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Research Article

Genotypic variation for agronomical and physiological traits affecting drought resistance in Common Bean (*Phaseolus vulgaris L.*)

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The main objective of this study was to evaluate drought resistant genotypes previously developed in CIAT and local cultivars for yield traits and to identify agronomical and physiological traits associated with drought stress environments under the local environment in Yemen. The study materials were selected (16 genotypes) based on phenotypic, physiological traits and drought tolerance indexes in 2006 and 2007, then evaluated in 2008, 2009 and 2010 at three locations representing low rainfall drought (LRD) stress at the southern highland region (SHR) at Ibb – Yemen. Both experiments were subjected to medium to severe drought stress. Genotypes responded differently to drought stress and normal conditions; accordingly these bean genotypes categorized into four groups. The most important group, the group that includes MIB-154, MIB-155, Ser-72, BFB-141, SXB-416, Ser-111, Ser-88, NSL and Taiz-305 genotypes. This group expressed uniform superiority under both normal and drought conditions. The most important group, the group that includes MIB-154, MIB-155, Ser-72, BFB-141, SXB-416, Ser-111, Ser-88, NSL and Taiz-305 genotypes. This group expressed uniform superiority under both normal and drought conditions. Among phenotypic, physiological traits and drought tolerance indexes; delayed leaf senescence (DLS), growth recovery tolerance (LRT), grain filling index (GFI), seed production efficiency (SPE), stomatal conductance, early maturity and stress tolerance index (STI) were found to be the most suitable indices for screening bean lines for drought tolerance under both NS and SD environments as they were highly correlated with both (Yp) and (Ys). Moreover, stability indices analysis of the promising genotypes eight location x three years (2011, 2012 and 2013); proved that genotypes MIB-155, MIB-156, BFB-141, SXB-416 and NSL has high yields with low response indices.

Keywords: Delayed leaf senescence, growth recovery tolerance, grain filling index and stress tolerance index

INTRODUCTION

Drought stress is a worldwide production constraint of common bean (Wortmann et al., 1998). In Yemen, drought is endemic in the Southern Upland Agricultural Research –Ibb where rainfall is limited, year-to-year fluctuations in the amount is ranged between 220-755 mm. The common bean therefore cannot be grown in this area without supplemental irrigations (three to six) as we move from central Ibb to the marginal. The ability of crop cultivars to perform reasonably well in variable rainfall and water stressed environments is an important factor for stability of production under drought stress environments (Showemimo, 2007).

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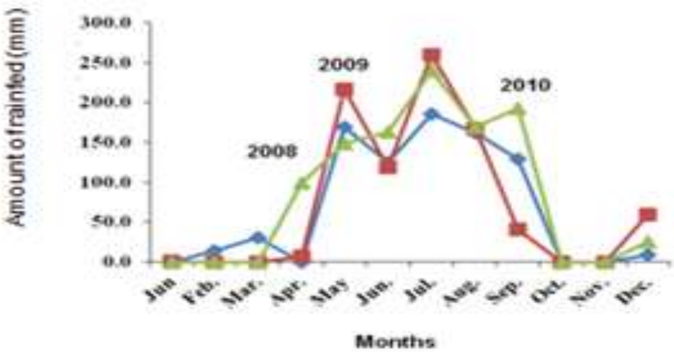
Figure 1. Monthly precipitation on (mm) at high rainfed environments of the years 2008, 2009 and 2010



To find sources of drought resistance in common bean germplasm, one should consider its evolutionary origin and domestication. The wild populations of common bean (the immediate ancestors of cultivars) are distributed from the northern and central highlands of Mexico to northwestern Argentina (Teran, and Singh, 2002). Challenges and opportunities for enhancing sustainable been production for drought adaptation is one of the aim of International Centre for Tropical Agriculture (CIAT), Colombia. In this context, a large number of bean germplasm accessions have been developed and evaluated for drought tolerance in various parts of the world and desirable lines identified. In addition, more drought-tolerant breeding lines still need to be evaluated in order to identify new and better adapted sources of drought tolerance under various environmental conditions.

Significant differences exist among bean genotypes in drought tolerance, yield and yield components in both non-stress and drought-stress conditions (Abebe et al.. 1998: Acosta et al.,1999: Sammour et al., 2007). In general, the low yielding genotypes did not register severe yield reduction. On the other hand, Ramirez-Vallejo and Kelly (1998) found positive correlation between seed yield in DS and NS environments. Thus, genotypes that had high yielding in the DS were also have high yielding in NS environment (Teran and Sing, 2002). However, Rosielle and Hamblin (1981) predicted that high yielding genotypes in drought stress were likely to be low yielding in well watered environments. Recently, Chiulele, et al., (2011) found that correlation analysis among DS and NS yield indicated that selecting cowpea genotypes based on yield potential would improve yield under both DS and NS yield environments.

The most effective selection criterion for screening drought resistant genotypes among various morphological, physiological, phenological, yield, and yield related traits were identified in several crops. However, very few studies have used quantitative indices of stress tolerance to assess drought tolerance in bean (Fernandez, 1992). Also, through a good drought tolerance index one should be able to identify superior genotypes in both drought prone and favorable environments.

The objectives of this study were (i) To compare drought resistant genotypes previously developed in CIAT and local cultivars, (ii) to identify optimal selection criterion as phenotypic and morpho-physiological traits that might impart "drought resistance" and (iii)To study the response and stability of bean cultivars grown in diverse bean growing SHR - Ibb regions of Yemen.

MATERIALS AND METHODS

Experimental Environments

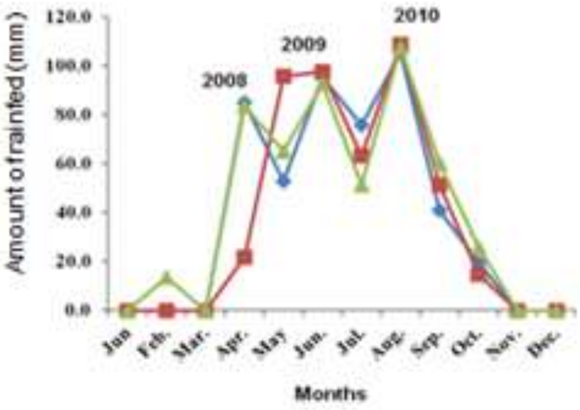
The SHR-Ibb regions in Yemen (latitude 13°36' N, longitude 44°01' E, longitude, 1900 m), is characterized as free rain fall environment in winter season (December through April) and heavy rain environment in the center about 755 mm (Figure 1) and reduced as we move to the marginal about 225 mm (Figure 2) in summer (May to September). The free rainy season environment was selected as controlled experimentation environments and the rainy environment was selected as natural experimentation environment. The soil is fine silty clay : 1.3% Organic manure, 0.19% N, 13% $CaCO_3$, 0.63 ms/cm EC (1:1), and pH (7.6).

Experiments

Observation

By taking advantage of this situation, observation on > 200 genotypes (CIAT) made during summer high rainfall season 2004 and spring season 2005 at research station. Out of 200 genotypes: 26 genotypes including three local and recommended cultivars: Taiz-303, Taiz-304 and Taiz-305 were selected based on yield, morphological and physiological traits, and disease infection that might or might not impart drought resistance.

Figure 2. Monthly precipitation on (mm) at low rainfed environments of the years 2008, 2009 and 2010



First Experiment

This experiment was conducted during winter season on 2006 and 2007. The seeds were planted as a completely randomized block design in a split plot arrangement with three levels of water supply: 80% FC (well-watered), 40% FC (simulation of intermittent drought), and without irrigation (simulation of terminal drought conditions) as main plots, and genotypes as subplots. Plants in the intermittent drought stressed (IDS) receive no water application after the floral establishment whereas plants with terminal drought stressed (TDS) receive no water application after the initial establishment. The field trial was planted in continuous rows with each genotype per replication planted in six rows of 5 m length with a row-to-row distance of 0.5 m and a plant-to-plant spacing of 0.60 m.

Second Experiment

The second experiment was conducted under low rainfall drought (LRD) stress during 2008, 2009 and 2010. Out of the 26 CIAT genotypes, 16 promising genotypes and the recommended cultivar (Taiz-305), were evaluated during three relatively dry cropping seasons in 2008, 2009 and 2010 at three location representing LRD conditions. Monthly rainfall during low rainfall growing season was recorded (Figure 2). The length of each row was 5 m. with 6 m^2 harvested for yield. All trials were grown in fields with residual soil fertility. Plots were kept free from weeds, diseases and insect pests by averages of a hand labor. A randomized complete block design with three replications was also used for each experiment.

In both experiments, the drought stress (DS) and normal stress (NS) plots were grown adjacent to each other both in a similar design and plot size. The DS plots received one gravity irrigation (approximately 40-45 mm of water) 2-5 d before planting and an additional irrigation 10 to 12 d after emergence. The NS plots received three to five additional irrigations as required for normal crop growth and development. The drought intensity index (DII) for each growing season was calculated as DII = I - Xds/Xns, where Xds and Xns are the average seed yield of all genotypes under DS and NS environments, respectively. DII for the trials conducted in 2006, 2007 were 0.485 and 0.611 and in 2008, 2009 and 2010 were 618, 671 and 0.671 respectively, indicating that both experiments were subjected to medium to sever drought stress.

Stability Analysis

Yield performances of the nine bean promising genotypes were evaluated in eight locations in Yemen (Ibb); Al-Qaydah, Shaban, Maitam, Giblah, Mashwarh, Al-Aodian, Al-Sahool and Wadi Al-Dhahr for 3 years (2011, 2012 and 2013), thus we obtained 24 environments with a randomize block design and replicated 3 times. The plot size was 5 rows of 6 m length with inter-row and intra-row spacing of 0.60 m x 0.20 m. Each row was over planted and later thinned to 2 plants/stand 2 weeks after emergence. 34.5 kg N/ha in the form of urea and 69 kg/ha of (P_2O_5) as single super phosphate fertilizer. Three central rows as net plot were harvested for grain yield. Mean yield (x) and coefficient of regression (b-value) were used as measures of yield response of genotypes in varying environments and adaptation patterns. The first stability parameter was the mean square deviation from regression (s^2d), the second; was coefficient of determination (r^2). The third stability parameter was Ecovalence (W).

Seed Yield and Yield Attributes:

At harvest: Seed yield (kg ha^{-1}), 100 seed weight (g/$plant^{-1}$), pod numbers/plant, seeds numbers/plant and harvest index were recorded and values for the former two were adjusted to 14% moisture by weight. Days to maturity (DM) that is number of days to maturity was also recorded. Harvest index (HI) that is seed biomass dry weight at harvest/total shoot biomass dry weight at mid-pod filling × 100. Pod partitioning index (PPI) that is pod biomass dry weight at harvest/total shoot biomass dry weight at mid-pod filling × 100. Pod production efficiency (number g^{-1}) (PPE): that is pod number per area/total shoot biomass dry weight at mid-pod filling per area. Grain filling index (GFI) for each genotype can be estimated from 100 seed dry weight under rainfall conditions/seed dry weight under irrigated conditions × 100. Seed production efficiency (SPE) (number g^{-1}) that is seed number per area/total shoot biomass dry weight at mid-podfilling per area is determined (Board and Maricherla, 2008).

Quantitative Drought Resistance Indices

Quantitative indices of stress tolerance were calculated using the following formulae Rosielle & Hamblin (1981) for mean productivity (MP), tolerance index (TOL), Fischer & Maurer (1978) for stress susceptibility index (SSI), stress intensity and Kristin et al., (1997); Farshadfar &Sutka, (2003) for geometric mean productivity (GMP) and stress tolerance index (STI).

Growth, Morphological and Physiological Traits

After three weeks of drought stresses dry weight of the roots drought weight g /plant^{-1} (RDW) and shoots drought weight g /plant^{-1} (SDW) were determined and the shoot/root ratio of plant was calculated for dry weights at the sampling stage.

Some morphological and physiological parameters were estimated as Delayed leaf senescence (DLS) that is a measure of the amount of leaf area that remained senescence. We scored leaf firing at regular intervals during the stress period on a 1 to 5 scale. where 5 = less than 20 percent of leaf senescence , and 1 = over 80 percent leaf senescence. Growth recovery tolerance (GRT) that is ability of a genotype to produce new leaves and seed after rain, We scored recovery resistance on a 1 to 5 scale where 5 = over 80 percent of the plants in a row recovered and 1 = less than 20 percent recovered. Root nodule mass (RNM) that is a measure of the amount of root nodules. We scored RNM at regular intervals during the stress period on a 1 to 5 scale, where 1 = less than 20 percent of low RNM , and 5 = over 80 percent of the high RNM. Relative water content % (RWC) is a useful measure of the physiological water status of plants was determined according to the method of Teran, and Singh, (2002). Determination of leaf electrolytes ions (LEI) in term of percent of injury was determined according to the method of Premachandraet al. (1991). Water use efficiency (kg ha^{-1} mm^{-1}) (WUE): was estimated on the basis of dividing seed yield ha^{-1} by the effective total rainfall (mm). Stomata conductance, was measured in fully expanded, uppermost leaves of plants using an infrared gas analyzer (LiCOR-6200, Portable Photosynthesis System, Nebraska, USA). Free proline content μ mole g^{-1} (PC) was determined according to the method of Bates et al. (1973).

Statistical Analysis:

Multiple correlation coefficients among different phenotypical, morphological and physiological traits, drought indexes were also determined. For data analysis, the cropping seasons and replications were considered as random effects and DS versus NS environments and common bean genotypes as fixed effects (McIntosh, 1983). All data were analyzed by a SAS statistical package. In this paper, only the nine promising genotypes (MIB-154, MIB-155, Ser-72, BFB-141, SXB-416, Ser-111, Ser-88, NSL) were presented and the data which is related to the percentage of reduction of different parameters of drought stress as compared with controls were not shown in tables.

RESULTS AND DISCUSSION

Grouping of Genotypes on the Basis of Yield and Quantitative Drought Resistance Indices

Genotypes differed very markedly in their response to drought stress and the degree of the inhibitory effect of drought stress depends on the type and intensity of drought stress. The moderate drought stress (IDS) had less injurious effect than severe drought stress (TDS and LRS) stresses. The reduction in seed yield was to the extent of 34.3%, 44.4% and 41.4% when the genotypes subjected to IDS, TDS and LRS stresses as compared with their respective NS conditions. On the other hand, genotypes responded differently with drought stress, accordingly these bean genotypes can be categorized into four groups. The first group that includes genotypes: MIB-154, MIB-155, Ser-72, BFB-141, SXB-416, Ser-111, Ser-88, NSL expressed uniform superiority under both normal and drought conditions. These genotypes were considered as non-stress and drought stress tolerant NS-DST genotypes (Table 1). The second group includes the genotypes that perform favorably in drought stressed environments. The genotypes of this group) Ser-121, Ser-88, NUA-59, Ser-65, SXB-409, MIB-383, MIB-158, MIB-157, and Ser-110) were considered as drought stress tolerant DST genotypes. The third group (NUA-4, SXB-407, MIB-386, Ser-73, Ser-104, Ser-417 and Taiz-305) includes the genotypes that perform favorably only in non-drought stressed conditions and we can consider them as non-drought stress NS genotypes. The fourth group (local cultivars: Taiz-304 and Taiz-304 and others) performed poorly under both NS and DS conditions. The taxa belongs to this group was considered as drought susceptible (DSUS) genotypes (Data of the last three groups are not shown). Earlier, Fernandez (1992) categorize bean genotypes into four groups; high yielding and drought tolerant (not reduced by drought) (group A), high yielding and drought susceptible genotypes (reduced by drought) (Group B), low yielding and drought tolerant genotypes (group C) and low yielding and drought susceptible genotypes

Table 1. Overall average of non-stress environment yield (Yp), stress environment yield (Ys), Percent reduction (PR), drought susceptibility index (DSI) of bean genotypes as affected by IDS, TDS and LRD stresses and non-stress conditions

Traits/	**Yp**			**Ys**			**PR**			**DSI**		
Genotypes	**IDS**	**TDS**	**LRD**	**IDS**	**TDS**	**LRD**	**IDS**	**TDS**	**LRD**	**IDS**	**TDS**	**LRD**
Mib-155	2.620	2.602	2.245	1.823	1.570	1.544	27.4	35.8	31.2	0.45	0.74	0.54
Mib-156	2.539	2.572	2.335	1.707	1.567	1.566	24.4	39.1	32.9	0.40	0.81	0.57
S-72	2.552	2.258	2.546	1.631	1.197	1.345	37.6	47.0	47.2	0.62	0.97	0.82
NSL	2.399	2.846	2.379	1.861	1.638	1.436	24.0	38.9	29.3	0.39	0.80	0.51
BFB-141	2.520	2.495	2.265	1.804	1.636	1.451	28.4	36.4	40.3	0.47	0.75	0.70
SXB-416	2.710	2.731	2.592	1.730	1.609	1.321	33.1	39.2	49.1	0.54	0.81	0.85
Ser-111	2.333	2.602	2.325	1.626	1.372	1.314	36.7	49.2	43.5	0.60	1.01	0.75
Ser-88	2.417	2.481	1.923	1.571	1.279	1.149	37.1	48.5	40.2	0.61	1.00	0.70
Taiz-305	2.106	2.090	1.875	0.897	0.765	0.793	59.8	65.8	60.4	0.98	1.36	1.05
Mean	2.466	2.520	2.276	1.628	1.404	1.324	34.3	44.4	41.6	0.56	0.92	0.72
LSD(p=0.05)	0.279	0.325	0.337	0.245	0.212	0.255	10.9	10.09	13.1.2	0.19	0.15	0.54
CV%	11.9	18.8	12.8	15.1	15.1	16.6	21.2	28.4	32.9	21.1	21.7	10.60

Table 2. Overall average of stress tolerance (TOL), geometric average (GMP), mean percent (MP), susceptible tolerant index (STI) of bean genotypes as affected by IDS, TDS and LRD stresses and non stress conditions

Traits/	**TOL**			**GMP**			**MP**			**STI**		
Genotypes	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	0.69	0.93	0.70	4.58	4.34	3.47	2.17	2.14	1.89	0.55	0.52	0.41
Mib-156	0.58	1.01	0.77	4.31	4.03	3.66	2.10	2.07	1.95	0.52	0.48	0.44
S-72	0.92	1.06	1.20	3.75	2.70	3.42	1.99	1.73	1.95	0.45	0.32	0.41
NSL	0.59	1.11	0.61	4.56	4.94	3.06	2.16	2.29	1.77	0.54	0.59	0.36
BFB-141	0.72	0.91	0.91	4.54	3.96	3.06	2.16	2.04	1.81	0.54	0.47	0.37
SXB-416	0.83	1.07	1.27	4.21	4.53	3.42	2.09	2.19	1.96	0.50	0.54	0.41
Ser-111	0.86	1.28	1.01	3.44	3.44	3.05	1.90	1.96	1.82	0.41	0.41	0.36
Ser-88	0.90	1.20	0.77	3.67	3.17	2.21	1.97	1.88	1.54	0.44	0.38	0.26
Taiz-305	1.26	1.38	1.13	1.78	1.49	1.39	1.48	1.40	1.31	0.21	0.18	0.17
Mean	0.82	1.11	0.93	3.87	3.62	2.97	2.00	1.97	1.78	0.46	0.43	0.35
LSD(p=0.05)	0.33	0.11	0.70	0.24	0.04	3.47	0.21	0.27	1.89	0.10	0.10	0.41
CV%	20.6	17.4	0.8	22.9	24.8	3.7	17.9	19.7	2.0	22.7	10.8	0.4

(group D). According to this categorization, the local cultivars Taiz-303 and Taiz-304 fail in group D, Other genotypes embedded in group C; since their yield reduced to less than half of the yield; between 24.0-49.1%.

The yield reduction percentage of DSUS genotypes were more than 50%,depending on the degree of drought IDS > TDS = LRS stresses (Table 1).Stress intensity (SI) is categorized into mild, moderate and severe. Stress intensity is mild when the stress intensity is situated between zero and twenty-five percent of yield reduction, moderate when the stress intensity is situated between twenty-five and fifty percent yield reduction and severe when the stress intensity is fifty percent yield reduction (Chiulele, et al., 2011).

From the results of quantitative drought resistance indices also it was evident that DSI (Table 1) and TOL (Table 2) reduced significantly the NS-DST and DST genotypes in comparison with DSUS genotypes under IDS, TDS and LRS stresses (Table 1) while MP, GMP and STI increased significantly the NS-DST and DST genotypes in comparison with DSUS genotypes (Table 2). The drought tolerant genotypes had MP, GMP and STI > 1.73, 2.70 and 0.41 respectively while DSI and TOL were < 0.85and 1.27 respectively. However, the increment of GMP, MP and STI and reduction in DSI and TOL was higher under IDS than TDS and LRS stresses (Table 2). Similar results were obtained by Fernandez (1992) who reported an increment of GMP, MP and STI and reduction in DSI and TOL and concluded that quantitative indices of stress tolerance can be used to assess drought tolerance in bean.

Phenotypic and Growth Variation.

Yield Attributes:

Overall average number of pod numbers/plant, seeds numbers/plant, and 100 seed weight were reduced significantly by 31.3, 52.5 and 39.5%, at IDS stress and

Table 3. Overall average of yield under normal (Yp) and drought stress (Ys) environments, pods/plant (PPP), seed/plant (SPP),100 seed weight (HSW), harvest index (HI) of bean genotypes as affected by IDS, TDS and LRD stresses

s/ Traits	Pods per plant			Seeds per plant			100 SW			H I (%)		
	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	21.9	17.4	16.2	85.4	76.3	64.2	22.3	19.4	14.8	48.1	49.4	58.3
Mib-156	20.3	15.9	17.2	80.5	76.5	69.3	20.2	19.8	16.8	50.9	53.7	55.9
S-72	16.5	13.7	17.1	73.6	59.9	69.2	21.2	15.8	16.2	35.2	34.5	57.8
NSL	24.4	15.3	15.6	78.9	90.8	58.6	20.9	23.3	12.9	55	57.4	55.1
BFB-141	19.4	15.9	16	75.8	68.2	62.3	20.9	18.1	14.3	43.3	43.8	58.4
SXB-416	22.1	14.3	16.1	73.9	80.9	64.5	19.3	21.1	15	49.3	50.8	42.7
Ser-111	17	14.5	16.5	69.3	73.4	65.4	18.4	18.7	13.9	43.3	42.7	44.8
Ser-88	17.4	13.7	15.6	74.1	69.9	61.3	20.8	17.5	15	42	42.8	46.9
Taiz-305	11.9	13	11.6	38.2	32.5	34.2	13.5	11.5	11	31.4	30.6	33.2
Average	19	14.9	15.8	72.2	69.8	61.0	19.7	18.4	14.4	44.3	45.1	50.3
$LSD_{(p=0.05)}$	2.9	1.3	0.9	13	4.3	12.9	7.5	1.1	2.6	7.8	8.9	9.2
CV%	22.3	22.7	23.2	23	22.9	21.1	22.2	12.3	20.2	11.7	13.9	17.5

Table 4. Overall average of pod partitioning index (PPI), pod production efficiency (PPE), grain filling index (GFI), and seed production efficiency (SPE) of bean genotypes as affected by IDS, TDS and LRD stresses

Traits/	PPI			PPE			GFI			SPE		
Genotypes	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	59.4	48.8	37.5	51.6	42.3	32.5	55.0	45.7	38.9	202.9	168.6	130.6
Mib-156	46.9	43.9	36.6	40.7	38.1	31.7	48.1	45.0	30.9	181.9	164.9	128.5
S-72	49.8	27.2	32.8	43.2	23.6	28.5	49.4	24.2	30.5	166.6	89.0	115.7
NSL	43	52.4	42.7	37.3	45.4	37.1	44.3	54.7	30.7	157.3	193.5	137.5
BFB-141	46.6	43.8	39.9	40.4	38.0	34.6	56.2	39.7	39.8	153.2	133.2	134.9
SXB-416	46.6	36.6	36.9	40.5	31.8	32.0	44.1	34.9	29.9	161.7	127.6	128.6
Ser-111	45.1	46	43.3	39.1	39.9	37.5	47.8	47.3	30.0	170.7	164.7	149.7
Ser-88	47.6	36.2	47.7	41.3	31.4	41.4	43.7	37.6	28.9	178.6	132.7	166.6
Taiz-305	65.7	38.7	49	57.0	33.6	42.5	43.6	36.9	27.0	150.8	93.4	122.8
Average	50.1	41.5	40.7	43.5	36.0	35.3	48.0	40.7	31.8	169.3	140.8	135.0
$LSD_{(p=0.05)}$	5.7	6.9	6.8	6.6	7.8	9.1	4.9	6.8	5.1	11.8	14.9	20.3
CV%	13.6	18.8	17.9	14.2	16.9	16.4	20.2	19.1	19.8	19.7	17.1	17.8

by 31.3, 52.5 and 39.5%, at TDS stress and by 34.7, 53.2 and 37.0%, at LRS condition respectively, as compared with the controls. In contrast, the harvest index increased significantly with the intensity of drought where LRS >TDS = IDS. These results indicated that the TDS inhibited pod and seed yield than biological yield whereas IDS and LRS inhibited biological yield than pod and seed yield.

On the other hand, NS-DST genotypes recorded also significant and higher reduction in average number of pod numbers/plant, seeds numbers/plant, and 100 seed weight and HI% in comparison with other genotypes in all drought conditions (Table 3). The significant reduction in biomass, number of seeds and pods, harvest index, seed yield, and seed weight in common bean indicated that the plants were subjected to moderate to high drought stress (Acosta-Gallegos and Adams, 1991; Ramirez-Vallejo and Kelly, 1998).
The effect of drought intensity on pod partitioning index (PPI) and pod production efficiency (PPE), GFI and SPE were significantly higher in IDS >TDS = LRS stresses. NS-DST genotypes had high values of PPI, PPE, GFI and SPE in comparison with other genotypes (Table 4).The significant reduction in pod partitioning index and pod wall biomass was considered as an important phenotypic traits that reflect greater ability to mobilize photosynthates to grain under drought stress (Beebe et al., 2008).

Roots, Shoots Dry Weights and Roots/Shoot Ratio

Shoot and root dry weights of bean genotypes were significantly decreased in response to IDS, TDS and

Table 5. Overall average of shoot dry weight, root dry weight and shoot root ratio and days to maturity of bean genotypes as affected by IDS, TDS and LRD stresses

Traits/	**Shoot dry weight**			**Root dry weight**			**Shoot root ratio**			**Day to maturity**		
Genotypes	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	36.6	32.3	28.8	6.2	5.8	4.5	5.9	5.6	6.4	81.1	82.9	82.7
Mib-156	40.1	35.2	25.1	6.1	5.8	5.3	6.6	6.1	4.7	78.4	81.2	78.3
S-72	41.7	29.1	34.4	6.0	5.2	5.6	7.0	5.6	6.1	74.0	74.2	77.4
NSL	31.7	45.7	29.4	5.9	6.4	3.7	5.4	7.1	7.9	77.4	78.5	77.6
BFB-141	32.7	32.2	35.7	6.4	5.9	5.4	5.1	5.5	6.6	80.7	78.2	80.7
SXB-416	44.9	37.4	33.2	5.9	6.2	5.6	7.6	6.0	5.9	79.4	79.5	78.6
Ser-111	32.6	30.5	26.1	5.7	5.7	3.7	5.7	5.4	7.1	76.3	78.0	76.2
Ser-88	30.4	27.5	32.3	5.8	4.8	4.2	5.2	5.7	7.7	84.1	78.4	82.7
Taiz-305	26.1	26.8	18.8	3.9	3.3	1.6	6.7	8.1	11.8	89.7	91.7	89.0
Average	35.2	33.0	29.3	5.8	5.5	4.4	6.1	6.1	7.1	80.1	80.3	80.4
$LSD_{(p=0.05)}$	3.20	18.60	3.70	8.90	1.70	1.30	0.03	0.13	0.11	11.9	9.3	13.1
CV%	11.20	27.00	29.50	13.60	8.80	22.10	9.70	11.30	28.50	22.1	11.3	7.0

LRS stresses as compared with non-stress conditions. Therefore, 50.1%, 65.4% and 55.0% decreases in shoots dry weights and 39.1%, 55.3% and 62.5% decreases in roots dry weights were observed in response to IDS, TDS and LRS stresses, respectively (Table 5). However, the superior genotypes NS-DST genotypes were proved significant and superior SDW and RDW over the other genotypes under NS and DS conditions. Interestingly, shoot/Root ratio under LRS was more than that under IDS which equal that under TDS. The NS-DST genotypes had no significant differences in root/shoot ratio under IDS whereas they have significant decrease in root/shoot ratio under LRS stress as compared with the controls (Table 5). The inhibitory effects of drought stress on plant growth have been frequently recorded in many plant species (Omae et al., 2007; Hussain et al.2009; Aly et al., 2012; Abdou Razakou et al., 2013).

Days to Maturity

Days to maturity of resistant bean genotypes were significantly decreased by IDS, TDS and LRS stresses as compared to non-stress conditions. Therefore, the most resistant genotypes NS-DST genotypes had between: 74.0 – 78.4 days after sowing (DAS), 74.2 – 78.2 DAS and 71.8 – 72.9 DAS at IDS, TDS and LRS stresses respectively. On the other hand, the most susceptible genotypes resistant maturated 89.1, 91.7, and 91.7 DAS at IDS, TDS and LRS stresses respectively (Table 5). Beebe et al. (2008) found significant variation in days maturity, and the drought-selected genotypes presented shorter days to maturity, but in some cases, better yield potential under favorable conditions.

Morphological and Physiological Traits

Visual Observation:

The visual observations had clearly demonstrated that there were marked differences in the response of these bean genotypes to water deficit. The results of delayed leaf senescence (DLS) score showed that the most genotypes resistant NS-DST genotypes had higher DLS > 2.6 while the DSUS genotypes had DLS < 2.0. On the other hand the most susceptible genotypes showed DLS < 1.51, 1.83, and 2.00 at IDS and TDS and LRS stresses, respectively (Table 6).

However, The results of growth recovery tolerance (GRT) trait also showed that the same genotypes were the most resistant, since they scored LRT between 2.56 - 3.35, 2.70 – 3.74 and 3.00 – 3.70 at IDS, TDS and LRS stresses respectively, whereas the most susceptible genotypes resistant scored < 1.51, 1.45, and 1.70 at IDS and TDS stresses and LRS respectively (Table 6). The visual screenings under IDS and TDS and LRS stresses conditions had clearly demonstrated that there were marked differences in the response of these bean genotypes to water deficit. It was noted that the local cultivars Taiz-303 and Taiz-304 and some CIAT genotypes failed to recover growth, so they were excluded in the further field trials.

The visual observations of root nodules mass (RNM) of mature plant had clearly demonstrated that there were marked differences in the response of these bean genotypes to water deficit. The results of RNM score showed that the most resistant NS-DST genotypes had between 3.37 – 3.58, 3.33 – 3.51 and 3.37 – 3.58 at IDS, TDS and LRS stresses respectively, whereas the most susceptible genotypes resistant gave 1.91, 2.18, and 1.91 at IDS, TDS and LRS stresses (Table 6) respectively. A delayed-leaf-senescence (DLS) trait has been discovered in cowpea that conferred some resistance to reproductive-stage drought in erect cowpea cultivars. The DLS trait enabled them to recover after the drought and produce a larger second flush of pods that compensated for the low yield by the first flush of pods (Gwathmey and Hall, 1992).Severe drought stress-has reduced nodulation in common

Table 6. Overall average delayed leaf senescence (DLS), growth recovery tolerance (GRT), root nodule mass (RNM) and (RWC), of bean genotypes as affected by IDS, TDS and LRD stresses

Traits/	**DLS**			**GRT**			**RNM**			**RWC**		
Genotypes	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	2.99	2.4	2.8	2.83	2.83	2.63	3.37	3.32	3.16	80.0	73.2	70.7
Mib-156	2.33	2.01	3.8	3.05	3.06	3.26	2.92	3.15	3.62	75.3	77.5	69.3
S-72	2.21	1.95	2.7	2.79	2.83	3.70	3.36	3.43	3.49	75.2	74.3	67.7
NSL	1.92	3.48	2.7	2.78	3.74	2.18	3.47	3.51	2.93	77.7	72.8	66.3
BFB-141	2.75	2.25	2.8	2.76	2.7	2.45	2.69	2.77	2.98	79.6	72.7	64.2
SXB-416	2.35	2.29	2.6	3.83	3.27	3.20	3.58	3.33	3.06	73.8	73.5	65.9
Ser-111	1.85	1.95	2.3	2.01	2.76	3.33	3.37	3.56	3.25	72.8	69.9	59.9
Ser-88	2.05	1.77	2.1	2.28	2.47	2.64	2.46	2.61	2.81	69.1	69.9	58.5
Taiz-305	1.51	1.83	2.0	1.45	1.45	1.70	1.91	2.18	2.06	64.2	54.1	58.0
Average	2.22	2.21	2.64	2.64	2.79	2.79	3.01	3.10	3.04	74.2	70.9	64.5
$LSD_{(p=0.05)}$	1.9	1.3	1.2	13.0	4.3	3.1	3.7	4.1	6.8	7.5	1.1	20.3
CV%	22.3	22.7	17.5	23	22.9	15.7	29.5	14.9	17.9	22.2	12.3	17.8

bean by an average of 43% and N_2 fixation to one sixth of a well-irrigated control (Teran, and Singh, 2002).

Water Relationship

Relative Water Content % (RWC)

The range in RWC among genotypes and cultivars in the stress condition was very broad 74.2, 70.9 and 64.5% at IDS, TDS and LRS stresses, respectively indicating that there were considerable differences among the tested genotypes and cultivars in their ability to produce water potential of soil solution in the stress condition (Table 6). However, NS-DST genotypes had higher RWC > 65% while the DSUS genotypes had RWC > 60%. Lower water potential of soil solution is responsible for decreased absorption of water by plant. All this is in agreement with Munne-Bosch., et al. (2006) who demonstrated that RWC decreased progressively under water deficit.

Water Use Efficiency (WUE)

The range of agronomic water-use efficiency (WUE) among genotypes in the stress condition was also very broad 6.4, 5.1and 3.8kg ha^{-1} mm^{-1} at IDS, TDS and LRS stresses, respectively indicating that genotypic differences in WUE average were significantly high in comparison with the chick (local) cultivar. The results indicated clearly that WUE under stress was higher in the resistant genotypes than in the susceptible genotypes because of the relative differences in their water use and seed yield and biomass. NS-DST genotypes had higher WUE > 4.0% while the DSUS genotypes had RWC >3.0 kg ha^{-1} mm^{-1}.The differences in WUE at TDS and LRS stresses are evident (Table 7).

Greater biomass production under stress was associated with relatively greater water use and lower WUE. Guerra et al. (2000) found that under severe drought stress, WUE in pinto beans ranged from 1.5 to 4.4 kg ha^{-1} mm^{-1} water. Under favorable milder climatic conditions, the average WUE value was 10 kg ha^{-1} mm^{-1} water in the drought stress environment and 8.7 kg ha^{-1} mm^{-1} water in the non-stress environment. Using one of the drought adapted small seeded red genotypes (SER 16), Builes et al. (2011) reported that WUE values up to 9.2 kg ha^{-1} mm^{-1} water under drought stress. Under controlled conditions, genotypes with high WUE will survive and grow better in water-limiting environments than genotypes with low WUE, which is not affordable in nature.

Stomata Conductance (Sc)

The results of the stomata conductance (Sc) of the flag leaf from the top of the bean lines have been shown in Table 7. The perusal of the data clearly showed that a drastic decrease in the Sc with different drought stress. The deleterious effect was high under IDS < TDS < LRS stresses. The magnitude of reduction was more in the drought resistant NS-DST genotypes than in susceptible DSUS genotypes. Similar results were obtained by Lu et al. (1998) and Cruz de Carvalho et al. (1998) who found genotypic variation in Sc in other crops. They also have shown remarkable positive correlations between yield increases and increases in cowpea and common bean genotypes in stomatal conductance, reporting that the cowpea genotypes kept their stomata partially opened and had a lower decrease in their net photosynthetic rates than the common bean.

Free proline Content and Leaf Electrolytes Ions:

Free Proline Content (FPC):

The data of proline accumulation demonstrated that there were marked differences in the response of these

Table 7. Overall average of water use efficiency(WUE), stomatal conductance(Sc), free proline content (PC) and determination of leaf electrolytes ions (LEI)of bean genotypes as affected by IDS, TDS and LRD stresses

Traits/	WUE			Sc			FPC			LEI		
Genotypes	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD	IDS	TDS	LRD
Mib-155	6.9	5.7	4.3	86.1	87.9	93.2	99.6	111.4	127.7	0.22	0.31	0.40
Mib-156	6.0	5.5	4.0	97.0	95.7	88.4	98.3	104.6	134.2	0.34	0.40	0.33
S-72	7.3	4.3	4.0	90.7	102.0	78.4	92.8	102.9	127.7	0.37	0.31	0.28
NSL	6.7	6.0	4.0	103.6	98.1	76.0	85.8	115.9	119.1	0.27	0.34	0.39
BFB-141	6.5	5.0	3.7	95.1	105.1	91.9	100.7	122.1	119.3	0.26	0.32	0.42
SXB-416	7.1	5.8	4.0	99.4	88.4	79.9	89.4	121.2	122.6	0.33	0.28	0.33
Ser-111	6.0	6.1	4.1	116.2	91.2	83.9	100.9	95.1	127.2	0.26	0.35	0.34
Ser-88	7.0	4.4	3.7	103.6	96.0	96.4	85.4	104.2	114.1	0.44	0.41	0.42
Taiz-305	4.2	2.8	2.6	119.9	105.6	97.9	61.9	92.5	98.5	0.55	0.50	0.57
Average	6.4	5.1	3.8	101.3	96.7	87.3	90.5	107.8	121.2	0.34	0.36	0.39
$LSD_{(p=0.05)}$	3.2	2.7	9.9	13.6	11.9	9.3	8.9	7.7	9.9	10.5	4.7	5.1
CV%	20.2	27.0	17.8	13.9	15.7	19.1	24.6	8.8	17.8	21.5	23.6	19.8

bean genotypes to water deficit. The results of FPC showed that the most resistant NS-DST genotypes had between 92.8 – 100.9, 104.2 – 122.1 and 119.1 – 134.2 μ mole g^{-1} at IDS, TDS and LRS stresses, respectively, whereas the most susceptible genotypes resistant had 61.9, 92.5, and 98.5μ mole g^{-1} μ mole g^{-1}at IDS, TDS and LRS stresses respectively (Table 7). Proline accumulation, particularly, is a well-known response to drought stress (Raifa et al., 2009). It may be noted that proline leads to the maintenance of membrane integrity (Parvaiz and Satyawat**,** 2008) and genotypes tend to support greater environmental variations, so that genotypes derived from improvement programs tend to be more adapted to the specific cultivation conditions, in agreement with statements of Machado Neto and Barbosa Duraes 2006 who found also that the variety Guarumbe was already identified as proline accumulator during germination in stress situations, different from cultivar Apore and as resistant to water stress.

Leaf Electrolytes Ions (LEI):

One of the expressions of membrane damage is the leakage of some cell components; in this work, leakage of ions was assessed under conditions of drought stress i.e. increased or decreased in accordance with the rhythm of membrane stability index. Also, the lost ions were proportional with the level of stress. The results of LFI score showed that the most resistant NS-DST genotypes had significantly low LFI between 0.26 – 0.37, 0.31 – 0.40 and 0.26 – 0.43 at IDS, TDS and LRS stresses , respectively whereas the most susceptible genotypes had LFI 0.53, 0.64, and 0.55 at IDS, TDS and LRS stresses, respectively (Table 7). This data indicated that membrane stability index of the investigated plants was severely deteriorated by drought stress. Similar results were obtained by Al-Abssy and Al-Hakimi (2010) who found that increased rates of solute leakage into non-electrolyte media were commonly associated with stress and attributed to membrane modifications.

Selection Criteria in Responses to Drought Stress and Mechanism of Tolerance

Yield and dry matter accumulation

The above results suggested that yield and its components can be used as the main criteria in responses to drought stress and mechanism of tolerance, since yield is the integrated expression of the entire array of traits related to productivity under both NS and SD environments. However, Yp and Ys are strongly associated positively with NS and SD (IDS, TDS and LRS) and can be used for selecting tolerant bean genotypes based on yield potential. On the other hand, each yield components associated with specific environment; the pods and seeds number were the most suitable for screening bean lines for drought tolerance under both NS and SD environments, while 100 seed weight and HI can be used as selection criteria for screening bean lines for drought tolerance under NS and SD (IDS, TDS and LRS) environments, respectively. Increasing the ability for seeds and pods formation efficiency as affected by drought stress is also good seeds and pods formation indices due to its high and significant correlation with both Yp and Ys and with each other as grain filling index (GFI), and seed production efficiency (SPE), were positively and significantly correlated with both Yp and Ys. These results suggest that tolerance of drought during flowering and pod-filling is in some way related to the ability of a genotype to maintain pod and seed numbers under these conditions. GFI and SPE associated with the superior performance of the most tolerant NS-DST genotypes and correlated positively and significantly with seed yield under all stresses which were clearly associated with drought escape (Table 8). Simango and Lungu. (2010) reported that direct selection for

Table 8. Correlation coefficient of overall average of (Yp), (Ys), pods/plant (PPP), seed/plant (SPP), 100 seed weight (HSW), harvest index (HI), GFI, SPI SDW, RDW, SRR of bean genotypes as affected by IDS, TDS and LRD stresses

Traits	Yp	Ys	PPP	SPP	HSW	HI	GFI	SPI	SDW	RDW
IDS										
Yp	1.00									
Ys	0.77**	1.00								
PPP	0.68**	0.90**	1.00							
SPP	0.80**	0.96**	0.82**	1.00						
HSW	0.76**	0.89**	0.71**	0.96**	1.00					
HI	0.52*	0.83**	0.94**	0.74**	0.56**	1.00				
GFI	0.47*	0.55*	0.48*	0.46*	0.45*	0.49*	1.00			
SPI	0.52*	0.49*	0.48*	0.58*	0.53*	0.50*	0.60*	1.00		
SDW	0.72**	0.64**	0.47*	0.66**	0.77**	0.24	0.72**	0.03	1.00	
RDW	0.81**	0.94**	0.72**	0.96**	0.94**	0.62*	0.59*	0.41*	0.79**	1.00
SRR	0.33	0.10	0.04	0.11	0.30	-0.20	0.56*	0.46*	0.80**	0.27
TDS										
Yp	1.00									
Ys	0.90**	1.00								
PPP	0.54*	0.76**	1.00							
SPP	0.96**	0.93**	0.57*	1.00						
HSW	0.98**	0.94**	0.57*	0.99**	1.00					
HI	0.93**	0.90**	0.65**	0.91**	0.95**	1.00				
GFI	0.66**	0.48**	0.54*	0.54*	0.59*	0.69*	1.00			
SPE	0.84**	0.73**	0.68**	0.80**	0.81**	0.86**	0.92**	1.00		
SDW	0.92**	0.94**	0.62**	0.95**	0.97**	0.91**	0.54*	0.76**	1.00	
RDW	0.96**	0.85**	0.58*	0.90**	0.94**	0.93**	0.69**	0.85**	0.88**	1.00
SRR	-0.55*	-0.76**	-0.50*	-0.71**	-0.68**	-0.55*	-0.60*	-0.48*	-0.80**	0.430**
LRD										
Yp	1.00									
Ys	0.66**	1.00								
PPP	0.70**	0.88**	1.00							
SPP	0.69**	0.85**	1.00	1.00						
HSW	0.53*	0.69**	0.87**	0.89**	1.00					
HI	0.46*	0.84**	0.74**	0.71**	0.62**	1.00				
GFI	0.90**	0.77**	0.70**	0.67**	0.67**	0.66**	1.00			
SPE	0.49*	0.96**	0.89**	0.81**	0.83**	0.73**	0.70**	1.00		
SDW	0.75**	0.83**	0.92**	0.91**	0.91**	0.76**	-0.77**	-0.25	1.00	
RDW	0.68**	0.79**	0.93**	0.93**	0.96**	0.76**	-0.65**	-0.11	0.96**	1.00
SRR	-0.55*	-0.77**	-0.91**	-0.93**	-0.84**	-0.72**	-0.49*	-0.26	-0.79	-0.90**

number of pods per plant, harvest index and 100 seed weight would be effective under water stressed conditions since the positive correlation ship was mainly due to direct effects.

The analysis of phenotypic differences in shoot traits that contribute to superior adaptation reflected its important as avoidance mechanism by increasing the ability of seeds and pods formation efficiently under drought stress. Similar results were reported by Beebe et al., (2008) who found that pod partitioning index and lower proportion of pod wall biomass are important phenotypic traits that reflect greater ability to mobilize photosynthates to grain under drought stress. The ability to accumulate high dry matter of shoot and root also associated significantly with both Yp and Ys and all the other yield components under all water stress reflecting the efficiency of SDW and RDW to be used as criteria. Interestingly, shoot/root ratio was also correlated negatively and significantly with Yp and Ys

Table 9. Correlation coefficient of (Yp), (Ys), (DLS), (GRT), (RWC), (WUE), (RNM), (LEI), (LEI), (MSI), (PC) of bean genotypes as affected by IDS, TDS and LRD stresses

Traits	Yp	Ys	DTM	DLS	GRT	RNM	RWC	WUE	SC	LEI
IDS										
Yp	1.00									
Ys	0.77**									
DTM	-0.55*	-0.63	1.00							
DLS	0.60*	0.68**	-0.46*	1.00						
GRT	0.90**	0.64**	-0.33	0.21	1.00					
RNM	0.68**	0.68**	-0.84**	0.59*	0.55*	1.00				
RWC	0.70**	0.90**	-0.63**	0.60*	0.48*	0.67**	1.00			
WUE	0.81**	0.74**	-0.65**	0.44*	0.58*	0.70**	0.63**	1.00		
SC	-0.84**	-0.72**	0.44*	-0.33	-0.60*	-0.46*	-0.77**	-0.74**	1.00	
LEI	-0.59*	-0.83**	0.66**	-0.54*	-0.43*	-0.76**	-0.91**	-0.56*	0.52*	1.00
FPC	0.84**	0.79**	-0.73**	0.22	0.60*	0.63**	0.80**	0.62*	-0.60*	-0.85**
TDS										
Yp	1.00									
Ys	0.90**	1.00								
DTM	-0.43*	-0.51*	1.00							
DLS	0.69**	0.64**	-0.67**	1.00						
GRT	0.98**	0.92**	-0.44*	0.73**	1.00					
RNM	0.66**	0.64**	-0.66**	0.47*	0.66**	1.00				
RWC	0.65**	0.83**	-0.78**	0.29	0.69**	0.72**	1.00			
WUE	0.92**	0.87**	-0.53*	0.53*	0.90**	0.83**	0.75**	1.00		
SC	-0.64**	-0.53*	0.67**	-0.51*	-0.55*	-0.58*	-0.44*	-0.71**	1.00	
LEI	-0.59*	-0.75**	0.72**	-0.39	-0.58*	-0.76**	-0.75**	-0.70**	0.47*	1.00
FPC	0.65**	0.69**	-0.38	0.72**	0.58*	0.32	0.48*	0.50*	-0.49*	-0.46*
LRD										
Yp	1.00									
Ys	0.66**	1.00								
DTM	-0.82**	-0.74**	1.00							
DLS	0.49*	0.77**	-0.65*	1.00						
GRT	0.71**	0.51*	-0.69**	0.43*	1.00					
RNM	0.72**	0.86**	-0.83**	0.73**	0.85**	1.00				
RWC	0.64**	0.95**	-0.70**	0.73**	0.61*	0.91**	1.00			
WUE	0.69**	0.92**	-0.80**	0.49*	0.64**	0.85**	0.90**	1.00		
SC	-0.87**	-0.49*	0.82**	-0.55*	-0.49*	-0.51*	-0.45*	-0.54*	1.00	
LEI	-0.85**	-0.74**	0.91**	-0.51*	-0.91**	-0.93**	-0.78**	-0.84**	0.72**	1.00
FPC	0.71**	0.90**	-0.80**	0.74**	0.78**	0.98**	0.94**	0.90**	-0.48*	-0.89**

and all other yield components specifically under TDS and LRS indicating that severe drought stress inhibited root more than shoot. Accordingly, the root length can be used as good criterion for screening for drought tolerant lines (Table 8). However, Singh et al. (1999) suggested that different cowpea plant organs (leaf, shoot and root) should be used to screen for drought tolerance.

Visual Observation

The results also clearly prove that the second group of selection criteria is the visual observation traits that contribute significantly to growth and yield in the event of drought. Visual symptoms of DLS, GRT and RNM were the most useful criteria for screening bean genotypes for drought tolerance as these visual observations were positively and significantly correlated with both Yp and Ys under all stresses except Yp of LRS. Drought escape mechanisms as expressed in the days to maturity also could be useful criteria for screening bean genotypes as days to maturity were strongly associated negatively with yield and other traits such as visual observation traits and RWC, WUE and

Table 10. Correlation coefficient of (Yp), (Ys),(PR), (DSl), (TOL), (GMP), (MP), (STI) of bean genotypes as affected by IDS, TDS and LRD stresses and non-stress conditions

Traits	Yp	Ys	PR	DSI	TOL	GMP	MP	STI
IDS								
Yp	1.000							
Ys	0.772**	1.000						
PR	-0.709**	-0.992**	1.000					
DSI	-0.706**	-0.991**	0.999**	1.000				
TOL	-0.620**	-0.962**	0.987**	0.988**	1.000			
GMP	0.808**	0.994**	-0.972**	-0.971**	-0.931**	1.000		
MP	0.821**	0.991**	-0.967**	-0.965**	-0.918**	0.999**	1.000	
STI	0.813**	0.995**	-0.974**	-0.972**	-0.932**	1.000**	0.999**	1.000
TDS								
Yp	1.000							
Ys	0.897**	1.000						
PR	-0.759**	-0.966**	1.000					
DSI	-0.764**	-0.967**	1.000**	1.000				
TOL	-0.403*	-0.766**	0.897**	0.893**	1.000			
GMP	0.951**	0.987**	-0.912**	-0.914**	-0.659**	1.000		
MP	0.963**	0.983**	-0.906**	-0.908**	-0.635**	0.997**	1.000	
STI	0.953**	0.985**	-0.909**	-0.911**	-0.654**	1.000**	0.997**	1.000
LRD								
Yp	1.000							
Ys	0.663**	1.000						
PR	-0.234	-0.852**	1.000					
DSI	-0.240	-0.856**	1.000**	1.000				
TOL	0.274	-0.470*	0.857**	0.853**	1.000			
GMP	0.848**	0.934**	-0.609**	-0.615*	-0.124	1.000		
MP	0.897**	0.877**	-0.500*	-0.506*	0.012	0.990**	1.000	
STI	0.853**	0.923**	-0.585*	-0.591*	-0.098	0.999**	0.991**	1.000

accumulation of FPC traits especially under severe drought stress (TDS and LRS) stresses. Moreover, the early maturing bean cultivars tend to be very sensitive to drought that occurs during the early stages of the reproductive phase (Table 9). The tolerance has been attributed to several drought avoidance mechanisms that include delayed leaf senescence, hastened or delayed reproductive cycle (Gwathmey & Hall, 1992).

Water Relationship

Based on the physiological findings, RWC, WUE and FPC were the most suitable for screening bean lines for drought tolerance as they were positively and significantly correlated with both Yp and Ys under all stresses except Yp of LRS (Table 9). Sc and LEI were correlated negatively and significantly with both Yp and Ys and other indices under stresses except Yp of LRS (Table 9). However, RWC, WUE, Sc and FPC could be good parameter to discriminate bean genotypes under all stresses. Thus, reduction of water loss through improving RWC, WUE, and maintain high reduced leaf conductance, and protecting membrane stability by reducing leaf electrolyte ions, are important parameters could be related to drought tolerance mechanisms. This tolerance has been attributed to several drought avoidance and tolerance mechanisms. Among the important visual and morphological traits that may contribute to drought adaptation is the water use efficiency (WUE), relative water content (RWC) which were identified as important traits in response to drought in some cultivars (Anyia and Herzog 2004; Souza et al. 2004). Lu et al. (1998) have shown remarkable positive correlations between yield increases and increases in stomatal conductance (SC) under stress in Pima cotton (Gossypiumbarbadense) and bread wheat (Triticumaestivum) (Waseem et al, 2006). Water deficit significantly increased the proline content of five cowpea genotypes (Hamidou et al. 2007). RWC was a good parameter to discriminate genotypes of traditional crops under water stress (Slabbert et al. 2004).

Quantitative Drought Resistance Indices

The correlation between quantitative indices of stress

Table 11. Average yield, b-value (Slops), coefficient of determination (r^2), standard deviation (s^2d) and ecovalence value (W) of bean genotypes and their stability indices.

Genotypes	Yield average	b	S^2d	r^2	W
Mib-155	1.866	1.096	0.045	0.829	0.114
Mib-156	1.831	1.587	0.083	0.688	0.121
S-72	1.886	1.456	0.071	0.717	0.316
NSL	1.766	0.159	0.014	0.376	0.126
BFB-141	1.773	0.752	0.017	0.500	0.112
SXB-416	1.745	0.240	0.054	0.426	0.127
Ser-111	1.733	0.718	0.016	0.487	0.301
Ser-88	1.436	2.215	0.151	0.551	0.312
Taiz-305	0.709	0.777	0.018	0.323	0.285
Average	1.638	1.000	0.052	0.544	0.111

Table 12. Correlation coefficients of stability indices for seed yield, (b), S^2d, r^2 and W of bean genotypes.

Traits	Yield average	B	S^2d	r^2	W
Yield average	1.000				
b	0.186	1.000			
S^2d	0.143	0.634**	1.000		
r^2	0.186	0.905**	0.872**	1.000	
W	0.303	0.729**	0.622**	0.662**	1.000

tolerance and Yp and Ys indicated that the stress tolerance index was strongly and positively correlated with Yp and Ys, mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI). However, the correlation coefficient between stress and non-stress yield was 0.772, 0.897 and 0.663 under IDS, TDS and LRS stresses, respectively indicating strong association between Yp and Ys. On the other hand, the correlation of PR, DSI and TOL with Yp and Ys were negative and significant (Table 10).

Saba et al. (2001) concluded that DSI and TOL were not useful indices to select for drought tolerant genotypes in plant breeding programs, because, DSI exhibited negligible heritability and TOL was less heritable than other indices. Therefore they cannot be used in identifying genotypes with both high yield and drought tolerance characteristics. Thus STI, GMP and MP can be used as effective selection criteria as it is operationally and conceptually, much easier to determine seed yield in bean crop in severe stress conditions IDS, TDS, LRS and even in normal condition as reported herein. However, Ishiyaku and Aliyu (2013) reported that DRI and DSI are particulary useful in the classification of genotypes in terms drought tolerance irrespective of their yield potential.

Stability Analysis of Seed Yield

MIB-155, MIB-156, BFB-141, SXB-416 and had highly significant seed yield between 1.745 and 1.866 t/ha, with approximately b-value of 1.00, very low mean square deviation from regression, low eco-valence value and highly significant coefficient of determination. The coefficient of determination was ranged between 42.6% for SXB-416 and 82.9% MIB-156) suggesting that linear regression accounted for 43–83% variation in bean yield (Table 11). Thus, these genotypes performed best across the environments indicating wide adaptability. These genotypes could be introduced to farmers in these agro-ecological zones.

Rank correlation values in Table 12 revealed positive, low and non-significant associations between mean yield and coefficient of regression (b), deviation from regression (s^2d), coefficient of determination (r^2), and ecovalence (W). Coefficient of regression (b) and deviation from regression (s^2d), coefficient of determination (r^2), and ecovalence (W) were positive and highly significantly correlated, thus, indicating that the relative stability ranking of these bean genotypes are consistent when the different stability indices are used separately (Table 12). Similar results were reported by Gebeyehu and Assefa (2003) and Khalifa., et al. (2013) in bean.

CONCLUSION

Our data confirm that the mechanism of drought tolerance of NS-SD genotypes (MIB-154, MIB-155, Ser-72, BFB-141, SXB-416, Ser-111, Ser-88, NSL) was reflecting a balance among escape, avoidance and tolerance while maintaining adequate productivity. However, we can concluded that the most drought tolerant NS-DS genotypes have significant ability to set higher seeds and pods number per plant, accumulating dry matter efficiently and conserve much more water and osmolytes in leaves more than the other counterparts. Drought stress mostly reduced leaf growth and increases dry matter allocation into root fraction, leading to a declining shoot/root ratio. The tolerance of these genotypes has been attributed to several drought avoidance mechanisms that included delayed leaf senescence (DLS), growth recovery tolerance (LRT), grain filling index (GFI), seed production efficiency (SPE), stomatal conductance, and early maturity. As these traits were simple, cheap, and reliable, so they can be used as selection criteria to select drought tolerant lines. Stress tolerance index (STI) was considered as one of the mechanisms **o**f drought tolerance that can be used as selection criteria for both NS and DS conditions. Stability indices analysis proved that genotypes MIB-155, MIB-156, BFB-141, SXB-416 and NSL has high yields with low response indices, therefore, they are the most promising genotypes that can be grown under poor environmental conditions.

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