-15-8 genotype under control conditions. In contrast, the lowest value (0.154 g) was measured in the KKF-BY-15-28 genotype at -5 bar PEG treatment. With increasing PEG concentration, a decreasing trend in hypocotyl fresh weight was observed across all genotypes. Plumule fresh weight values were found to be sensitive to PEG treatments (Table 2). The highest plumule fresh weight (0.386 g) was determined in the KKF-BY-15-8 genotype under control conditions, whereas the lowest value (0.008 g) was observed in the KKF-BY-15-28 genotype at -5 bar PEG treatment. In terms of radicle fresh weight, the highest value (0.285 g) was measured in the KKF-BY-15-28 genotype under control conditions (Table 2). Conversely, the lowest radicle fresh weight (0.006 g) was also recorded in the KKF-BY-15-28 genotype at -5 bar PEG dose. Overall, PEG treatments markedly restricted root biomass accumulation.

Table 2. Fresh weight values (g) of different genotypes under PEG 6000 treatment.

Genotype	Dose (bar)	Hypocotyl Fresh Weight (g)	Plumule Fresh Weight (g)	Radicle Fresh Weight (g)
KKF-BY-15-8	0	0.926 ^a	0.386 ^a	0.101 ^c
	2.5	0.192 ^{fg}	0.060 ^c	0.025 ^{cd}
	5	0.717 ^{bc}	0.030 ^c	0.029 ^{cd}
	Mean	0.611 ^a	0.158 ^a	0.052 ^b
KKF-BY-15-28	0	0.189 ^g	0.300 ^{ab}	0.285 ^a
	2.5	0.497 ^d	0.021 ^c	0.055 ^{cd}
	5	0.154 ^g	0.008 ^c	0.006 ^d
	Mean	0.280 ^c	0.110 ^a	0.116 ^a
Karaman-2016	0	0.817 ^b	0.096 ^c	0.093 ^c
	2.5	0.627 ^c	0.032 ^c	0.039 ^{cd}
	5	0.413 ^{de}	0.045 ^c	0.053 ^{cd}
	Mean	0.423 ^b	0.072 ^a	0.091 ^{ab}
Berrak	0	0.474 ^d	0.168 ^{bc}	0.183 ^b
	2.5	0.330 ^{ef}	0.028 ^c	0.070 ^{cd}
	5	0.464 ^{de}	0.020 ^c	0.020 ^d
	Mean	0.619 ^a	0.058 ^a	0.061 ^b
Mean PEG Concentrations	0	0.602 ^a	0.237 ^a	0.165 ^a
	2.5	0.411 ^b	0.035 ^b	0.047 ^b
	5	0.437 ^b	0.026 ^b	0.027 ^b
Mean squares	Genotype	32.743 ^{***}	1.437 ^{**}	2.850 [*]
	Dose	26.260 ^{***}	20.700 ^{***}	36.043 ^{***}
	GxD	28.039 ^{***}	1.994 [*]	4.906 ^{***}

Values represent replication means. Means within the same column followed by different lowercase letters differ significantly at $p \leq 0.05$ according to Duncan's multiple range test. Differences among genotype means are indicated by uppercase letters. ANOVA was used to evaluate the effects of Genotype (G), Dose (D), and $G \times D$ interaction. Significance levels: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Dry Weight Parameters

Dry weight data varied depending on genotype and treatment dose (Table 3). In particular, genotype, dose, and their interaction effects on hypocotyl dry weight were found to be statistically significant ($p < 0.001$). For plumule dry weight, genotype ($p < 0.001$), dose, and the genotype $\times$ dose interaction ($p < 0.05$) were significant. Similarly, genotype and the genotype $\times$ dose interaction had significant effects on radicle dry weight ($p < 0.05$).

Table 3. Dry weight values (g) of different genotypes under PEG 6000 treatment.

Genotype	Dose (bar)	Hypocotyl Dry Weight (g)	Plumule Dry Weight (g)	Radicle Dry Weight (g)
KKF-BY-15-8	0	0.450 ^a	0.038 ^a	0.016 ^a
	2.5	0.142 ^{fg}	0.000 ^c	0.001 ^d
	5	0.347 ^b	0.000 ^c	0.001 ^d
	Mean	0.313 ^a	0.013 ^a	0.006 ^{ab}
KKF-BY-15-28	0	0.110 ^{gh}	0.021 ^b	0.010 ^b
	2.5	0.259 ^{cd}	0.003 ^c	0.003 ^{cd}
	5	0.055 ^h	0.001 ^c	0.001 ^d
	Mean	0.141 ^d	0.008 ^{ab}	0.004 ^{bc}
Karaman-2016	0	0.318 ^b	0.009 ^{bc}	0.007 ^{bc}
	2.5	0.303 ^{bc}	0.001 ^c	0.000 ^d
	5	0.172 ^{efg}	0.000 ^c	0.000 ^d
	Mean	0.182 ^c	0.006 ^{ab}	0.008 ^a
Berrak	0	0.177 ^{ef}	0.013 ^{bc}	0.015 ^a
	2.5	0.152 ^{efg}	0.004 ^c	0.010 ^b
	5	0.218 ^{de}	0.000 ^c	0.000 ^d
	Mean	0.264 ^b	0.003 ^b	0.002 ^c
Mean PEG Concentrations	0	0.264 ^a	0.020 ^a	0.012 ^a
	2.5	0.214 ^b	0.002 ^b	0.003 ^b
	5	0.198 ^b	0.000 ^b	0.000 ^c
Mean squares	Genotype	31.813 ^{***}	1.696 [*]	7.855 ^{***}
	Dose	11.457 ^{***}	26.243 ^{***}	69.070 ^{***}
	GxD	25.026 ^{***}	3.126 ^{**}	4.087 ^{**}

The results are presented as the means of replications. Means within the same column followed by different lowercase letters are statistically different at the $p \leq 0.05$ level according to Duncan's multiple range test. Differences among genotype means are indicated by uppercase letters, where different letters denote statistically significant differences. ANOVA results showed that the effects of Genotype (G), Dose (D), and the $G \times D$ interaction were statistically significant. Levels of significance were defined as follows: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Examination of hypocotyl dry weight values revealed that the highest value (0.450 g) was recorded in the KKF-BY-15-8 genotype under control conditions (Table 3). The lowest hypocotyl dry weight (0.055 g) was determined in the KKF-BY-15-28 genotype under -5 bar PEG treatment. These findings clearly indicate that drought stress adversely affected dry matter accumulation.

In terms of plumule dry weight, the highest value (0.038 g) was observed in the KKF-BY-15-8 genotype under control conditions (Table 3). In contrast, no measurable plumule dry weight (0.000 g) was recorded for the KKF-BY-15-8 genotype at both -2.5 and -5 bar, as well as for the Karaman-2016 and Berrak genotypes at -5 bar, indicating severe suppression of shoot dry matter accumulation under high osmotic stress.

Regarding radicle dry weight, the highest value (0.015 g) was observed in the Berrak genotype under control conditions (Table 3). No measurable radicle dry weight (0.000 g) was obtained for the Karaman-2016 genotype under both -2.5 and -5 bar treatments, as well as for the Berrak genotype under -5 bar treatment. High PEG doses severely restricted root dry matter accumulation across all genotypes.

Discussion

In this study, the effects of PEG 6000-induced osmotic drought stress on seedling development during the germination stage were comprehensively evaluated in different common bean genotypes. The findings demonstrated that increasing stress severity significantly reduced plumule and radicle lengths, as well as the fresh and dry weights of the hypocotyl, plumule, and radicle. However, the magnitude of these reductions varied among genotypes, indicating that drought tolerance at the germination stage in common bean is genotype dependent.

Plumule length is one of the principal parameters reflecting the sensitivity of shoot development to drought stress during germination. In the present study, PEG 6000 treatments reduced plumule length in all genotypes in a dose-dependent manner. Osmotic drought stress decreases cellular water potential, leading to reduced cell turgor and restricted cell wall expansion. This process suppresses cell elongation at early developmental stages, particularly in actively growing shoot tissues, thereby limiting shoot growth (Hsiao, 1973; Kramer & Boyer, 1995). The higher sensitivity of growth processes compared to other metabolic activities, such as photosynthesis, provides the primary physiological explanation for the rapid inhibition of shoot elongation under osmotic stress (Verslues et al., 2006). Consistent with previous studies conducted on *Phaseolus vulgaris*, PEG-induced drought stress was reported to suppress plumule development earlier and more severely than root development (Torres-Hernández et al., 2022; Beyaz & Uslu, 2025). The significant genotype $\times$ dose interaction observed in this study further indicates that shoot development exhibits genotype-specific responses to drought stress.

Radicle length represents a critical adaptive trait determining early-stage water acquisition capacity (Beebe et al., 2013; Sindarov & Yuldashov, 2025). In the present study, PEG 6000 treatments reduced radicle length in all genotypes, with root elongation being markedly restricted at -5 bar. However, under moderate stress conditions (-2.5 bar), certain genotypes were able to partially maintain root elongation. Previous reports indicate that under mild osmotic stress, root growth is generally less affected than shoot growth, reflecting an adaptive water-foraging strategy (Beebe et al., 2013; Polania et al., 2017; Sindarov & Yuldashov, 2025).

PEG 6000-induced drought stress substantially limited fresh biomass accumulation during germination. Hypocotyl, plumule, and radicle fresh weights declined in all genotypes as stress intensity increased. This reduction in fresh weight is directly associated with decreased tissue water content and reduced cell volume (Özkorkmaz et al., 2020; Aliu et al., 2025). Because shoot tissues are generally more prone to water loss than root tissues, the decline in plumule fresh weight was more pronounced (Polania et al., 2017; Özkorkmaz et al., 2020). Similar findings have been reported in PEG-based drought studies conducted on common bean and other legume species (Özkorkmaz et al., 2020; Aliu et al., 2025; Sindarov & Yuldashov, 2025).

Dry weight parameters reflect the plant's capacity for permanent biomass production (Polania et al., 2017). In this study, PEG 6000 treatments significantly reduced hypocotyl, plumule, and radicle dry weights, particularly under severe stress conditions. Reduced photosynthetic rates and limited carbon assimilation under drought stress are among the primary causes of decreased dry matter accumulation (Polania et al., 2017; Aliu et al., 2025). Although some genotypes may partially maintain dry matter accumulation under mild stress, this capacity is largely lost under severe osmotic stress (Sindarov & Yuldashov, 2025). The marked reductions observed at -5 bar in the present study suggest that the physiological tolerance threshold during early seedling development was exceeded.

Collectively, the findings obtained under PEG 6000-induced osmotic stress indicate that drought tolerance at the germination stage is a genotype-specific, stress-intensity-dependent, and multi-component response (Beebe et al., 2013; Polania et al., 2017; Sindarov & Yuldashov, 2025). Under moderate stress (-2.5 bar), the partial maintenance of radicle length and biomass parameters in some genotypes may be associated with an adaptive strategy prioritizing root development. In contrast, under severe stress (-5 bar), the simultaneous suppression of both root and shoot growth indicates that the physiological tolerance limit was surpassed (Özkorkmaz et al., 2020; Aliu et al., 2025). This phenomenon can be explained by reduced cellular turgor, restricted carbon assimilation, and limited metabolic resources required for growth under osmotic stress (Farooq et al., 2017).

Among the evaluated genotypes, no single genotype exhibited superior performance across all parameters, indicating that drought tolerance at the germination stage is a multi-component trait involving different adaptive strategies (Beebe et al., 2013; Polania et al., 2017). Under severe stress (-5 bar), the Berrak genotype maintained the longest radicle length (23.000 mm), suggesting better root elongation capacity under limited water availability, which is consistent with root traits associated with early-stage drought adaptation (Beebe et al., 2013; Sindarov & Yuldashov, 2025). The Karaman-2016 genotype, despite having the shortest plumule length (0.667 mm) at -5 bar, preserved relatively higher radicle fresh weight (0.053 g), which may indicate a strategy prioritizing root biomass over shoot elongation under severe stress, as previously suggested for drought-tolerant responses (Polania et al., 2017). The KKF-BY-15-8 genotype exhibited moderate performance across most growth and biomass parameters, with a notable ability to maintain a higher hypocotyl dry weight (0.347 g) under severe stress. In contrast, the KKF-BY-15-28 genotype, while showing high values under control conditions, exhibited the most substantial reductions in fresh and dry biomass parameters (e.g., radicle fresh weight dropping from 0.285 g to 0.006 g, and hypocotyl dry weight from 0.110 g to 0.055 g) under -5 bar PEG treatment. This severe decline suggests that KKF-BY-15-28 is particularly sensitive to osmotic stress with respect to biomass accumulation (Özkorkmaz et al., 2020; Aliu et al., 2025), despite its relatively moderate performance in certain length parameters (Sindarov & Yuldashov, 2025). Previous studies emphasize that the combined evaluation of root and shoot growth during early seedling development provides more reliable discrimination of drought-tolerant genotypes than single parameters alone (Beebe et al., 2013; Polania et al., 2017; Sindarov & Yuldashov, 2025).

In this context, the present results demonstrate that morphological and biomass-based parameters measured at the germination stage constitute effective and practical indicators for the preliminary screening of drought tolerance in common bean. This approach may provide significant contributions to the selection of drought-tolerant genotypes in advanced breeding programs (Aliu et al., 2025; Sindarov & Yuldashov, 2025).

Conclusions

In this study, the effects of PEG 6000-induced osmotic drought stress on early post-germination seedling development were evaluated in different common bean genotypes. The findings demonstrated that

increasing stress severity markedly reduced plumule and radicle lengths and led to significant decreases in the fresh and dry weights of the hypocotyl, plumule, and radicle. In particular, severe drought stress (−5 bar) substantially restricted early seedling development across all genotypes, indicating that the physiological tolerance threshold had been exceeded. Significant differences were observed among genotypes in their responses to drought stress. Significant differences were observed among genotypes in their responses to drought stress, but no single genotype proved uniformly superior. The Berrak and Karaman-2016 genotypes showed certain advantages in root length and root fresh weight retention, respectively, under severe stress, whereas the KKF-BY-15-28 genotype exhibited the highest sensitivity, particularly in biomass-related parameters, with the greatest percentage reductions from control to severe stress. The KKF-BY-15-8 genotype generally displayed intermediate performance. These results demonstrate that morphological and biomass-based parameters measured during the early seedling stage serve as effective and practical indicators for distinguishing drought tolerance in common bean. However, tolerance assessment should be based on a holistic evaluation of multiple parameters rather than a single trait. The Berrak and KKF-BY-15-8 genotypes displayed intermediate performance in certain parameters; however, this relative advantage diminished as stress intensity increased. These results demonstrate that morphological and biomass-based parameters measured during the early seedling stage serve as effective and practical indicators for distinguishing drought tolerance in common bean. The findings may facilitate the early identification of drought-tolerant genotypes and contribute to more efficient planning of time and resource allocation in advanced breeding programs. In this context, screening approaches based on early seedling development parameters can be considered valuable tools for developing common bean cultivars adapted to drought-prone environments.

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