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DEVELOPMENT OF INTERMITTENT DROUGHT STRESS TOLERANT COMMON BEAN GENOTYPES IN UGANDA

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) varieties that are high yielding and drought-tolerant are crucial in coping with the effects of drought, that is prevalent among small scale producers living in Uganda. The objective of this study was to assess the level of drought tolerance in bean genotypes to be used for the initial development of drought-tolerant genotypes in Uganda. Three local genotypes and five exotic drought-tolerant lines were phenotyped under well-watered and drought-stress conditions. Drought tolerant genotypes were selected basing on high value for the geometric mean for seed yield and low drought susceptibility indices. The exotic lines, SEN 98, SCR48 and SEN 99, emerged superior in these attributes, and in pod partitioning index (PPI) and pod harvest index (PHI). Thus, these genotypes could be useful sources of genes for drought tolerance in the bean breeding programme in Uganda. The local genotype, NABE 15 was similar to the three promising materials for PPI and PHI. Pods per plant and seed weight were the yield components most affected by drought, with reductions of 82 and 78 %, respectively, for SEN 98.

Key Words: Drought tolerance, *Phaseolus vulgaris***,** phenotype

RÉSUMÉ

Les variétés à haut rendement du haricot commun (*Phaseolus vulgaris* L.) qui sont tolérant à la sécheresse sont très importantes pour faire face aux effets néfastes de la sécheresse, auxquels sont confrontés les petits producteurs en Ouganda. L'objectif de cette étude était d'évaluer le niveau de tolérance des écotypes de haricot commun pouvant être utilisées pour un début de création de variétés tolérante à la sécheresse en Ouganda. Trois écotypes locaux et cinq venus d'ailleurs ont été évalués sous différentes conditions de disponibilité en eau ; bien arrosé et non arrosé. Des écotypes tolérants à la sécheresse ont été sélectionnés sur la base de leur rendement en grains en considérant leur moyenne géométrique et de leur faible indice de susceptibilité à la sécheresse. Les écotypes venus d'ailleurs tels que SEN 98, SCR48 et SEN 99 sont les meilleurs de cette sélection, ils présentent également les indices de partionnement (PPI) et de récolte (PHI) les plus élevés. Ainsi, ces écotypes pourraient être utilisés comme sources génétiques de tolérance à la sécheresse dans les programmes d'amélioration végétale en Ouganda. Pour ce qui concerne les PPI et PHI, l'écotype local NABE 15 avait les mêmes performances que les trois écotypes performants venus d'ailleurs, Mais le nombre de graine par gousse et le poids des graines sont très affectés par la sécheresse, avec une baisse de 82 et de 78% respectivement par rapport à l'écotype SEN 98.

Mots Clés: Tolérance à la sécheresse, *Phaseolus vulgaris***,** phénotype

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important dietary protein source that often substitutes for meat and other protein rich animal products which are rarely afforded by the poor (Broughton *et al*., 2003; Haggblade and Dewina, 2010). However, on-farm yields for new varieties is much less than the expected yields of 1.5–2 tonnes per hectare in Africa (CIAT, 2008). Fluctuations in dry bean production and yield per hectare have been reported, despite the increases in area under production (FAO, 2013). On-going efforts in bean research and development in Uganda are targeted at breeding against major biotic stresses. However, drought is becoming more frequent and prolonged due to climate variability (NAPA, 2007). Long dry spells during the rainy season are sufficient to reduce bean production and worse results are expected with prolonged droughts (NAPA, 2007). An annual yield reduction of 300,000 metric tonnes was reported in sub-Saharan Africa (Wortmann *et al.,* 1998). Thus, in light of the current global and regional trends in climate change (EAC, 2011), the development of drought-tolerant crop varieties is more relevant in order to cope with the effects of reduction in water availability during the season (NAPA, 2007). This is, especially important since less than 1% of the arable land in Uganda is under irrigation (Kiiza, 2001).

Plants use various mechanisms to cope with drought stress and these may be classified as drought escape, avoidance and tolerance (Turner *et al*., 2001). In drought escape, the life cycle is shorter and the plant is able to set some seeds to avoid complete crop failure (Acquaah, 2007). Drought avoidance allows exclusion of environmental factor from the plant's tissue through development of an aggressive root system, thick and waxy cuticles or through other leaf modifications (Blum, 2005; Acquaah, 2007). In drought tolerance, the plant employs osmotic adjustment to maintain turgidity (Beebe *et al*., 2013). Drought tolerance is quantitatively inherited, thus it can be estimated by comparing the performance of breeding lines under stress and non-stress conditions (White and Singh, 1991; Asfaw and Blair, 2014).

According to Ramirez and Kelly (1998), drought tolerance is the relative yield of a genotype compared to other genotypes subjected to the same drought stress. As such, direct measurement of seed yield is the most efficient way to screen for drought tolerance (White and Singh, 1991). Ramirez and Kelly (1998) suggested that selection based on high geometric mean seed yield, followed by selection for low drought susceptibility index values are the most effective approaches to select for drought tolerance in beans.

Yield stability under water stress can be attributed to drought escape, root traits, and other plant mechanisms, but the relevance of high levels of photosynthate translocation and partitioning as an effective selection method for improving drought adaptation in common bean is supported by Beebe *et al*. (2013) and Asfaw and Blair (2014).

Some of the Ugandan market-preferred bean genotypes have been bred for resistance to biotic stress; however, information on their tolerance to abiotic stresses like drought is lacking (Nkalubo, 2011). As a coping strategy, drought tolerance has gained significance, both locally and globally, in varietal breeding (UNFCCC, 2007; EAC, 2011). It is, especially important for crops such as common bean that are widely associated with food security and nutrition (CIAT, 2008). In trying to lessen the vulnerability of market-preferred common bean genotypes to drought, the Bean Programme under the National Crops Resources Research Institute (NaCRRI) at Namulonge obtained some drought-tolerant lines from the Centre for International Tropical Agriculture (CIAT) at Kawanda to enhance breeding efforts for drought tolerance. However, these genotypes are neither readily available in Uganda nor adapted to the agro-ecological zones, which are highly variable (Basalirwa, 1995). The objective of this study was to assess the level of drought tolerance in genotypes to be used for the initial development of drought-tolerant bean genotypes in Uganda.

MATERIALS AND METHODS

Study site. The study was conducted in three screenhouses instead of one, due to lack of sufficient space. The temperature and humidity in the screenhouses ranged from 18–36 °C and 45-100%, respectively. Soil water holding capacity was 29 ml 100 g^{-1} fresh soil.

Germplasm. Eight genotypes were used in this study (Table 1); five genotypes originating from CIAT were selected on the basis of yield potential from a field experiment carried out by the National Bean Breeding Programme at Namulonge in Uganda. From breeding activities at CIAT in Colombia, high pod partition index, pod harvest index, low drought susceptibility index and vigorous root systems are among the key traits used to select drought tolerant lines (Beebe *et al*., 2013). The five CIAT genotypes were selected on the basis of expression of these traits. The two local drought-sensitive genotypes preferred by the market in Uganda were provided by the National Bean Programme. In addition, a known check for drought and other bean plant stresses, K132 (CAL, 96), was used as the main control variety in the study. The general characteristics, origin, pedigree and response to drought of the 8 genotypes are outlined in Table 1.

Germplasm establishment and management. Screening for drought tolerance was done twice, from August 2011 to November 2011 and December 2011 to February 2012. A total of sixteen seeds were planted at 3-5 cm depth in a 10-litre dishpan. Seedlings were thinned to 8 at the two-leaf stage. Sandy-clay-loam soil (46:40:13) was used as the growth medium. Nitrogen, phosphorus and potassium (NPK) (20:20:20) fertiliser was applied at the rate of 0.1 g per10 kg of soil in three splits; namely, at planting, flowering and at mid pod-filling. Weeds were uprooted by hand.

The experiments were laid out in a randomised complete block design in a split plot arrangement, with 4 replications in each screen house. In each replicate, watering regime served as the main plot treatment and genotype as the sub-plot treatment. The dishpans were placed on timber planks to prevent water absorption from the floor.

The water-stressed seedlings were supplied with equal amounts of tap-water in late morning hours, according to the watering regimes shown in Table 2. Stress treatments were applied starting from 14 days after planting. The well-watered treatment was irrigated daily throughout the growth cycle. Days between watering were used to simulate cyclic drought stress and the amount of water applied to the stressed treatments was kept constant (Table 2). Watering was carried out after every 6, 9 or 12 days in cycle one and 3, 5 and 7 in the second cycle (Table 2). The same amount of water (l litre) was applied to all the 3 stress levels at the specific watering times.

A soil moisture and pH meter probe (Model: N01-716576, Gothic Arch Greenhouses, P. O. Box 1564 Mobile, AL 36633 USA), which records a value of 1 to 8 when inserted in the soil, was used to control fluctuations of soil water.

Data collection. Data were collected on yield and potential physiological indicators of drought stress, namely (i) fresh leaf weight to calculate relative water content, (ii) leaf rolling and (iii) primary leaf lamina drooping. The study used a 5-point scale where 0 = Not rolled or drooped leaf; 1= shallow V-shaped leaves; 3= deep V-shaped leaves; 5 = fully capped leaves or lamina fully collapsed and wrinkled, and 7 = tightly rolled leaves or lamina fully collapsed and dried (Fig. 1).

Relative water content (RWC) was used to evaluate plant water status during the stress period, at mid-pod filling stage according to Morgan (1986):

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

Where:

FW = weight of two leaves from the second trifoliate leaf from the bottom, freshly cut from the bean plant;

DW = constant weight of the two fresh leaves, cut into sections and dried in an oven at 70 °C; and

TW = weight of the two leaves, cut into sections and left to saturate in water for 24 hours.

In order to distinguish wilting caused by *Fusarium solani f. sp. Phaseoli* from that associated with water stress, plants were closely monitored for root rot infection by visual

TABLE 1. Bean parents, their characteristics, pedigree, origin and drought tolerance in Uganda

Genotypes	Characteristics	Pedigree	Source	Drought response
K 132	Large and red mottled seed Bush growth habit Yield: 1500-2000 kg ha^{-1} Susceptible to bean fly High market preference	Calima-2 x Argentino1	NaCRRI	Sensitive
NABE 15	Small and cream seed Yield: 1800-2000 kg ha^{-1} Bush growth habit High market preference Early maturing Resistant to anthracnose	Kanyebwa x AB 136	NaCRRI	Sensitive
NABE 4	Red mottled seed Yield: 2000-2500 kg ha^{-1} High market preference Tolerant to halo blight Susceptible to bean fly	SUG 47 x CAL 96	NaCRRI	Sensitive
SEN 98	Black seed	(G3834xG4493) x(G4792xG5694)	CIAT	Tolerant
SEN 99	Black seed	(G3834xG4494) x(G4792xG5694)	CIAT	Tolerant
SCR 48	Red seed Resistant to *Bean common mosaic virus* (BCMV)		CIAT	Tolerant
SCN 6	Black seed Resistant to BCMV	(SC15318xFF15280)x(MIB157xMIB222)	CIAT	Tolerant
SCN 9	Black seed Resistant to BCMV	(SC15318xFF15280)x(MIB157xMIB222)	CIAT	Tolerant

NaCRRI = National Crops Resources Research Institute, CIAT = International Center for Tropical Agriculture, BCMV = Bean Common Mosaic Virus

TABLE 2. Watering regimes used to attain different stress levels for drought experiment under screenhouse condition in Uganda

Treatment	No stress	Mild stress	Intermediate stress	Severe stress
Days between watering - Cycle 1	0	6	9	12
Days between watering - Cycle 2	0	3	5	7
Water added per addition (liters)	0.4-0.5	1	1	1

Cycle = A round of screening activity

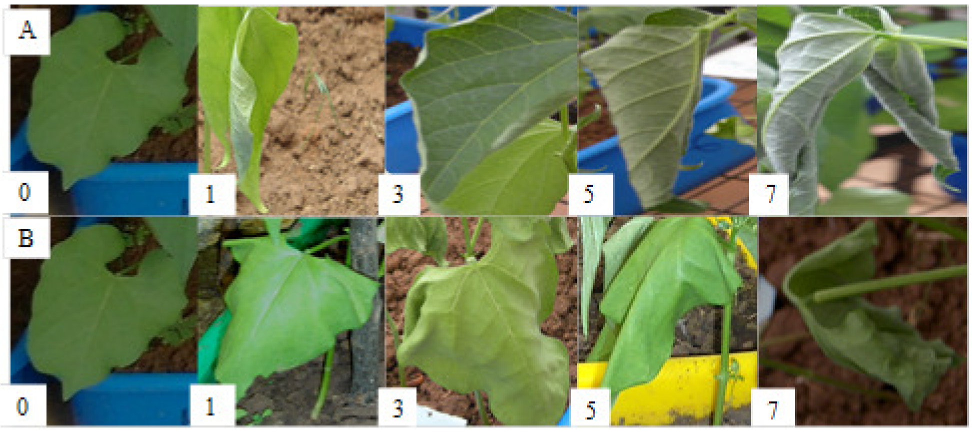

Figure 1. Scale used to score drought stress effect assessment in common bean genotypes. A = leaf rolling, B = primary leaf lamina drooping, 0 = Not rolled / drooped leaf; 1= shallow V-shaped leaves; 3= deep V-shaped leaves; 5 = fully capped leaves / lamina fully collapsed and wrinkled, and 7 = tightly rolled leaves / lamina fully collapsed and dried.

inspection of the stem base for necrosis (Teran and Singh, 2002).

Dry weights of leaves, stems and reproductive structures were collected in destructive sampling, at mid-pod filling (RAO *et al.*, 2007) in 3 of the 12 replications. Just before leaf chlorosis, a stage when the plant had no more flowers and the seeds were clearly defined in the pods (RAO et *al.*, 2007), the above-ground part of one plant per genotype per dishpan was cut using a razorblade; divided into leaves, stems and reproductive structures; and placed in different clean paper bags. The samples were oven-dried at 60 ^{o}C to constant weights prior to determining dry weight.

Sampling for seed yield began at physiological maturity, when 90% of the pods had changed colour from green to yellow (Munoz-Perea *et al.,* 2006). The seeds were oven-dried at 30 ^{o}C for three weeks, before recording seed weight. Seed weight was measured as the average seed weight per plant. Other above-ground dry weights were determined by harvesting all plants in each dish pan at maturity and drying them at 60 ^{o}C for days, to constant weights.

The parameters assessed included pods per plant, seeds per pod, seed dry weight and shoot dry weight. Total shoot dry weight was obtained by summing the weights of all the above-aground parts.

Arising from the measured variables, the following indices used in differentiating drought-tolerant from drought-sensitive parents were calculated as defined in Beebe *et al.* (2013).

$$Harvest\ index\ (HI) = \frac{Seed\ biomass\ dry\ weight\ at\ harvest}{Total\ shoot\ biomass\ dry\ weight\ at\ harvest} * 100$$

$$Pod\ partitioning\ index\ (PPI) = \frac{Pod\ biomass\ dry\ weight\ at\ harvest}{Total\ shoot\ biomass\ dry\ weight\ at\ mid-pod\ filling} * 100$$

$$Pod\ harvest\ index\ (PHI)\ for\ each\ genotype = \frac{Seed\ biomass\ dry\ weight\ at\ harvest}{Pod\ biomass\ dry\ weight\ at\ harvest} * 100$$

$$Drought\ intensity\ index\ (DII) = 1 - \frac{Mean\ yield\ from\ stressed\ environment}{Mean\ yield\ from\ well\ watered\ environment}$$

(Ramirez-Vallejo and Kelly, 1998). Values of DII exceeding 0.70 indicates severe drought.

$$DSI = \frac{1 - \frac{Yield\ from\ stressed\ environment}{Yield\ from\ well\ environment}}{DII}$$

Where:

DSI = Fischer and Maurer drought susceptibility index

GM for seed yield = $\sqrt{WW * DS}$

Where:

GM = Geometric mean, WW = weight of seed from well watered environment, and DS = weight of seed from drought stressed environment.

$$PR = \frac{\text{Yield from well watered environment}}{\text{Yield from stressed environment}} * 100$$

Where:

PR = Percent reduction in yield due to drought stress for each genotype.

Data analysis. Data were subjected to analysis of variance (ANOVA) using GenStat computer package (Release 14.1, PC/Windows 7; VSN International Ltd., 2011). Where ANOVA revealed significant differences, treatment means were separated using Fisher's Protected Least Significant Difference (LSD) test at P<0.05. Simple correlation coefficients among some traits were determined using the mean values for the first and second screening.

In addition, genotypes were ranked according to performance. Drought susceptibility index (DSI), percent reduction (PR) in seed yield and geometric mean were calculated from screenhouse means before being subjected to ANOVA. This is because lower values are expected if calculated from individual plant data since the average of a series of quotients is lower than the quotient of the average of the two variables (stressed and well watered) involved (Professor Paul Gibson, Department of Agricultural Production, Makerere University, personal communication, November 5, 2012).

RESULTS

Genotype performance was influenced by the watering regimes and some plants were killed by severe drought stress imposed before pod set (Fig. 2). The drought intensity indices were very high, ranging from 0.83 to 0.99 (Table 3). Nonetheless, significant (P < 0.05) differences were observed among genotypes in leaf rolling, pod and seed number, and seed weight within watering regimes. The interaction of genotypes by watering and screening cycle was not different except in lamina drooping and pod number (Table 4). The two drought screening experiments were significantly different (P < 0.05) for growth parameters but not for yield and associated parameters. However, genotype performance within screening significantly differed (P < 0.01) except in relative leaf water content, pod partitioning index and dry seed weight. The four watering regimes were also significantly different (P < 0.05) for all parameters (Table 4).

Growth parameters. The performance of genotypes varied under the different conditions of watering regimes, with three of the five CIAT obtained genotypes performing better than the other genotypes (Table 5). The mean performance of the genotypes, SEN 99 (4.2, 4.3) and SCR 48 (4.2, 4.5), were significantly different (P < 0.05) from all the other genotypes for LD-P under intermediate and severe stress conditions. On the other hand, SEN 98 was only different from NABE 4 and SCN 9 for the same trait under intermediate stress. Genotype SEN 98 also had the highest leaf relative water content (37%) that was significantly different (P < 0.05) from that of NABE 4 and K132 under severe drought stress. Leaf roll of SEN 98 was high (4.1) but not significantly different from that of NABE 15 and NABE 4 under severe drought stress.

Yield and associated parameters. Seed yield for SEN 98 was significantly different (P < 0.05) from that of the other genotypes under moderate water stress (Table 5). In addition, genotype SEN 98 followed by SEN 99 and SCR 48 had the highest seed yield averaged across water-stressed treatments. However, only the seed yield for SEN 98 averaged across three water-stressed treatments was significantly different (P < 0.05) from that of SCN 9, NABE 4 and K132 (Table 6). The geometric mean (GM) seed yield for SEN 98 (0.65, 0.32) was also significantly different (P < 0.05) from the GM of SCN 9 (0.2, 0.04) and NABE 4 (0.19, 0.1) under moderate and severe water stress (Table 6). Genotype SEN 98 also had the lowest average yield reduction in seed yield.

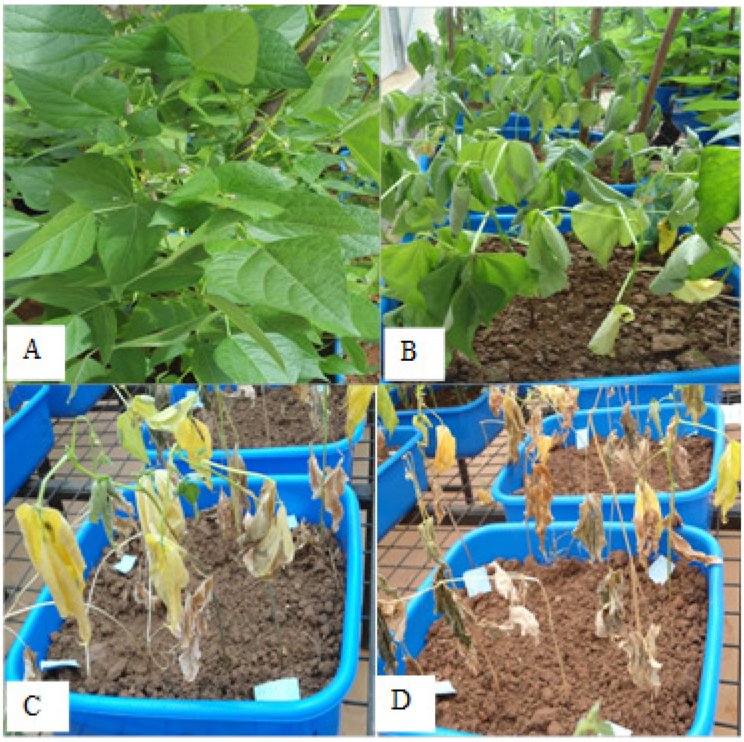

Figure 2. Effect of the 4 watering regimes used for screening parental bean genotypes for tolerance to drought stress in a screenhouse in Uganda. A = well watered, B = moderate stress, C = intermediate stress, D = severe stress.

TABLE 3. Drought intensity index values for varying intermittent drought stress levels used for screening 8 common bean parental genotypes for tolerance to drought

Stress levels	Drought intensity index			
	Moderate drought stress	Intermediate drought stress	Severe drought stress	Mean
Cycle one	0.83	0.96	0.99	0.93
Cycle two	0.87	0.94	0.99	0.93

Cycle = A round of screening activity

Ranked according to performance, SEN 98, SEN 99, SCR 48 and NABE 15 were the best in seed yield, GM, DSI and PR. Genotypes SEN 98 and SEN 99 produced significantly ($P < 0.05$) higher seed per pod than SCN 9, NABE 4 and K132 under moderate water stress. Genotypes SEN 99, SCR 48 and NABE 15 also produced significantly ($P < 0.05$) more pods per plant than SCN 9, NABE 4 and K132 (Table 7).

In the case of the indices that reflect mobilisation of assimilates to the grain, the pod partitioning indices for SEN 98, SCR 48 and SEN 99 were significantly different ($P < 0.05$) from that of NABE 4 and K132, under intermediate water stress (Table 7). Under moderate water stress, SEN 98, SEN 99 and NABE 15 had harvest index values significantly different ($P < 0.05$) from K132, SCN 9 and NABE 4. In addition, the pod harvest index for SEN 98 was significantly different ($P < 0.05$) from that of K132 under intermediate water stress.

TABLE 4. Variance for growth parameters for 8 common bean genotypes grown under varying watering regimes in a screenhouse study in Uganda

Source of variation	Degree of freedom	Growth parameters				Yield and associated parameters				
		Primary leaf drooping	Leaf rolling	Relative water content	PPI	Seed number pod^{-1}	Pod number $plant^{-1}$	Pod harvest index	Harvest index	Dry seed weight (g $plant^{-1}$)
Cycle (C)	1	54.96*	32.96*	33523.4*	7498.6	20.16	0.29	5466.4	3050.2	3.08
Replication/cycle	16 (4)	8.95**	5.17**	1972.8**	5600.0***	4.86*	2.36	9312.8***	1263.7***	1.14
Water	3	577.47*	492.63*	9707.6**	37993.6**	251.54**	246.04***	110218.9*	22071.5**	183.39**
Water x cycle	3	56.46***	39.47***	103.8	1025.4	7.13*	0.45	4192.8	455.1	2.44*
Main plot error	48 (12)	2.93***	1.77***	352.8*	307.7	2.46***	1.85***	2235.8***	269.8***	0.78*
Genotype	7	14.08*	4.00**	156.7	2291.9	5.60	16.19**	4431.2	767.0	6.74$_{**}$
Genotype x cycle	7	3.77***	0.58**	66.5	740.6	1.85**	1.85**	2615.6**	255.0**	0.48
Genotype x replication/C	112 (28)	0.99***	0.25	109.8	366.4	0.63	0.73	1018.0	82.36	0.56
Genotype x water	21	1.31	0.85**	102.1	465.3	1.19*	4.03**	914.3	80.1	3.10**
Genotype x water x C	21	1.01*	0.32	179.3	364.0	0.56	1.41**	824.3	79.70	0.97*
Sub plot error	336 (84)	0.57	0.21	170.4	260.2	0.62	0.62	950.8	79.09	0.55
Total	575 (191)	4.71	3.38	523.2	1159.2	2.33	2.42	1936.3	253.4	1.73

Cycle (C) = A round of screening activity, Water = watering regime, PPI = pod partitioning index , ***, **, * = significant levels at $P < 0.001$, 0.01, 0.05, respectively, Degree of freedom in parenthesis is for leaf relative water content (RWC) and pod partitioning index (PPI) which involved destructive sampling of one replication per screen house at mid-pod filling

TABLE 5. Growth parameters of eight bean genotypes under varying watering regimes in a screenhouse study in Uganda

Genotype	Primary leaf lamina drooping				Leaf roll				Leaf relative water content			
	WW	MOD	INT	SEV	WW	MOD	INT	SEV	WW	MOD	INT	SEV
SEN 98	0.66	2.20	5.00	5.08	0.19	1.04	2.63	4.14	56	44	42	37
SCR 48	0.44	2.75	4.22	4.52	0.13	0.72	2.23	3.94	55	51	30	29
SEN 99	0.32	1.95	4.15	4.34	0.22	0.68	2.53	4.00	60	51	27	26
NABE 15	0.94	3.54	5.38	5.24	0.18	1.18	2.85	4.51	53	48	24	25
SCN 6	0.82	3.14	4.97	5.11	0.15	0.81	2.23	4.30	61	47	36	30
NABE 4	1.13	3.42	5.63	5.18	0.05	0.95	2.42	4.33	56	53	26	23
SCN 9	0.75	3.03	5.58	5.08	0.14	0.73	2.26	3.91	61	50	36	31
K132	0.80	3.67	5.38	5.06	0.16	1.35	3.42	4.73	59	51	29	23
LSD (5%)	0.49	0.69	0.53	0.42	0.14	0.31	0.40	0.33	ns	ns	15.4	13.1

WW = well watered; MOD = moderate intermittent drought stress; INT = intermediate intermittent stress; SEV = severe intermittent drought stress; ns = not significant and Least significant difference (LSD) for within watering regimes was calculated from variance of genotype x replication nested within screening (G x Replication/C)

TABLE 6. Seed yield and associated indicators of water stress for eight common bean genotypes under varying watering regimes in a screenhouse study in Uganda

Genotype	Dry seed weight (Y, g plant^{-1})					DSI	PR	Geometric mean (GM, g plant^{-1})				Rank			
	WW	MOD	INT	SEV	DSavg			MOD	INT	SEV	GMavg	DSI	PR	GMavg	Y, DSavg
SEN 98	3.71	0.95	0.17	0.05	0.39	0.96	89	1.52	0.65	0.32	0.83	1	1	1	1
SCR 48	3.18	0.47	0.26	0.06	0.26	0.98	91	0.98	0.46	0.22	0.55	2	2	3	2
SEN 99	3.31	0.46	0.17	0.04	0.22	0.99	92	1.13	0.52	0.26	0.64	3	3	2	3
NABE 15	2.46	0.37	0.10	0.05	0.17	0.99	92	0.91	0.40	0.21	0.51	3	3	4	4
SCN 6	2.19	0.30	0.14	0.01	0.15	0.99	92	0.54	0.43	0.00	0.32	3	3	5	5
NABE 4	1.64	0.19	0.05	0.03	0.09	1.01	93	0.33	0.19	0.10	0.21	6	6	6	6
SCN 9	1.48	0.16	0.07	0.01	0.08	1.03	96	0.34	0.20	0.04	0.19	8	8	7	7
K132	1.36	0.14	0.05	0.00	0.06	1.02	95	0.39	0.04	0.00	0.14	7	7	8	8
LSD (5%)	0.74	0.13	ns	0.04	0.25	ns	ns	0.27	0.34	0.14	ns				

WW = well watered; MOD = moderate intermittent drought stress; INT = intermediate intermittent stress; SEV = severe intermittent drought stress; ns = not significant; avg = Average dry seed weight of the 3 water-stressed treatments; DSI = Average drought susceptibility index; PR = Average percent reduction in seed yield; Rank 1= most desired, Rank 8 = least desired and Davg SE = “ $((SE_{mod}^{2} + SE_{int}^{2} + SE_{sev}^{2})/9)$

TABLE 7. Yield associated indicators of water stress for 8 common bean genotypes under varying watering regimes in a screenhouse study in Uganda

Genotype	Seed number per pod				Pod number per plant				Pod partition index				Pod harvest index				Harvest index			
	WW	MOD	INT	SEV	WW	MOD	INT	SEV	WW	MOD	INT	SEV	WW	MOD	INT	SEV	WW	MOD	INT	SEV
SEN 98	3.7	1.5	0.9	0.4	4.4	1.1	0.8	0.4	102	39	19	13	86	54	42	29	35	21	13	7
SCR 48	3.2	1.2	0.8	0.3	4.7	1.3	0.6	0.4	96	31	31	13	81	48	36	18	36	18	14	7
SEN 99	3.6	1.8	0.8	0.3	3.7	1.4	0.6	0.3	89	42	31	10	75	57	37	20	32	22	12	6
NABE15	2.9	1.4	0.7	0.4	3.6	1.8	1.0	0.6	69	31	12	9	92	61	37	25	35	21	10	6
SCN 6	3.7	1.2	0.9	0.0	2.6	0.6	0.4	0.1	57	22	17	7	85	37	46	5	32	12	12	2
NABE 4	2.5	0.6	0.5	0.2	2.3	0.6	0.3	0.4	58	18	8	4	77	25	28	18	29	9	7	4
SCN 9	3.5	1.0	0.5	0.1	2.2	0.6	0.3	0.1	54	22	22	6	75	33	37	7	33	12	10	2
K132	2.5	0.7	0.4	0.0	1.7	0.4	0.3	0.0	50	27	4	1	76	37	12	0	28	10	3	0
LSD (5%)	0.67	0.49	ns	0.24	0.74	0.42	ns	0.24	10.7	15.2	11.1	8.2	ns	26.1	22.3	15.0	4.2	6.8	7.3	4.6

WW = well watered; MOD = moderate intermittent drought stress; INT = intermediate intermittent stress; SEV = severe intermittent drought stress; LSD = least significant difference and ns = not significant

TABLE 8. Effect of drought stress indicators and yield of different genotypes in a screenhouse study in Uganda

Genotype	Yield and yield associated drought stress indicators[a]				Growth parameters[b]		
	Pod partitioning index	Seed number per pod	Pod number per plant	Dry seed weight (g plant^{-1})	Relative water content	Primary leaf drooping	Leaf rolling
SEN 98	77(6)	75(3)	82(4)	78(1)	15(1)	-3.4(2)	-2.4(5)
SCR 48	74(3)	77(4)	84(5)	80(2)	18(2)	-3.4(2)	-2.2(1)
SEN 99	69(1)	74(2)	80(2)	82(4)	25(7)	-3.2(1)	-2.2(1)
NABE15	75(5)	71(1)	61(1)	81(3)	21(3)	-3.8(6)	-2.7(7)
SCN 6	74(3)	81(6)	86(7)	83(5)	23(5)	-3.6(4)	-2.3(4)
NABE 4	82(8)	80(5)	81(3)	83(5)	23(5)	-3.6(4)	-2.5(6)
SCN 9	69(1)	85(7)	85(6)	83(5)	22(4)	-3.8(6)	-2.2(1)
K132	79(7)	87(8)	87(8)	84(8)	25(7)	-3.9(8)	-3.0(8)
SED	4	0.3	0.3	0.3	1	0.2	0.1

[a]Expressed as a percentage of well watered; [b]Not expressed as a percentage of well watered; Standard error of the difference (SED) = “ $(SE_{WW}^2 + SE_{DSavg}^2)$; Ranks: 1 = least reduced, 8 = most reduced, are enclosed in the parentheses

Drought stress. As a result of high drought intensity, high differences were observed between well-watered and stressed treatments. Genotypes NABE 15, SEN 99, SEN 98 and SCR 48 had the least reduced number of seed per pod and dry seed weights, ranking in positions 1-4. Genotypes SEN 99 and SCR 48 ranked 1-2 in leaf lamina drooping and leaf rolling; whereas SEN 98 had the lowest reduction in leaf relative water content. Genotype SCN 9 also had the least reduced PPI and LR; however, its dry seed weight, pod number per plant and number of seed per pod were highly reduced (Table 8).

DISCUSSION

The performance of genotypes in well-watered and water stressed environments revealed that that drought can be very intense as reflected by the high values of drought intensity index (DII) (Table 3). Values of DII exceeding 0.70 indicate severe drought (Ramirez-Vallejo and Kelly, 1998). Very intense drought stress is known to interfere with full expression of the genetic potential of a plant. Thus, an attempt was made to lower the drought intensity during the second screening of this study by reducing the days between watering. However, this was not achieved because the second screening was carried out during the dry season when temperatures were higher (18 to 36 ^{o}C). In other words, if days between watering were not lowered, drought intensity would have been significantly higher during the dry season. Nonetheless, significant differences were observed under moderate and intermediate stress for some measured variables.

Only watering regime effect was significantly different for all parameters (Table 4) implying that the four regimes created high variability. Genotypes were significantly different in leaf rolling, pod and seed number, and seed weight within watering regimes signifying diversity. This was expected because the materials had different genetic backgrounds (Acquaah, 2007). The interaction of genotypes by watering and screening was not different except in lamina drooping and pod number. The means from the two screening activities were thus used for data interpretation. Stressed treatments were however not averaged because the genotype and water regime interaction were significant for key yield traits including; seed yield, pod and seed number (Table 4).

Growth parameters: High leaf rolling was exhibited by SEN 98, a genotype which also had the highest dry seed weight under water stress (Table 5 and Table 6). This suggests that leaf rolling in this genotype could have been a drought avoidance mechanism to reduce water loss through the leaves other than a result of water deficit in leaf tissue (Acquaah, 2007; Monsanto, 2012). SEN 98 also had the highest leaf relative water content. On the other hand, the low leaf rolling and drooping obtained in SEN 99 and SCR48 and the high leaf rolling and drooping observed in K132 were indicators of water stress as reflected by their dry seed weights. Leaf traits like leaf rolling and drooping are known to reduce loss of water through transpiration under drought stress (CIAT, 2004; Monsanto, 2012). However, besides the plant's ability to conserve water, these attributes may also result from loss in turgidity resulting from water stress as observed in most genotypes.

Yield and associated variables. Number of pods per plant, followed by dry seed weight were the yield component most reduced by drought (Table 8). Pods per plant and seeds per pod depend on the number of branches and productive pods/seeds generated, thus drought can affect this by altering remobilisation of assimilates to other parts. In this study, many empty pods were produced under drought stress. Water stress at flowering and pod filling resulted into fewer pods that were small and short; with poorly-filled seeds due to limited photosynthetic activity or poor partitioning of assimilates. These findings relate to studies by Leoport *et al.* (2006) and Setegn *et al.* (2010) who reported the number of productive pods per plant as one of the most reduced yield components in legumes phenotyped under water stress. Asfaw and Blair (2014) also reported a reduction in seed per pod and seed weight of common bean. Seed and productive pod number are important parameters because they influence seed yield per plant and are, thus, very crucial in on-farm yield. Dry seed weight under drought stress had high significant positive correlations with pod per plant and suggests that it would be easy to select for both traits at the same time. A similar relationship was observed in the present study between dry seed weight, and seeds per pod, harvest index and pod partitioning index implying that emphasis on selection could be placed on seed yield (weight).

Genotype SEN 98 yielded highly and had the least reduction in seed yield (Tables 6 and 8). Based on yield, this was the most stable genotype under drought stress. Since seed yield is an important factor in commercial bean production, genotypes with low or no seed yield reductions under drought stress would be the most suited for farmers. Considering partitioning of assimilates, SEN 98, SCR 48 and SEN 99 emerged superior to K132 and NABE 4 in pod partitioning index (PPI) and pod harvest index (PHI), which according to Rao *et al*. (2004) and Beebe *et al.* (2008), means that they have a greater ability to mobilise photosynthates to grain under drought stress.

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REFERENCES

Acquaah, G. 2007. Principles of plant genetics and breeding. First Edition. Blackwell Publishing Ltd, Malden, USA; Oxford, UK or Carlton Australia.

Asfaw, A. and Blair, M.W. 2014. Quantification of drought tolerance in Ethiopian common bean varieties. *Agricultural Sciences* 5:124-139.

Basalirwa, C.P.K. 1995. Delineation of Uganda into climatological rain fall zones using principal component analysis. *International Journal of Climatology* 15 (10):1161-1177.

Beebe, S.E., Rao, I.M., Cajiao, I. and Grajales, M. 2008. Selection for drought resistance in common bean also improves yield in phosphorus limited and favourable environments. *Crop Science* 48:582-592.

Beebe, S.E., Rao, I.M., Blair, W. and Acosta-Gallegos, J.A. 2013. Phenotyping common beans for adaptation to drought. *Frontiers in Physiology* 4:1-20.

Blum, A. 2005. Drought resistance, water use efficiency, and yield potential – Are they compatible, dissonant, or mutually exclusive? *Australian Journal of Agricultural Research* 56:1159-1168.

Broughton, W., Hernández, G., Blair, M., Beebe, S., Gepts, P. and Vanderleyden, J. 2003. Beans (*Phaseolus* spp.) model food legumes. *Plant and Soil* 252:55-61.

CIAT (International Center for Tropical Agriculture). 2004. Coping with drought: Strategies to improve genetic adaptation of common bean to drought-prone regions of Africa. CIAT Occasional Publication Series, Addis Ababa, Ethiopia. No.38. pp. 1-38.

CIAT (International Center for Tropical Agriculture). 2008. The impact of improved bush bean varieties in Uganda. Highlights - CIAT in Africa.Cali, Columbia. No.43. Available online: http://webapp.ciat.cgiar.org/africa/pdf/highlight43.pdf. Accessed on 3rd/February/2013.

East African Community (EAC) Secretariat. 2011. East African community climate change. Master Plan 2011-2031, Arusha, Tanzania. pp. 72- 98. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1 &ved=0CB0QFjAA&url=http%3A%2F%2 Fwww.eac.int%2Fenvironment%2Findex.php%3Foption%3Dcom_docman%26task%3Ddoc_downl oad% 26gid%3D180%26Itemid%3D159&ei=1_3NgVJur_MYPaPIX6gfAL&usgAFQjCN_FyUBsQ7Ke_2sXwGLsuH-xDCi2xrQ&sig2=O07heDzEgQs4KadK_F3mldg&bvm=bv.791890_06,d.ZWU. Accessed on 10th November 2014.

Master Plan 2011-2013, Arusha, Tanzania. pp. 72-98.

FAO (Food and Agricultural Organisation). 2013. Statistical Database.http://www.faostat.fao.org/. Accessed on 7th April 2013.

GenStat. 2011. GenStat Release 14.1 (PC/Windows 7). GenStat Procedure Library. Release PL22.1. VSN International Ltd. Rothamsted, UK.

Haggblade, S. and Dewina, R. 2010. Staple food prices in Uganda: Prepared for the COMESA policy seminar on "Variation in staple food prices: Causes, consequence, and policy options", Maputo, Mozambique, 25-26 January 2010 under the African Agricultural Marketing Project (AAMP). pp. 4-5. http://programmes.comesa.int/attachments/186_AAMP%20Uganda%20background%20paper%20(13%20Jan).pdf. Accessed on 4th October 2012.

Kiiza, N. 2001. Rainfall reliability for crop production. Unpublished Project Report (Oct 2001). Department of Civil Engineering, Makerere University, Uganda.

Leport, L., Turner, N.C., Davies, S.L. and Siddique, K.H.M. 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy* 24 (3):236-246.

Monsanto. 2012. Early season drought stress in corn and soybean - WI. Agronomic alert. Technology development and agronomy. pp. 1-2. http://www.aganytime.com/Corn/Pages/Article.aspx?name=Early-Season-Drought-Stress-in-Corn-and-Soybeans-WI&fields=article&article=136. Accessed on 14th July 2014.

Morgan, J.M. 1986. The effect of N nutrition on the water relations and gas exchange characteristics of wheat (*Triticum aestivum* L.). *Plant Physiology* 80: 53.

Munoz-Perea, G.C., Teran, H., Allen, R.G., Wright, J.L., Westermann, D.T. P. and Singh, S.P. 2006. Selection for drought resistance in dry bean landraces and cultivars. *Crop Science* 46:2111-2120.

NAPA (National Adaptation Programmes of Action). 2007. Climate change Uganda National Adaptation Programmes of Action, Kampala, Uganda. pp. 1-71.

Nkalubo, S. 2011. Who will save our beans? In: New vision news paper, Published on January 31, 2011. http://www.newvision.co.ug/D/9/37/745437. Accessed on 4th October 2011.

Ramirez-Vallejo, P. and Kelly, J. 1998. Traits related to drought resistance in common bean. *Euphytica* 99:127-136.

Rao, I.M., Beebe, S., Polania, J., Ricaurte, J., Cajiao, C. and Garcia, R. 2004. Evaluation of drought resistance and associated traits in advanced lines. Annual Report 2004. Project IP-1: Bean improvement for the tropics. CIAT, Cali, Colombia. pp. 5-13.

Rao, I.M., Polania, J.A., Rivera, M. and Ricaurte, J. 2007. Phenotyping common beans for adaptation to drought: Protocol for field and greenhouse evaluation. pp. 1-17. Available online: http://www.flickr.com/photos/ciatevents/sets/72157629659518859/. Accessed on 1st November 2011.

Setegn, G., Heike, W. and Sven, S. 2010. Effects of drought stress on seed sink strength and leaf protein patterns of common bean genotypes. *African Crop Science Journal* 18(2):75-88.

Teran, H. and Singh, S. 2002. Comparison of sources and lines selected for drought resistance in common bean. *Crop Science* 42:64-70.

Turner, N.C., Wright, G.C. and Siddique, K.H.M. 2001. Adaptation of grain legumes (pulses) to water limited environments. *Advances in Agronomy* 71:193-23.

UNFCCC (United Nation Framework Convention on Climate Change). 2007. Climate change: Impacts, vulnerabilities, and adaptation in developing countries, Bonn, Germany. pp. 5-68.

White, J. and Singh, S.P. 1991. Physiology of yield potential and stress tolerance. pp. 501-560. In: van Schoonhoven, A. and Voysest, O. (Ed.). Common bean: Research for crop improvement. CABI, Walingford, UK, and Centro Internacional de Agricultura Tropical, Cali, Colombia.

Wortmann, C.S., Kirkby, R.A., Eledu, C.A. and Allen, D.J. 1998. Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. CIAT Pan-African Bean Research Alliance, CIAT Publication, Cali, Columbia.