Ethiop. J. Agric. Sci. 30(4) 223-236 (2020)

Screening Mung bean [*Vigna radiata* (L.) Wilczek] Genotypes for Drought Tolerance

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Abstract

Drought is among the major constraints in mung bean production. The main goal of the current study was to investigate the response of 60 mung bean genotypes to two constrasting moisture regimes using diverse indices. The experiment was made at Jinka Agricultural Research Center using a 6 x 10 alpha lattice design replicated twice. Correlation analysis revealed that seed yield under stressed condition was positively correlated with stress tolerance index (STI), yield index (YI), harmonic mean (HM), mean relative performance (MRP), and relative drought index (RDI). PCA of the first two components accounted for 93.4% of the total variations where PC1 contributed for 64.39% of the variations. Based on cluster analysis, 60 mung bean genotypes used in the current study were grouped into five distinct clusters. In conclusion, this study showed that selection based on indices with seed yield under moisture-stress (Ys) and seed yield under non moisture-stress (Yp) conditions are useful for mung bean breeders. Therefore; stress tolerance index (STI), yield index (YI), harmonic mean (HM), geometric mean productivity (GMP) and mean relative performance (MRP) were found to be more suitable indices since these indices had the highest correlation with seed yield under both moisture-stressed and non moisture-stress conditions.

Keywords: Correlation, Drought Stress, Drought Tolerance Indices, Mung Bean, Variability.

Introduction

Climate change has negative consequences on sustainable development as it undermines the gains of intensive farming in developing countries. In recent years, climate change has received a significant amount of attention due its significant effect on the changes in temperature and rainfall patterns, water scarcity, natural disasters, and extreme weather events (Land Portal, 2018). According to Bangar *et al*. (2019), drought stress is undoubtedly one of the most devastating environmental stresses. The intensity and the area under drought have been tremendously increasing globally due to erratic rainfall, limited water sources, and other drastic changes in global environmental conditions. Hence, drought is considered among the major yield-limiting factors in crop production. Similar to the global situation, drought contributes for substantial yield losses in Ethiopia. Crops mainly affected by drought in the country are those extensively cultivated in the semi-arid areas. Among these crops, mung bean (*Vigna radiata*), a legume crop rich in protein, is one of them. The relative yield performance and drought-related indices of genotypes under drought-stressed and non drought-stressed conditions were used as criteria to identify durum wheat genotypes tolerant to moisture scarcity (Mohammadi *et al*., 2010). These indices have been employed in the selection of drought-tolerant genotypes of different crop types. Although a number of indices are available to measure the tolerance of crop to drought, the geometric mean productivity (GMP) (Fernandez, 1992) is considered among the best indicators as it less sensitive to extreme values. Stress tolerance index (TOL) which is based on the differences in yields measured under non-stress (Yp) and stress (Ys) conditions (Rosielle and Hamblin, 1981) is also extensively used. Other widely applied drought-related indices include stress susceptibility index (Fischer and Maurer, 1978), yield index (Lin *et al.,* 1986), yield stability index (Bouslama and Schapaugh, 1984), stress intensity (Fernandez, 1992), stress susceptibility percentage index (Moosavi *et al*., 2008), stress tolerance index (Fernandez, 1992), drought intensity index (Beebe *et al.,* 2013), relative drought index (Fischer *et al.*, 1998), mean relative performance (Hossain *et al.,* 1999), harmonic mean (Dadbakhch *et al.,* 2011), and yield stability index (Bouslama and Schapaugh, 1984).

Although several types of indices are implemented to determine the performance of crops under drought conditions, but these indices were not exploited in mung bean improvement program in Ethiopia. Since mung bean is extensively cultivated in drought-prone areas in the country, it is necessary to apply key indices to assess the performance of mung bean germplasm to drought. Hence, the major goal of this study was to determine the performance of mung bean germplasm to drought using selected indices. In addition, the study is aimed at identifying the best drought-related index to be used in screening for drought tolerance in mung bean.

Materials and Methods

Description of the Study Area

The field experiment was conducted from November 2018 to January 2019 at Jinka Agricultural Research Center (JARC), Southern Nations, Nationalities and Peoples (SNNP) Region. Jinka Agricultural Research Center is located 729 km southwest of Addis Ababa at 36^0 33' 02.7" E, 05^0 46' 52.0" N and at an altitude of 1420 m above sea level. The maximum, minimum, and average temperature of the center is 27.68^0C, 16.61^0C and 22.14°C, respectively while the mean annual rainfall is 1381 mm. The soil type of the center is Cambisols (Mesfin *et al*., 2017).

Experimental Materials

A total of 60 mung bean genotypes were used for this study. Out of these, 44 genotypes were obtained from Melkassa Agricultural Research Center, while the remaining 16 genotypes were collected from SNNP Region.

Experimental Design and Procedures

The experiment was laid out using a 6 × 10 alpha lattice design replicated twice. The genotypes were grown under two field conditions, namely moisture stressed and non moisture-stressed. Under non moisture-stress condition, experimental plants were weekly irrigated until physiological maturity stage, while under moisture-stressed regime, irrigation water was withheld from the flower bud initiation to physiological maturity stage.

Data Collection

Three central rows were harvested from both non moisture-stressed and moisture stressed plots to determine seed yield per plot which was later adjusted to 12.5% moisture content before extrapolating to hectare basis. The drought tolerance indices were quantified using equations indicated in Table 1.

Data Analyses

Pearson correlation coefficient between drought tolerance indices and seed yield was performed using Statistical Analysis System 9.0 (SAS, 2008). Cluster analysis and principal component analysis of genotypes for Yp, Ys, and drought tolerance indices using the Ward linkage method (Ward, 1963) were computed using Minitab Software Version 17 (Minitab, 2010). The Biplot was used to identify tolerant and high yielding genotypes that were computed using Minitab Software, based on the first two principal components.

Table 1. Drought tolerance indices used to determine the performance of mung bean genotypes to drought.

Drought Tolerance Indices	Equation	Reference
Yield Index (YI)	$Ys/\bar{Y}s$	Lin *et al*., 1986
Yield stability index (YSI)	Ys / Yp	Bouslama and Schapaugh, 1984
Stress Intensity (SI)	$(Yp-Ys)/\bar{Y}p$	Fernandez, 1992
Stress susceptibility percentage index (SSPI)	$[Yp-Ys /2(\bar{Y}p)]\times 100$	Moosavi *et al*., 2008
Stress Susceptibility Index (SSI)	$(1-(Ys/Yp))/ SI$	Fischer and Maurer, 1978
Stress tolerance index (STI)	$(Yp * Ys) / (\bar{Y}p)^2$	Fernandez, 1992
Drought intensity index (DI)	$1-(Ys/Yp)$	Beebe *et al*., 2013
Tolerance index (TOL)	$Yp – Ys$	Rosielle and Hamblin, 1981
Geometric mean productivity (GMP)	$\sqrt{(Y_p x Y_S)}$	Fernandez, 1992
Relative drought index (RDI)	$(Ys/Yp)/ (\bar{Y}s / \bar{Y}p)$	Fischer *et al*., 1998
Mean relative performance (MRP)	$(Ysi / \bar{Y}s) + (Ypi / \bar{Y}p)$	Hossain *et al*., 1999
Harmonic Mean (HM)	$2 x (Yp x Ys) / (Yp + Ys)$	Dadbakhsh *et al*., 2011

Where; Ys, Yp, $\bar{Y}s$, and $\bar{Y}p$ represent yield under stress, yield under non-stress for each genotype, yield mean in stress and non-stress conditions for all genotypes, respectively.

Results And Discussion

Association of Mung bean Genotypes Based on Seed Yield and Drought Tolerance Indices

The analysis of variance for mean squares indicated the presence of a substantial variations among the mung bean genotypes under the two moisture regimes (Table 2). This shows the possibility of selecting better-performing genotypes under both non moisture-stressed and moisture-stressed environments. Our findings are in agreement with earlier study on durum wheat (Ahmadizadeh *et al*., 2012).

The seed yield of mung bean genotypes used in the current study ranged from 670 to 1456 kg ha^{-1} under the non-moisture stressed condition while it ranged from 313 to 1032 kg ha^{-1} under moisture stressed condition. The mean grain yield of these genotypes under the two moisture regimes were 1063 kg ha^{-1} from non moisture-stressed and 664 kg ha^{-1} from moisture stressed conditions. This shows that the exposure of mungbean genotypes to moisture scarcity caused a yield penalty of 37.53%. Earlier study on common bean reported 29.8% yield reduction due to moisture scarcity (Darkwa *et al*., 2016). Similar studies in bread wheat showed the yield reduction ranging from 30 to 50% due to drought (Darzi-Ramandi *et al.,* 2016; Sahar *et al*., 2016; Assefa *et al*., 2019). This shows that the productivity of mung bean is severely affected by moisture although the crop is extensively cultivated in the semi-arid environments with high moisture limitations. Since the ultimate goal of crop production is to increase productivity, seed yield under non moisture-stressed (Yp) and moisture-stressed (Ys) condition is considered as the most desirable parameters for screening drought tolerant and high yielding genotypes.

In this study, several indices were used to determine the response of all 60 mung bean genotypes to the drought. Among these, the values from the stress susceptibility percentage index (SSPI) which is based on the ratio of genotypic performance under stress and non-stress conditions ranged from 0.14 for the genotypes G55 and G60 to 0.32 for G6. While the yield stability index (YSI) of the 60 mung bean genotypes ranged from 0.43 for genotype G53 to 0.75 for G34, yield index (YI) ranged from 0.47 for genotype G53 to 1.54 for G34. This shows that G53 scored the lowest YSI and YI while G34 had the highest scores of YSI and YI. This consistent performance of the genotypes using two indices shows that the indices particularly YI can be considered as suitable parameter to investigate the performance mungbean genotypes under drought stress conditions. Yield index (YI) can also be used as a selection criterion, though it only ranks cultivars based on yield under stress condition (Ys). Based on yield stability index (YSI) and yield index (YI), genotypes with high yield stability index (YSI) and high yield index (YI) are considered as drought-tolerant. Similarly, genotypes with low yield stability index (YSI) and low yield index (YI) are considered as drought-susceptible. A similar study indicated that YSI is a powerful tool to investigate the performance of durum wheat genotypes under drought condition (Mohammadi *et al*., 2010). On the other hand, the values from drought intensity index (DI) ranged from 0.25 for genotype G34 to 0.57 for G53. Similarly, the values from the relative drought index (RDI) ranged from 0.69 for genotype G53 to 1.20 for G34. The stress intensity (SI) values ranged from 0.29 for genotypes G55 and G60 to 0.64 for G2 and G6. In general, the SI values for all the genotypes were below unity and within the acceptable range. This is in agreement with the previous study on durum wheat (Ahmadizadeh *et al*., 2012). This indicates that genotypes with lowest SI values are considered as drought-tolerant and are high yielders whereas; genotypes with the highest SI values are drought susceptible.

On the other hand, the values for a harmonic mean (HM) ranged from 433 for genotype G48 to 1184 for G24 while those for geometric mean productivity (GMP) ranged from 463 for genotype G48 to 1200 for G24. As shown above, the lowest scores for HM and GMP were obtained from G48 while the highest score from G24. This consistency in the response of genotypes to two different parameters shows that HM and GMP can be used to identify genotypes with increased tolerance to drought.

In addition, the stress tolerance index (STI), which is normally used to identify genotypes that produce high yield under both stressed and non-stressed conditions identified same genotypes as drought susceptible and drought tolerant. Similar findings were earlier reported for different crops (Fernandez 1992; Mohammadi *et al.,* 2010). Based on the stress susceptibility index (SSI), G6 is the most drought tolerant while G48 is the most drought susceptible genotype. This shows that genotypes with lowest SSI values are considered as drought-tolerant and are high yielders whereas; genotypes with the highest SSI values are drought susceptible.
In conclusion, those genotypes with the highest scores for stress susceptibility index (SSI), stress intensity (SI) and tolerance index (TOL) could be considered as

drought susceptible genotypes while those genotypes with the highest values of the harmonic mean (HM), yield index (YI), yield stability index (YSI), stress tolerance index (STI), and geometric mean productivity (GMP) could be desirable genotypes in moisture stress conditions. Moreover; stress tolerance index (STI), yield index (YI), harmonic mean (HM), geometric mean productivity (GMP), and mean relative performance (MRP) are convenient indices to select high yielding mung bean genotypes in both moisture stressed and non-stress conditions.

Table 2. Analysis of Variance (ANOVA) for Seed Yield (kg ha^{-1}) under Moisture-Stressed and Non moisture-Stressed Environments.

Source of variation	Non stressed Environment			Stressed Environment		
	DF	SS	MS	DF	SS	MS
Replication	1	36542	36542ns	1	5170612	5170612***
Genotype	59	6186958	104864***	59	1291065	21882***
Blocks (Rep)	10	1414030	141403***	10	2000513	200051***
Residuals	49	623957	12734	49	600451	12254
LSD (0.05)	224.3762			220.1093		
CV (%)	8.77			20.49		
Mean	1062.55			663.80		

DF= degree of freedom, SS= sum square, MS= mean square, Rep = replication

Table 3: Mean, Range, and Standard Deviations of 60 Mung Bean Genotypes Based on Drought-Tolerant Indices.

Indices	Range	Genotypes with maximum index	Genotypes with minimum index	Mean	Std.
YP	670 to 1456	G6	G48	1062.55	194.18
YS	312.89 to 1032	G34	G53	663.8	181.74
SSPI	0.14 to 0.32	G6	G3 and G55	0.19	0.04
YSI	0.43 to 0.75	G34	G53	0.61	0.08
SI	0.29 to 0.64	G6	G3, G55 and G60	0.37	0.08
HM	433.13 to 1183.82	G24	G48	813.31	191.34
GMP	463.03 to 1200.54	G24	G48	837.52	187.22
TOL	311 to 689	G6	G3 and G60	403.37	84.7
YI	0.47 to 1.54	G34	G53	0.99	0.27
DI	0.25 to 0.57	G53	G34	0.38	0.08
MRP	1.1 to 2.83	G24	G48	1.97	0.44
RDI	0.69 to 1.2	G34	G53	0.97	0.13
STI	0.18 to 1.24	G24 and G28	G48	0.65	0.28
SSI	0.74 to 1.61	G48	G6	1.03	0.2

Where; YP= yield under non stress (kg ha^{-1}), YS= yield under stress (kg ha-1), SSPI= Stress susceptibility percentage index, YSI= Yield stability index, SI= Stress Intensity, HM=Harmonic Mean (kg ha^{-1}), GMP= Geometric mean productivity (kg ha^{-1}), TOL= Tolerance index, YI=Yield Index, DI= Drought intensity index, MRP=Mean relative performance, RDI= Relative drought index, STI= Stress tolerance index, SSI= Stress Susceptibility Index.

Correlation Coefficient among Drought Tolerance Indices

The correlation among different drought tolerance related indices based on Pearson coefficients is presented in Table 4. Seed yield under stress environment was significantly (r=0.9***) and positively correlated with seed yield under non-stress condition, suggesting that indirect selection for moisture stressed environment based on the results of optimum moisture condition might be efficient. This contradicts with the previous study on maize where low yielding genotypes were more productive under moisture stress (Bonea and Urechean, 2011).

Under optimum moisture condition, seed yield was significantly and positively correlated with yield stability index (YSI), harmonic mean (HM), geometric mean productivity (GMP), yield index (YI), mean relative performance (MRP), relative drought index (RDI) and stress tolerance index (STI), indicating that these indices are effective in identifying drought-tolerant genotypes.

Under moisture scarcity, seed yield was significantly and positively correlated with yield stability index (YSI), harmonic mean (HM), geometric mean productivity (GMP), yield index (YI), mean relative performance (MRP), relative drought index (RDI) and stress tolerance index (STI). This shows that these indices are effective in identifying high yielding and drought-tolerant genotypes. On the contrary, seed yield was significantly and negatively correlated with tolerance index (TOL), drought index (DI) and stress susceptibility index (SSI) under moisture stressed condition. This indicates the limitations of these indices in identifying genotypes with drought tolerance potential.

Under moisture-stressed and non moisture-stressed conditions, seed yield was significantly and positively associated with a harmonic mean (HM), geometric mean productivity (GMP), yield index (YI), mean relative performance (MRP) and stress tolerance index (STI). This indicates that these indices are effective in identifying high yielding mungbean genotypes. Our findings is in agreement with earlier study on bread wheat (Assefa *et al*., 2019).

A positive correlation between tolerance index (TOL) and seed yield under normal moisture conditions (Yp) and a negative correlation between tolerance index (TOL) and seed yield under moisture stressed condition (Ys) suggested that selection based on tolerance index (TOL) resulted in reduced seed yield under optimum moisture condition. Hence, TOL appears to be useful for selecting genotypes with high yield under moisture stress condition, but failed to identify genotypes with high grain yield under both water regimes. On the other hand, TOL and SSI indices had a significantly positive correlation with each other (r=0.83**). As it was also observed in earlier study on durum wheat and maize (Ahmadizadeh *et al*., 2012; Bonea and Urechean, 2011).

A suitable index must have a significant correlation with seed yield under contrasting moisture regimes. Therefore; stress tolerance index (STI), yield index (YI), harmonic mean (HM), geometric mean productivity (GMP) and mean relative performance (MRP) were found to be more suitable indices since these indices had the highest correlation with seed yield under both moisture stressed and non-stressed conditions. In general, selection based on a combination of indices might provide useful in developing drought-tolerant mung bean varieties.

Principal component analysis

Principal components (PCs) of the drought tolerance indices and seed yield under moisture stressed and non moisture-stressed conditions of the 60 mung bean genotypes are presented in Table 5. The first two PCs explained about 93.4% of the total variations which is in agreement with earlier studies on cowpea and chickpea genotypes (Rezai *et al.*, 2015; Talebi *et al.*, 2011). The first principal component (PC1) alone explained for 64.39% of the total variations with high loading due to seed yield under stress (Ys), harmonic mean (HM), geometric mean productivity (GMP), yield index (YI), mean relative performance (MRP), and stress tolerance index (STI).

The PC2 explained 29.01% of the total variation on seed yield with high loading due to stress susceptibility percentage index (SSPI), stress intensity (SI), and tolerance index (TOL). Therefore, PC1 and PC2 were named as yield potential and drought stress susceptibility, respectively. This is in agreement with earlier work on bread wheat genotypes (Kaya *et al*., 2006).

Figure 1 shows that genotypes G34, G28, G15, G22, G46, G32, G12, and G43 which are grouped under Quadrant-I had the highest PC1 loading values for their high seed yield under moisture-stressed and non moisture-stressed conditions and intermediate PC2 loading for their low grain yield reduction due to moisture-stress. Similarly, genotypes in Quadrants I and II had intermediate to high seed yield under moisture-stressed and non-stressed conditions with low seed yield reduction caused by moisture stress. On the other hand, G3, G55, G48, G41, and G17 in Quadrant II with low PC1 and high PC2 values, respectively were identified as susceptible genotypes (Figure 1). Genotypes in Quadrants III and IV had low to intermediate seed yield under moisture-stressed and non moisture-stressed conditions.

Table 4. Correlation Coefficients among Drought Tolerance Indices.

Indices	YP	YS	SSPI	YSI	SI	HM	GMP	TOL	YI
YP	**1.00**								
YS	0.9***	**1.00**							
SSPI	0.36***	-0.09ns	**1.00**						
YSI	0.54***	0.84***	-0.58***	**1.00**					
SI	0.35***	-0.08ns	0.99***	-0.57***	**1.00**				
HM	0.95***	0.99***	0.03ns	0.78***	0.03ns	**1.00**			
GMP	0.96***	0.99***	0.09ns	0.74***	0.09ns	0.99***	**1.00**		
TOL	0.35***	-0.29***	0.99***	-0.58***	1.00***	0.03ns	0.08ns	**1.00**	
YI	0.90***	1.00***	-0.09ns	0.84***	-0.08ns	0.99***	0.99***	-0.09ns	
DI	-0.54***	-0.84***	0.58***	-1.00***	0.57***	-0.78***	-0.74***	0.58***	
MRP	0.96***	0.99***	0.09ns	0.74***	0.09ns	0.99***	1.00***	0.09ns	
RDI	0.54***	0.84***	-0.58***	0.99***	-0.58***	0.78***	0.74***	-0.58***	
STI	0.95***	0.98***	0.07ns	0.73***	0.07ns	0.99***	0.99***	0.06ns	
SSI	-0.98***	-0.98***	-0.33***	-0.56***	-0.33***	-0.93***	-0.95***	0.83***	

Where; YP= yield under non stress (kg ha^{-1}), YS= yield under stress (kg ha-1), SSPI= Stress susceptibility percentage index, YSI= Yield stability index, SI= Stress Intensity, HM=Harmonic Mean (kg ha^{-1}), GMP= Geometric mean productivity (kg ha^{-1}), TOL= Tolerance index, YI=Yield Index, DI= Drought intensity index, MRP=Mean relative performance, RDI= Relative drought index, STI= Stress tolerance index, SSI= Stress Susceptibility Index,

Table 5. Principal Component Analysis (PCA) of Drought Tolerance Indices.

Indices	PC1	PC2
Seed Yield Under Non Stressed Environments (Yp)	0.29	0.22
Seed Yield Under Moisture-Stressed Environment (Ys)	0.32	0.01
Stress Susceptibility Percentage Index (SSPI)	-0.03	0.48
Yield Stability Index (YSI)	0.28	-0.24
Stress Intensity (SI)	-0.03	0.47
Harmonic Mean (HM)	0.32	0.07
Geometric mean productivity (GMP)	0.31	0.09
Tolerance Index (TOL)	-0.04	0.47
Yield Index (YI)	0.32	0.01
Drought Resistance Index (DI)	-0.28	0.24
Mean Relative Performance (MRP)	0.31	0.09
Relative Drought Index (RDI)	0.28	-0.24
Stress Tolerance Index (STI)	0.31	0.09
Stress Susceptibility Index (SSI)	-0.28	-0.21
Eigenvalue	9.66	4.35
Cumulative (%)	64.39	93.40
Proportion (%)	64.39	29.01

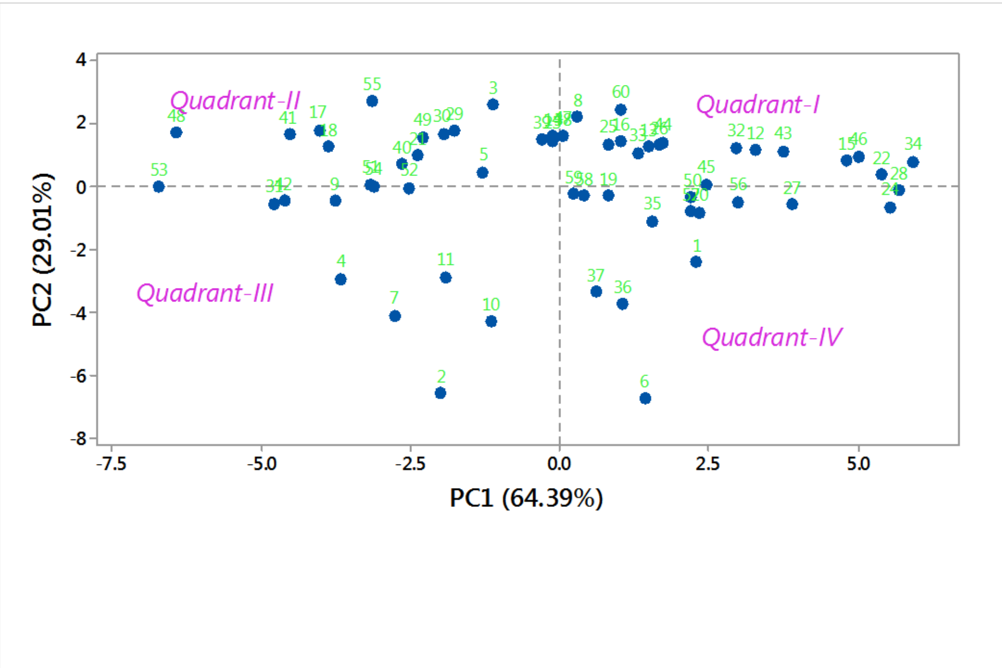

Figure 1. Score plot of mung bean genotypes for drought tolerance indices.

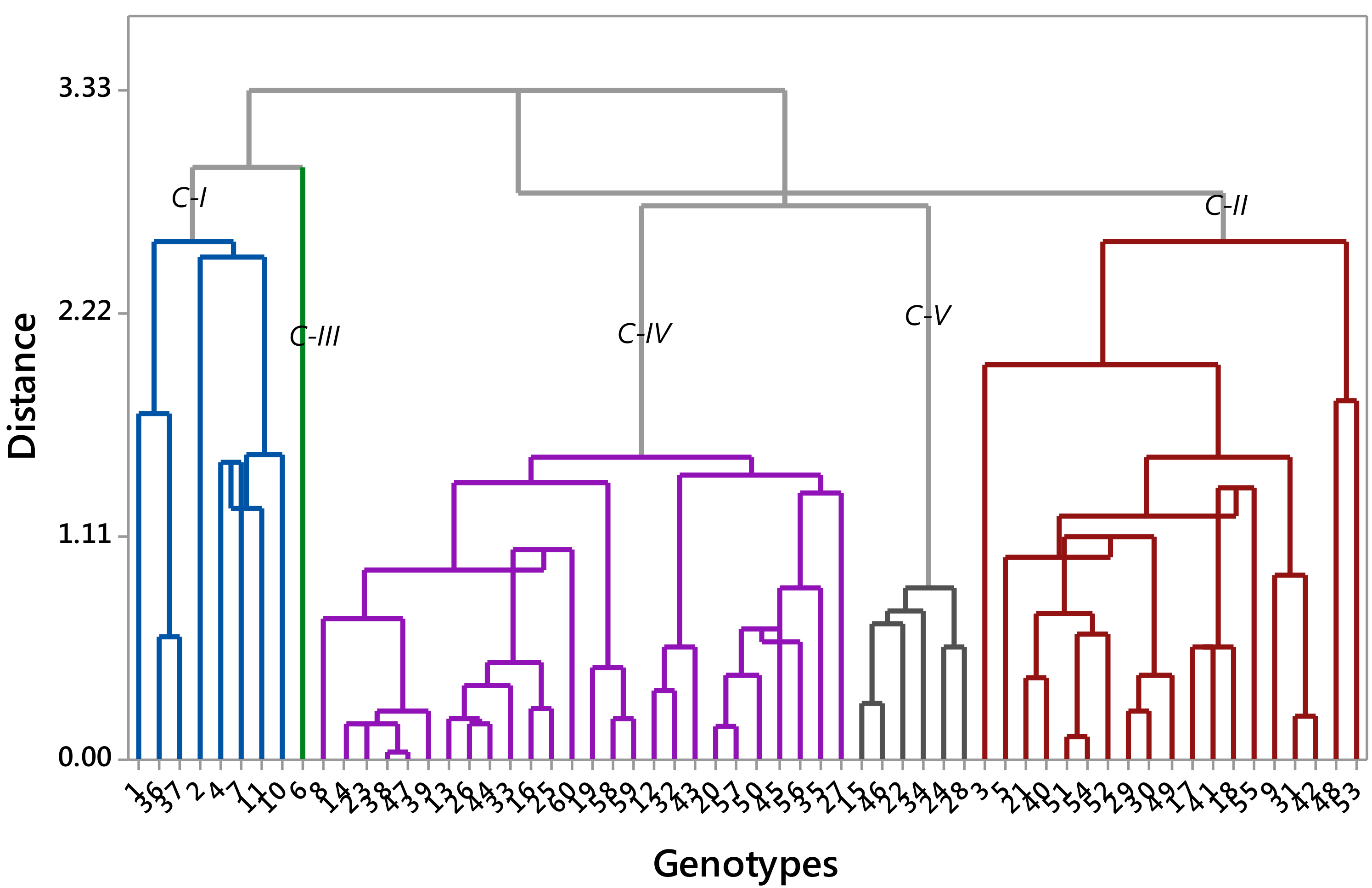

Figure 2. Dendrogram of 60 mung bean genotypes generated by the Wards clustering method using square Euclidean distance based on drought tolerance indices

Cluster Analysis

Cluster analysis revealed that the 60 mung bean genotypes used in the present study were grouped into five distinct clusters using 12 drought tolerance indices and seed yield (Figure 2). Cluster I comprised eight high yielding genotypes under moisture-stressed and non moisture-stressed conditions. In most cases, the genotypes had the highest values of stress tolerance index (STI), harmonic mean (HM), yield index (YI), and mean relative performance (MRP). This shows that these genotypes perform consistently under both water regimes. Nineteen genotypes belonging to cluster II that had moderate to high yield under non moisture-stressed environment and low yield under moisture-stressed environments, with low to moderate mean values of tolerance index (TOL) and drought index (DI). On the other hand, Cluster III contained one susceptible genotype with high yield in a non-stressed environment and low yield in stressed environments, with the highest mean value of tolerance index (TOL). Interestingly, Cluster IV contained 26 moderately drought tolerant genotypes while Cluster V contained 6 moderately drought susceptible genotypes. In general, the indices such as yield stability index (YSI), yield index (YI), tolerance index (TOL), and stress susceptibility index (SSI) had lower mean values in cluster II, Cluster IV and Cluster V as compared to Cluster I and Cluster III indicating that the genotypes in Clusters II, IV, and V were more tolerant to the drought condition.

Acknowledgments

The authors extend their gratitude to the Southern Agricultural Research Institute (SARI) for the financial support towards this research. Also, the authors' deep gratitude and acknowledgment go to Melkassa Agricultural Research Center (MARC) for providing the mung bean genotypes for this study. The authors also recognize the Jinka Agricultural Research Center (JARC) for its administrative facilitation during the implementation of this research.

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