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Identification of drought selection indices of common bean (*Phaseolus vulgaris* L.) genotypes in the Southern Highlands of Tanzania

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A study was conducted to evaluate common bean (*Phaseolus vulgaris* L.) genotypes for drought tolerance in the Southern Highlands of Tanzania. Treatments included 18 genotypes laid out in a 3×18 split plot arranged in randomized complete block design with three replications. The data on yield under water stress and non-water stress treatments were used to calculate indices that can be used for predicting tolerant genotypes. This was accomplished by ranking the yield indices within the selection indices. Results showed that, selection index, YI, identified BFS60, KG104-72 and SER16 as the most tolerant genotypes, while STI, MP and GM identified SER16, BFS60 and KG104-72. Another index, SSPI, identified RCB266, 41-EX-VAM and SER83 as most sensitive genotypes to water deficit while HM showed BFS60, SER16 and KG104-72 as genotypes tolerant to drought. In contrast, SSI discriminated 41-EX-VAM, RCB266 and PASS as most susceptible genotypes under drought. Ranking the means of yield indices, genotypes SER16, BFS60 and KG104-72 were identified as the most drought tolerant genotypes. Correlation analysis showed that Yp were highly significant ($p < 0.001$) and positively correlated with STI, SSPI, MP, HM, and GM while Ys were highly significant ($p<0.001$) and positively correlated with YI, STI, MP, HM and GM. The findings suggest that these indices are effective for discriminating genotypes with higher yields under non stress and stress conditions, respectively. Genotypes, SER16, BFS60 and KG104-72 are among the most tolerant to drought conditions therefore are recommended for cultivation in drought prone environments and subsequently as parental materials in breeding for drought tolerance.

Key words: Common bean, drought, selection indices, yield indices ranks.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is one of the widely cultivated crops in the Southern Highlands of Tanzania. It is considered to be one of the most important legumes for human consumptions as a source of dietary

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protein, calories, dietary fibers and minerals, especially iron and zinc (CIAT, 2008). Bean consumption provides protection from cardiovascular disease by a small depression in blood cholesterol (Kabagambe et al., 2005). In epidemiological studies of colon cancer, low incidence was observed in many Latin American countries where the consumption of common bean is high (Hangen and Bennink, 2002). Clinical studies consistently showed that when consumed solely as a carbohydrate-rich food; beans reduced postprandial glucose elevations in both diabetic and non-diabetic participants (Thompson et al., 2012).

In Tanzania, it is estimated that over 75% of rural households depend on bean for daily dietary requirements (CIAT, 2008). Despite the importance of common beans in Tanzania and other developing countries, its production mostly relies on local cultivars (Miklas et al., 2006; Tryphone et al., 2013). Like other plants, the development and productivity of the bean is adversely affected by biotic and abiotic factors (Jaleel et al., 2009). Among the abiotic factors, drought is the most limiting factor in crop production worldwide (Jones and Corlett, 1992; Sani et al., 2018) and is ranked second from insect pests and diseases that cause grain yield losses of about 60% of world bean producing areas. With the evolving phenomena of climate change, it is anticipated that drought will exert increasing impacts on crop productivity (Man et al., 2011). Drought causes reduction in yield, yield components and biomass accumulation of common beans (Munoz-Pereaet al*.,* 2006; Ambachew et al., 2015; Darkwa et al., 2016). Drought tolerance implies that the ability of a crop to grow and produce under water deficit conditions. A long term drought stress affects plant metabolic reactions associated with plant growth, water storage capacity and physiological performance of plants. In the Southern Highlands of Tanzania, the bulk of bean production is from small scale farmers who depend entirely on seasonal rainfall. In these areas, intermittent and/or terminal droughts are experienced in some years, while supplementing crops with irrigation during drought periods is uncommon and unaffordable. Therefore, variety evaluation for drought tolerance in the common bean is the most appropriate approach for plant breeders to identify superior genotypes for varieties development (Abebe et al., 1998; Darkwa et al., 2016). Selection indices, which provide a measure of drought tolerance based on loss of yield under drought and normal conditions have been used for screening genotypes (Mitra, 2001). Under water deficit conditions, crop plants resistance against damage has always been of great value and has been considered as one of the breeding objectives. In order to evaluate response of plant genotypes to drought stress, some selection indices based on a thematical relation between stress and optimum conditions have been developed. Therefore, plant breeders who are interested in genotypes which produce high yields under stressed condition came out with the use of drought tolerance selection indices for identifying high yielding genotypes. These indices include stress tolerance index (STI) (Rosielle and Hamblin, 1981), stress susceptibility percentage index (SSPI) (Moosavi et al*.,* 2008), drought resistance index (DI) (Blum, 1988), stress tolerance and mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP), harmonic mean (HM) (Jafari et al., 2009), stress susceptibility index (SSI) (Fischer and Maurer, 1978) and yield stability index (YSI) (Bouslama and Schapaugh, 1984). Some of these indices, however, have not been tested under Tanzania soil and weather conditions. Thus, scanty information is available on the use of these indices for evaluating bean genotypes under drought conditions. The objective of this study was to apply drought stress selection indices and identify drought tolerant genotypes to be used for breeding purposes in the Southern Highlands of Tanzania to advance bean production.

MATERIALS AND METHODS

The experiment was conducted at Inyala Agricultural Training Institute located at latitude 84°7'S, longitude 36° 51 E' and altitude of 1100 m above sea level (m. a. s. l). This location experiences unimodal rainfall pattern, which occurs between November and May every year. The overall average temperature is 17.5°C. The heaviest rainfall occurs from December to March. The soil characteristics of this area are loamy, slightly acidic with a pH of 5.5. Before planting, the land was cleared, ploughed and harrowed using oxen-pulled equipments. Composite soil samples were collected using a hand hoe at a depth of 15 to 20 cm and analyzed for physical and chemical characteristics at Uyole Agricultural Research Institute (ARI) soil laboratory (Table 1).

Weather data such as rainfall, minimum and maximum temperature, relative humidity and solar radiation were collected at Uyole weather station (Table 2). At planting, 18 common bean genotypes in which seventeen were known to be resistant to drought viz, SER125, MR13905-6,41-EX- VAM, BFS20, RCB233, CZ109-22, CZ104-61, KG25-21, SER82, SER83, KG104-72, SER16, KG4-30, SER45 SER124, BFS60, RCB266 and a susceptible check, PASS, were obtained from ARI-Uyole. The selection criteria of these genotypes for evaluation were based on seed size, yield, shoot types, field performance, resistance to drought and disease resistance. Fertilizers used were: triple super phosphate (TSP) (45% P_2O_5) and Urea (46% N). The experiment was laid out in 3 × 18 split plots arranged in a randomized complete block design (RCBD) with three replications. Plot size was 2 × 2 m and a spacing of 0.50 × 0.10 m resulting in a plant population of 200,000 plants per ha. The main plot (factor A) was water treatment at three different stress periods and sub plot (factor B) were 18 common bean genotypes. Planting was done in June 2015 by putting two seeds per hole at 5 cm depth in each row. Fertilizers were applied uniformly at a rate of 25.3 kg P/ha and 22.5 kg N/ha. Seven days after planting, seedlings were thinned to one plant per hill. Spraying with Amecron 50 EC insecticide at a rate of 2 mL/l was carried out to control bean stem maggot, termites and other insects by using a knap sack sprayer. Weeding was done three times using a hand hoe. Water stress was induced to main plots at flowering and mid pod filling when the plants had already attained 50% flowering and mid pod filling stages, respectively. The duration for water stress at both flowering and mid pod filling stages was 20

Table 1. Physical and chemical characteristics of soil collected from the experimental site.

Item	Unit	Quantity	Remarks (London, 1991)
Physical characteristics			
Clay	%	28.43	
Silt	%	33.01	Sandy loam
Sand	%	48.59	
Chemical characteristics			
Soil pH (1:25) H_2O	pH	5.3	Slightly acidic
CEC	cmol(+)/kg	15.41	High
K	cmol(+)/kg	0.12	Low
Ca	cmol(+)/kg	4.49	Medium
Mg	cmol(+)/kg	2.14	Medium
TN	%	0.13	Low
OC	%	0.82	Low
P	mg/kg	15.3	Medium

Table 2. Summarized mean monthly weather data collected during the experimental period.

Month	Rainfall (mm)	Temperature (°C)		Relative humidity (RH%)	Radiation ($MJm^{-2}d^{-1}$)
		Maximum	Minimum		
May	0	23.92	5.2	72.1	18.68
June	0	23.52	8.69	70.73	17.72
July	0	20.5	8.6	72.7	18.21
August	0	23.75	7.37	57.93	18.49
September	0	17.06	11.3	60.17	18.73
October	0	27.33	10.3	62.97	18.17
November	0	23.08	14.05	69.6	18.62

Source: Uyole Meteorological Station (2015).

days.

After harvest, yields of genotypes grown under non-water stress and water stress at flowering were used for calculating yield indices. These included, yield index (YI), stress tolerance index (STI), stress susceptibility percentage index (SSPI), mean productivity (MP), harmonic mean (HM), geometric mean productivity (GMP) and stress susceptibility index (SSI). They were calculated using the following relationships:

SSPI = $(Y_p - Y_s / 2 (\bar{Y}_p)) \times 100$ (Moosavi et al., 2008),
STI = $(Y_s \times Y_p) / Y^2_p$ (Fernandez, 1992),
YI= $(Y_s) / (\bar{Y}_s)$ (Gavuzzi et al., 1997),
MP = $(\bar{Y}s - \bar{Y}_p) / 2$ (Hossain et al., 1990),
SSI= (1 - (Ys / Yp)) / (1 - (Ys / Yp)) (Fischer and Maurer, 1978),
GMP = $\sqrt{YpxYs}$ (Fernandez, 1992)
HM = $\frac{2(YpxYs)}{Yp+Ys}$ according to Fernandez (1992).

where Y_S and Y_P are stress and non-stress (potential) yield of a given genotype, respectively. $\bar{Y}s$ and $\bar{Y}_p$ are average yields of all genotypes under stress and optimal conditions, respectively. Data analysis was carried out using GenStat 14th edition software and correlation coefficients among selection indices and grain yields under water stress and non-water stress conditions was performed.

RESULTS AND DISCUSSION

Identification of drought tolerant genotypes through ranking the yield indices calculated from a specific drought selection index

In order to investigate suitable stress resistance indices for screening of bean genotypes for drought tolerance, grain yield response to/under both non-stressed and stressed conditions were measured. This was used for calculating different sensitivity and tolerance indices (Table 3). It was noted that YI identified BFS60 and KG104-72 as the most drought tolerant. Using STI, MP and GMP, the genotypes, SER16, BFS60 and KG104-72 were identified as best cultivars for growing under drought conditions. Thus, these indices are useful for identifying genotypes that yield best under non-stressed and severe stressed conditions. These results are in

Table 3. The means of yield under stress and non-stress conditions and drought tolerance selection indices of bean genotype.

Genotype	YP (kg/ha)	YS (kg/ha)	YI (%)	STI (%)	SSPI (%)	MP (%)	HM (kg/ha)	GMP (kg/ha)	SSI (%)
SER82	1713	916	1.111	0.507	23.236	1314.5	1193.692	1252.600	0.888674
KG104-72	1939	1041	1.263	0.653	26.181	1490	1354.697	1420.700	0.884586
RCB266	2071	733	0.889	0.491	39.009	1402	1082.77	1232.089	1.234007
SER125	1623	956	1.160	0.502	19.446	1289.5	1203.248	1245.630	0.784962
KG25-21	1802	741	0.899	0.432	30.933	1271.5	1050.163	1155.540	1.12461
SER16	2183	1015	1.231	0.716	34.052	1599	1385.707	1488.540	1.021952
PASS	1200	461	0.559	0.179	21.545	830.5	666.1048	743.770	1.176264
SER124	1830	841	1.020	0.498	28.834	1335.5	1152.4	1240.576	1.032254
BFS20	1306	684	0.987	0.344	18.134	995	897.793	945.148	0.90968
CZ104-61	1807	759	0.921	0.443	30.554	1283	1068.989	1171.116	1.107757
KG4-30	1240	859	1.042	0.562	11.108	1049.5	1014.921	1032.066	0.586874
CZ109-22	1991	957	1.161	0.616	30.146	1474	1292.664	1380.358	0.991952
MR13905-6	1347	961	1.166	0.419	11.254	1154	1121.722	1137.750	0.547345
RCB233	1892	830	1.007	0.508	30.962	1361	1153.828	1253.140	1.072124
SER83	1906	841	1.020	0.518	31.050	1373.5	1167.052	1266.075	1.067255
BFS60	1999	1085	1.316	0.701	26.647	1542	1406.56	1472.724	0.873323
41-EX-VAM	1373	300	0.364	0.133	31.283	836.5	492.4088	641.794	1.492694
SER45	1648	728	0.883	0.388	26.822	1188	1009.886	1095.324	1.066282

Yp=Yield under non-stress, Ys=Yield under stress, YI=Yield index, STI= Stress tolerance index, SSPI = Stress susceptibility percent index, MP = Mean productivity, HM = Harmonic mean, GMP = Geometric mean productivity and SSI = Stress susceptibility percent index.

consistence with the findings of other authors' works (Kargar et al., 2004; Abdipour et al., 2008). On the other hand, SSPI identified RCB266, SER16 and 41-EX-VAM as the most drought tolerant genotypes. Further, HM identified BFS60, SER16 and KG104-72 as the most water stress tolerant genotypes, while SSI selected 41-EX-VAM, RCB266 and PASS as the most sensitive genotypes to drought stress. Therefore, genotype rankings by the drought indices were different from index to index. Therefore, different indices introduced different genotypes as a drought tolerant. According to previous studies, detection of drought tolerant genotypes has been suggested that by screening genotypes in non-drought conditions, both adaptability and yield potential are accessible (Kirigwi et al., 2004); but under stress environments, selection of genotypes with high yield performance can be favoured (Ceccarelli et al., 1992). According to Trethowan et al. (2002) and Fernandez, (1992), selection in alternating stress and non-stress drought environments enhance progress in development and selection of varieties. Further, selection for drought tolerance should be made using drought tolerance indices based on yield under both conditions for widely adapted genotypes (Sio-Se Mardeh et al., 2006).

Identification of drought tolerant genotypes by ranking means of yield indices of all selection indices

Breeding for drought tolerant is challenging and time-consuming, due to the need for simultaneously considering multiple abiotic and biotic factors modulating the level of drought-tolerance. The identification of drought tolerant genotypes based on single criterion was observed to be contradictory since different indices identified different genotypes as best drought tolerant. Therefore, to determine the most desirable drought tolerant genotype according to all selection indices, the mean rank of ranks of all drought tolerance criteria was calculated (Table 4). Based on these results, genotype with lowest mean was identified as the most tolerant. Genotypes with higher yields under all conditions can be used as parental materials for breeding purposes and will be suited in areas with short rains as well as in areas with long rains. In considering ranking of the means of all genotypes, SER16, BFS60 and KG104-72 exhibited the best ranks and they were considered as the most tolerant genotypes, while 41-EX-VAM, PASS and BFS20 as most sensitive genotypes under water stress conditions. That means, under water stress condition there was a reduction in shoot dry biomass as the result of decreasing photosynthesis, increasing growth inhibitors and decreasing hormones for the sensitive genotypes to partition the assimilates. These results are supported by authors' works (Farshadfar et al., 2012; Khalili et al., 2012).

The genotypes which possess high values of STI, MP, and GMP are considered tolerant to water stress. Genotype SER16 was ranked as the best based on STI, MP, and GMP indices and was considered to be the most

Table 4. The ranks of drought indices and ranks of means of drought indices ($\bar{R}$) of bean genotypes.

Genotype	Yp (kg/ha)	Ys (kg/ha)	YI (%)	STI (%)	SSPI (%)	MP (kg/ha)	HM (kg/ha)	GM (kg/ha)	SSI (%)	$\bar{R}$
SER82	11	7	7	5	13	9	6	7	13	9
KG104-72	5	2	2	3	12	3	3	3	14	5
RCB266	2	14	14	11	1	5	11	10	2	8
SER125	13	6	6	9	15	10	5	8	16	10
KG25-21	10	13	13	13	6	12	13	12	4	11
SER16	1	3	3	1	2	1	2	1	10	3
PASS	18	17	17	17	14	18	17	17	3	15
SER124	8	10	10	10	9	8	9	9	9	9
BFS20	16	16	16	16	16	16	16	16	12	16
CZ104-61	9	12	12	12	7	11	12	11	5	10
KG4-30	17	8	8	5	18	15	14	15	17	13
CZ109-22	4	5	5	4	8	4	4	4	11	5
MR13905-6	15	4	4	14	17	14	10	13	18	12
RCB233	7	11	11	7	5	7	8	6	6	8
SER83	6	9	9	6	4	6	7	5	7	7
BFS60	3	1	1	2	11	2	1	2	15	4
41-EX-VAM	14	18	18	18	3	17	18	18	1	14
SER45	12	15	15	15	10	13	15	14	8	13

Yp=Yield under non-stress, Ys=Yield under stress, YI=Yield index, STI= Stress tolerance index, SSPI = Stress susceptibility percent index, MP = Mean productivity, HM = Harmonic mean, GMP = Geometric mean productivity, SSI = Stress susceptibility percent index and $\bar{R}$= Mean of rankings.

drought tolerant and high-yielding under favourable and severe drought stress conditions (Table 4). This implies that the strong association between photosynthate assimilation and better remobilization of carbohydrates by drought-tolerant genotypes permits them to maintain high yield under water stress conditions. The findings are in agreement with that of Kargar et al. (2004), Abdipour et al. (2008) and Ilker et al. (2011) who recommended similar indices as the best in selecting high yielding wheat genotypes in both stress and non-stress conditions. Further, Jafari et al. (2009) indicated that STI was more useful in order to select favourable corn cultivars under stress and non-stress conditions. However, Khodrahmpour et al. (2011) and Khalili et al. (2012) noted that the best index to select varieties is STI as it can separate varieties which have high yield in both stress and non-stressed conditions.

Identification of suitable selection indices

Selection based on a combination of indices may provide a more useful criterion for improving drought tolerance; therefore, a suitable index must significantly correlate with grain yield under both conditions (Farshadfar et al., 2001; Mitra, 2001; Eddie et al., 2016). Correlation analysis was carried out among grain yield and drought tolerance indices to be used for screening the best genotype and indices for drought tolerance studies. To determine the most desirable drought tolerance selection indices, correlation coefficients between Yp and Ys and other quantitative drought indices were calculated. Results of correlation analysis (r) between yield in a non-water stressed, water stressed conditions and drought indices indicated that yield in a non-water stress condition was significant and positively correlated with YI (r = 0.5008*), STI (r = 0.7196***), SSPI (r = 0.7624***), MP (r = 0.9274***), HM (r = 0.7369***) and GM (r = 0.8346***); indicating that these indices are effective in identifying genotypes that yield high in non-water stressed environments. Yield in water-stressed conditions (Ys) was significant and positively correlated with YI (r = 0.988***), STI (r = 0.9238***), MP (r = 0.8194***), HM (r = 0.9659***) and GM (r = 0.9154***), implying that, these indices are more effective for selecting genotypes with high yields under water stressed conditions (Table 5).

On the other hand, Yp and Ys were significant and positively correlated with YI, STI, MP, HM and GM. This signifies that, latter indices can be used for selecting genotypes that yield high in both non stressed and stressed conditions. These observed relationships are in consistency with other studies. Toorchi et al. (2012) showed that correlation between MP, GMP, Ys and Yp was positive and significant. Khalili et al. (2012) reported that GMP, MP, and STI were significantly and positively correlated with yield under both conditions. The correlation coefficients indicated that MP, STI, GMP and HARM were the best criteria for identifying high yielding genotypes under stress and non-stress conditions (Zare, 2012; Kargar et al., 2014; Khalili et al., 2014). Farshadfar

Table 5. Correlation coefficient between Yp, Ys, and drought tolerance selection indices.

Variable	S/N	Yp	2	3	4	5	6	7	8	9
Yp (kg/ha)	1	-								
Ys (kg/ha)	2	0.5456*	-							
YI (%)	3	0.5008*	0.988***	-						
STI (%)	4	0.7196***	0.9238***	0.9031***	-					
SSPI (%)	5	0.7624***	-0.1264ns	-0.1702ns	0.1384^{ns}	-				
MP (kg/ha)	6	0.9274***	0.8194***	0.7834***	0.9044***	0.4651ns	-			
HM (kg/ha)	7	0.7369***	0.9659***	0.9466***	0.955***	0.1263ns	0.935***	-		
GM (kg/ha)	8	0.8346***	0.9154***	0.8886***	0.9473***	0.2811ns	0.9794***	0.9873***	-	
SSI (%)	9	0.2047^{ns}	-0.6971**	-0.7215***	-0.4735*	0.7806***	-0.171^{ns}	-0.497*	0.3583ns	-

Ns= Non-significant, *Significant at 0.05, **Significant at 0.01, ***Significant at 0.001.

et al. (2001) reported that the most appropriate index for selecting stress tolerant cultivars is one which has partly high correlation with yield under stress and non-stress conditions. Mitra (2001) recommended that a suitable index must have a significant and positive correlation with grain yield under all conditions. The positive correlation between yields of genotypes under unstressed with SSPI implies that it is useful in identifying genotypes that yield higher under unstressed conditions. The negative correlation between Ys and SSPI implies that the latter cannot be used in selecting genotypes with high yield under stressed conditions.

Conclusion

It is concluded that the rankings of means of ranks for yields under non-water stress, yield under stress and the used selection indices in the current study identified most tolerant genotypes as: SER16, BFS60, KG104-72, CZ109-22 and that YI, STI, MP and GM are suitable selection indices to identify genotypes with higher potential yield under both conditions. Also, SSPI and SSI are suitable for predicting genotypes that would give higher yields under unstressed condition. There is a need to investigate the presence of any physiological mechanisms and types of physiological mechanism involved in providing tolerance under limited moisture at specific plant developmental stages. This knowledge will help to improve selection criteria for drought tolerance of common bean. Genotypes, SER16, BFS60 and KG104-72, were observed to be superior in yield under water stress conditions; therefore they can be used as sources of breeding materials for drought tolerance in areas which are affected by drought at flowering. In areas where droughts occur during mid pod filling, genotypes KG4-30, RCB266, KG104-72 and SER125 should be used as sources of breeding materials for drought tolerance. In screening genotypes with high yields under non-water stress and water stress conditions, YI, STI, MP and GM indices can be used.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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