JOURNAL of Horticulture, Forestry and Biotechnology
Volume 29(2), 2025, 173-yy
https://jhfb.ro/index.php/jhfb
Print ISSN: 2066-1797
Online ISSN: 3045-1876

Screening for drought tolerance of common bean using several selection indices

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Manuscript received: 17 June 2025; revised: 16 September 2025; accepted: 19 September 2025

Abstract
Drought is one of the main factors that limit the production level, causing harvest losses of over 50%, depending on the duration and intensity of the water deficit. Production losses due to drought can be increased by interaction with other stress factors such as high temperatures. Many selection indices based on seed yield were developed and used for the evaluations of common bean germplasm for drought tolerance. The objectives of this study were to evaluate the yield response to drought stress for six Romanian varieties of common bean using 14 tolerance indices, to establish the efficiency of these selection criteria and the varieties with good drought tolerance. The biological material for this study was composed by six Romanian varieties of common bean studied in Timisoara during 2022-2024, under different levels of drought stress. Based on the obtained results, the following indices: yield index, drought resistance index, stress susceptibility percentage index, stress tolerance index, geometric mean productivity, mean productivity, shows very strong positive correlations with both yield under stress and non-stress conditions, indicating that they can be used with high efficiency for the selection of genotypes with superior yields under different water stress conditions. 'Star' and 'Avans' varieties showed a moderate tolerance to drought, achieving reasonable levels of plant yield under conditions with and without water stress.

Keywords: drought stress**, '***Phaseolus vulgaris'*, plant yield, selection criterion.

Introduction

Drought is one of the main factors limiting production levels, causing crop losses of over 50%, depending on the duration and intensity of the water deficit [31; 35; 40]. Water is considered the most limiting abiotic factor for the life of plants through photosynthesis. The ability of plants to overcome drought stress is due to the appropriate environmental and agricultural conditions and due to genetic factors, that can improve its ability to save water as the flow of water from roots to leaves decreases and as the water through transpiration decreases when stomata are open [23].

Water-deficit stress is an aggressive climate factor that damages crop yield, especially during the period of reproduction and grain filling [3]. Production losses due to drought can be increased by the interaction with other stress factors such as high temperatures, diseases and soil properties [26]. Loss of grain yield is considered the main concern of plant breeders; therefore, they emphasize yield performance under drought stress conditions. However, the variation of yield potential could arise from factors related to adaptation rather than to drought tolerance [5]. Drought tolerance can be defined as the ability of plants to grow and produce under water deficit conditions [20].

Drought stress on reproductive stages represents a major problem for common bean (*Phaseolus vulgaris* L.) because it affects the flowering and pod-filling processes which are highly drought-sensitive [13]. Numerous studies have demonstrated that the occurrence of water stress during the generative period of bean development causes a reduction in the number of flowers, pods and grains/pods. In this sense, the number of flowers per plant can be reduced by over 47%, associated with a reduction in the number of pods between 20 and 65% [7; 18; 26]. To evaluate the drought tolerance of genotypes, numerous morphological, phenological, and physiological selection methods and indices are used, but the most effective selection index is the grain production obtained under stress and non-stress conditions [1; 33; 37; 38].

The common bean plants are highly sensitive to variations of temperature, humidity, and available amount of nutrients [30], therefore unraveling the mechanisms associated to drought tolerance is of the most importance for its production. In the common bean plants, some morphological adaptations to drought have been observed including the loss of leaf area as a result from a series of events like the size reduction of the younger leaves, or the acceleration of leaf loss by senescence (Labastida 23). A comparative proteomic study regarding the isolated chloroplasts from leaves of cultivars under drought stress indicated that 44 proteins changed the reaction of control and stressed plants. Most of these proteins were involved in photosynthetic processes [39].

Breeding common beans for drought tolerance require matching drought adaptation traits with local environmental attributes such as drought patterns, growing season, temperature regime, soil fertility, pathogens [8]. Conventional breeding methods for drought tolerance in common bean have primarily relied on the selection of genotypes able to exhibit superior performance regarding grain yield under water stress, often in combination with yield traits under well-watered conditions [29; 32].

To mitigate drought-stress it is necessary to identify tolerant genotypes and then to transfer their tolerance traits into commercial varieties to obtain varieties that are both high-yielding and drought-stress-tolerant [2; 25]. Also, identification of divergent genotypes tolerant/sensitive could be of interest for studying the morpho-physiological and molecular mechanisms associated to drought tolerance in common bean, as well as for identifying quantitative trait loci associated with water scarcity [4].

The objectives of this study were to evaluate the yield response to drought stress for six Romanian varieties of common bean using 14 tolerance indices, to establish the efficiency of these selection criteria and the varieties with good drought tolerance.

Material and Method

The experiments were conducted on a black chernozem at the Life Sciences University Timisoara during 2022-2024, using a randomized block design with four replications. The plots were composed of four rows with 4 m length and 0.9 m width that makes a plot area of 3.6 m^2. The spacing of 40 x10 cm between rows and plants was used. All standard technological practices for snap beans were uniformly applied. The biological material was composed by six Romanian varieties of common bean: ‘Ami‘, ‘Ardeleana‘, ‘Avans‘, ‘Diva‘, ‘Star‘ and ‘Vera‘. Given the mean values of monthly temperatures and rainfall, it was observed that 2022 was the most favorable year, while 2024 characterized by higher temperatures during the summer associated with low rainfall levels, was considered the most unfavorable. Seed yield (g $plant^{-1}$) under stress (2024) and non-stress (2022) conditions were recorded for each replication plot of the varieties.

To screen tolerant varieties, 14 drought tolerance indices were calculated: SSI-Stress susceptibility index [15]; RDI–Relative drought index [16]; TOL-Drought tolerance [28]; MP-Mean productivity [28]; STI-Stress tolerance index [14]; GM-Geometric mean [14]; YI-Yield index [17]; YSI-Yield stability index [10]; DI-Drought resistance index [22]; ATI-Abiotic tolerance index [24]; SSPI- Stress susceptibility percentage index [24]; SNPI-Stress non-stress productivity index [24]; PR- Percentage reduction of yield [15]; RD-Reaction to drought [9].

The yield data was analyzed using ANOVA as per method for randomized block design, while the varieties mean were compared using Least Significant Difference Test as described by Ciulca [5]. Also, different multivariate statistical methods like Jaccard similarity coefficients, principal component, and UPGMA clustering were used.

Results and Discussion

Under conditions without water stress, the bean varieties achieved yields between 7.21 g for Vera and 14.23 g for Diva associated with an amplitude of 6.02 g. The varieties ‘Diva’ and ‘Avans’ capitalized on these conditions at a higher level, recording significant increases compared to the ‘Ami’, ‘Ardeleana’ and ‘Vera’ varieties. Under water stress conditions the yields were significantly lower, with limits from 3.19 g for the ‘Vera’ variety to 6.65 g for the ‘Avans’ variety and an amplitude of 3.46 g, respectively. Under these stress conditions, the ‘Avans’ and ‘Star’ varieties achieved significant increases of 36.23-108.46% compared to ‘Diva’, ‘Ardeleana’ and ‘Vera’ varieties. The average yield of ‘Avans’ variety was significantly higher by 13.12-95.56% compared to the yield of ‘Ami’, ‘Ardeleana’ and ‘Vera’ varieties.

Table 1. Yield of common bean genotypes under stress and non-stress drought conditions

Yield	Yns (g/plant)		Ys (g/plant)		MY (g/plant)	
Variety	Value	Rank	Value	Rank	Value	Rank
Star	13.04±0.27 ab	*3*	6.58±0.31 ab	*2*	9.81±0.53 ab	*2*
Diva	14.23±0.91 a	*1*	4.83±0.16 c	*4*	9.53±0.23 ab	*3*

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Vera	7.21±0.21 c	*6*	3.19±0.18 d	*6*	5.20±0.19 c	*6*
Avans	13.68±0.39 a	*2*	6.65±0.26 a	*1*	10.17±0.27 a	*1*
Ami	12.05±0.26 b	*4*	5.93±0.20 b	*3*	8.99±0.16 b	*4*
Ardeleana	8.06±0.20 c	*5*	3.59±0.12 d	*5*	5.83±0.21 c	*5*
$LSD_{5\%}$	*1.38*		*0.67*		*0.91*	

Yns-Yield under non stress conditions; Ys-Yield under stress conditions; MY-Mean yield. Means with different letters are significantly different

Based on the results presented in Table 2, it was observed that 'Star' and 'Ami' varieties exhibit the best tolerance to the water stress conditions that occurred during the experimentation period, according to the stress sensitivity index, the relative drought index, the yield stability index and the percentage reduction of yield. In the case of these varieties, drought caused a percentage reduction of yield ranging between 49.55% in the case of 'Ami' and 50.78% for 'Star' variety. Based on the previously mentioned indices, the highest sensitivity to water stress was found in 'Diva' and 'Vera' varieties, where there was registered a yield reduction from 55.79% for 'Diva' to 66.10% for' Vera' variety.

Considering drought tolerance, abiotic tolerance index, stress susceptibility percentage index and reaction to drought, their low values, which attest a high tolerance, were observed at 'Vera' and 'Ardeleana' varieties. In the case of these two varieties the drought had a smaller impact on yield causing a reduction of 2.54 g/plant for 'Vera' and 2.83 g/plant in 'Ardeleana' for every 100 mm of rainfall deficit recorded during the growing season. A low level of tolerance was estimated by the respective indices at 'Avans' and 'Diva' varieties, where under the influence of the water deficit from 2024, the plant yield decreased by 4.45-5.96 g/100 mm.

Table 2. Values and ranks of common bean genotypes for different drought tolerance index

Index	SSI		RDI		TOL		MP		STI		GM		YI	
Variety	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Star	0.852	*1*	1.205	*1*	6.46	*4*	9.81	*2*	0.615	*2*	9.26	*2*	1.331	*2*
Diva	1.137	*6*	0.810	*6*	9.41	*6*	9.53	*3*	0.493	*4*	8.29	*4*	0.977	*4*
Vera	0.960	*5*	1.056	*5*	4.02	*1*	5.20	*6*	0.165	*6*	4.79	*6*	0.645	*6*
Avans	0.885	*3*	1.160	*3*	7.04	*5*	10.17	*1*	0.653	*1*	9.54	*1*	1.346	*1*
Ami	0.874	*2*	1.175	*2*	6.12	*3*	8.99	*4*	0.512	*3*	8.45	*3*	1.200	*3*
Ardeleana	0.955	*4*	1.063	*4*	4.48	*2*	5.83	*5*	0.208	*5*	5.38	*5*	0.726	*5*
Index	YSI		DI		ATI		SSPI		SNPI		PR		RD	
Variety	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Star	0.504	*1*	0.672	*1*	25.04	*4*	27.35	*4*	11.96	*2*	49.55	*1*	4.09	*4*
Diva	0.339	*6*	0.331	*4*	32.65	*6*	39.83	*6*	8.76	*4*	66.10	*6*	5.96	*6*
Vera	0.442	*5*	0.285	*6*	8.06	*1*	17.02	*1*	5.74	*6*	55.79	*5*	2.54	*1*
Avans	0.486	*3*	0.654	*2*	28.10	*5*	29.79	*5*	12.05	*1*	51.42	*3*	4.45	*5*
Ami	0.492	*2*	0.591	*3*	21.64	*3*	25.90	*3*	10.75	*3*	50.78	*2*	3.87	*3*
Ardeleana	0.445	*4*	0.323	*5*	10.08	*2*	18.95	*2*	6.47	*5*	55.50	*4*	2.83	*2*

SSI- Stress susceptibility index; RDI –Relative drought index; TOL-Drought tolerance; MP-Mean productivity; STI-Stress tolerance index; GM-Geometric mean; YI-Yield index; YSI-Yield stability index; DI-Drought resistance index; ATI-Abiotic tolerance index; SSPI- Stress susceptibility percentage index; SNPI-Stress non-stress productivity index. PR- Percentage reduction of yield; RD-Reaction to drought.

According to mean productivity, stress tolerance index, geometric mean, yield index and stress non-stress productivity index, 'Diva' and 'Avans' varieties are considered the most tolerant, while 'Ardeleana' and 'Vera' express higher values and susceptibility to drought stress conditions.

Regarding drought resistance index, superior behavior under water stress conditions have been shown by 'Avans' and 'Star' varieties, who also recorded superior values for most of all selection indices except for drought tolerance, abiotic tolerance index, stress susceptibility percentage index and reaction to drought. An accentuated sensitivity, related to low values of the drought resistance index was registered in 'Ardeleana' and 'Vera' varieties.

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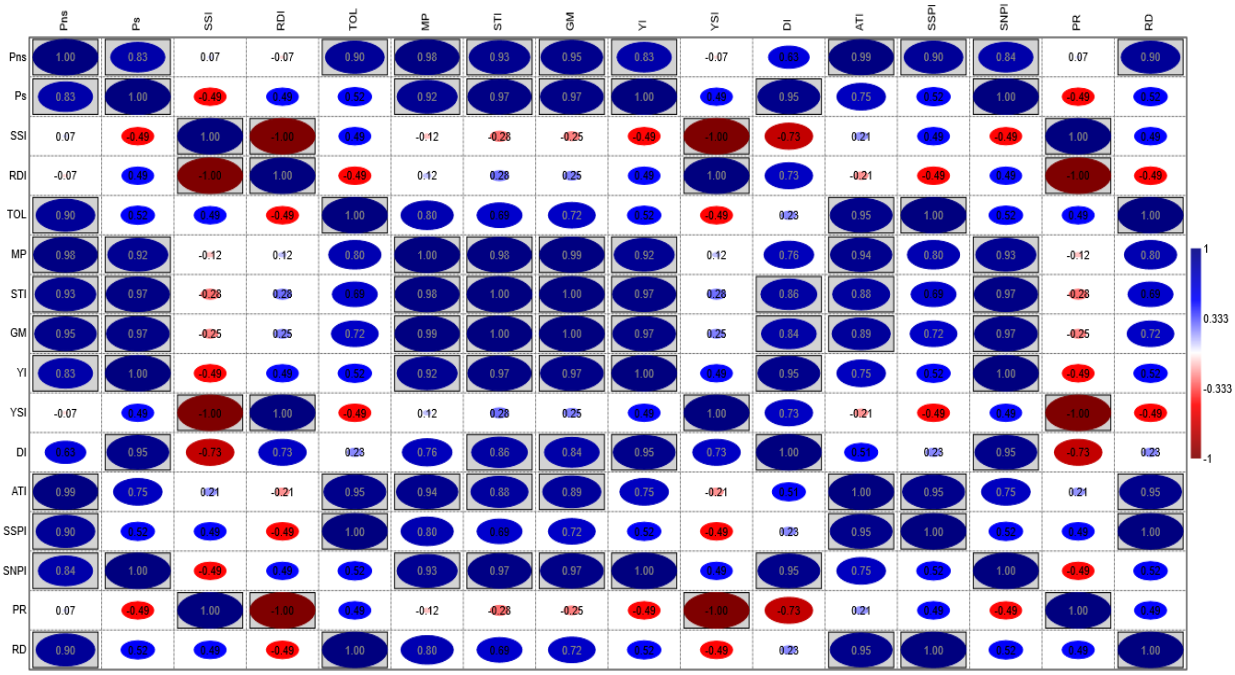

Figure 1. Correlations between drought tolerance indices and yield under stress and non-stress conditions

According to the information in Figure 1, it is observed that production under non-stress conditions showed positive and highly significant correlations with most indices except stress susceptibility index, relative drought index and yield stability index while with drought resistance index the correlation was positive but did not reach the level of significance.

Yield under stress conditions was significantly positively correlated with mean productivity, stress tolerance index, yield index, geometric mean, drought resistance index, stress non-stress productivity index, showing positive but non-significant relationships with most other indices except for stress susceptibility index and percentage reduction of yield where negative correlations were recorded.

For a better interpretation of the relationships, similarities and divergences between the different drought tolerance indices, a graphical analysis was performed based on the first two principal components, which comprise a large part (97.35%) of the total variability (Figure 2).

Thus, it is observed that the analyzed statistical indices are grouped into three categories.

The first group includes the relative drought index and yield stability index which showed significantly negative correlations with the stress susceptibility index and percentage reduction of yield.

These indices are not correlated with yield under stress and non-stress conditions, thus indicating that they have a reduced capacity to differentiate genotypes in terms of drought tolerance.

The second group includes the indices stress tolerance index, yield index, geometric mean, stress non-stress productivity index which show very close and statistically assured positive correlations with both yield under stress and non-stress drought conditions, indicating that they can be used with high efficiency for the selection of genotypes with superior yields under different water stress conditions.

The drought resistance index was positively correlated only with yield under drought stress conditions.

The third group includes indices: drought tolerance, stress susceptibility percentage index, abiotic tolerance index and reaction to drought which show positive correlations with both yields, but the intensity of the links is higher with respect to yield under conditions without water stress.

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Print ISSN: 2066-1797
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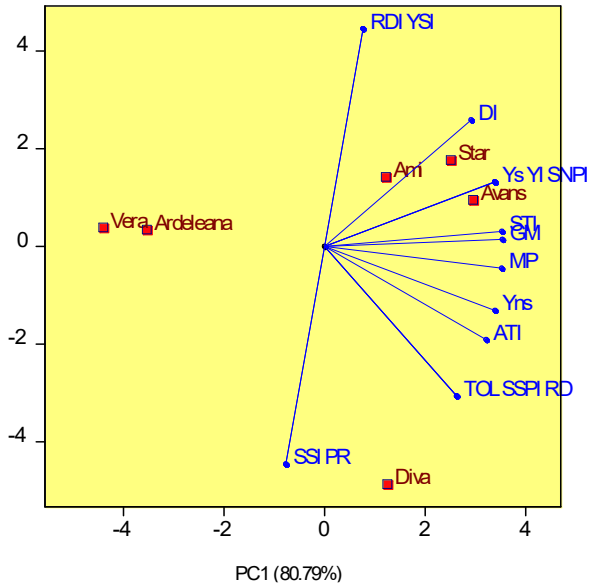

Figure 2. Biplot of first two principal components for different drought tolerance index of common bean genotypes

Based on the selection indices used, the six varieties were distributed in three clusters (Figure 3). The first cluster includes 'Star' and 'Avans' varieties that showed the best drought tolerance, along with the Ami variety that had above-average tolerance due to its high similarity to the two varieties previously presented. The 'Vera' and 'Ardeleana' varieties showed a high similarity between them associated with a diversity of approximately 45% compared to the other varieties. The 'Diva' variety that was most severely affected by drought is distributed in a separate cluster, recording a diversity of approximately 35% compared to the varieties with good tolerance from the first cluster.

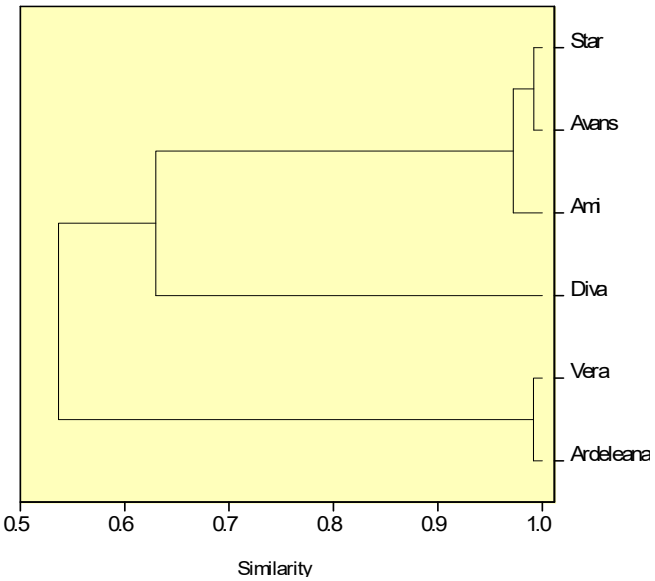

Figure 3. UPGMA clustering of bean varieties according to drought tolerance indices

Evaluating the level of drought tolerance of common bean varieties in the field is useful in designing a breeding strategy that incorporates traits related to drought tolerance in varieties with different commercial attributes [6]. In this regard varieties like 'Avans' and 'Star' can be considered given that they are the best yields under both stress and non-stress drought conditions. The tolerance of common bean varieties is dependent on their earliness. As such, the late varieties are more sensitive to dry conditions because of their long maturation period [19]. The drought tolerance indices were significantly affected by the main effect of

variety, as revealed from other studies [12; 36]. Similar results regarding correlation matrix among drought tolerance indices in common bean have been reported by other studies: [18; 27; 34].

Conclusions

According to the obtained results, mean productivity, stress tolerance index, yield index, geometric mean, drought resistance index, stress non-stress productivity index can be used as selection parameter in breeding programs to increase grain yield of bean under stress conditions as well under non-stress conditions.

'Star' and 'Avans' varieties showed a moderate tolerance to drought, achieving reasonable levels of plant yield under conditions with and without water stress. Given the variability of the studied varieties regarding their reaction to drought, these varieties could be considered for further studies of the morpho-physiological and/or molecular mechanisms involving drought tolerance of common bean.

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