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Full Length Research

Physiological Response of Soybean [*Glycine max* L. Merril] Genotypes to Drought-induced Stress: Preliminary Screening for Drought under South Sudan Agro-ecological (Ironstone/Mountains) Conditions

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Drought stress is a major environmental factor that adversely limits the growth and the production of crops. In order to screen 18 soybean genotypes, an experiment was conducted in University of Juba, (CNRES), Department of Agricultural Sciences Experimental Unit with an objective of screening 18 soybean accessions/genotypes for drought tolerance at two separate experiments (non-drought stress and drought stress sites) based on randomized complete block design (RCBD) with three replications. The data were collected on plant height (cm), root length (cm), biological yield (biomass in g), number of pods per plant, number of aborted pods, number of seeds per plant, seed weight per plant (g), Grain yield per plot (2.5 m^2), Harvest index (HI) and 100 seed-weight (g) at harvest. The result showed that drought stress is an important factor in growth and yield reduction especially when drought stress occur at reproductive stages such as initial pod filing, beginning of seed formation and full seed stages is responsible for yield reduction compared to non drought stress conditions. Furthermore, the results also indicated that drought stress affect all the morphological and reproductive parameters and the significant differences exist among the soybean accessions at ($P<0.05$) under both non- drought stress (ND) and drought stress (DS) conditions except, root length under non drought stress and the harvest index under drought stress condition. Drought stress also decreased the plant height and dry weight by 15% and 48.3% respectively and increased the root length by 19.4% and also adversely reduced the reproductive components such as number of pods/plant (44%), number of seeds/plant (58.4%), seed weight/plant (55%), grain yield/plant (60.3%), 100-seed weight (17.4%) and harvest index (24.4%). The most affected parameter by drought stress was the yield/plot by 60.3% reduction. Moreover, the results also indicated clearly that the effect of drought stress on the final yield was due to reduction in reproductive components. Although drought stress had great impact on the final grain yield, some accessions such as TGx 2010–15F, TGx 2006–3F, TGx 2008–4F, TGx 2010–12F, TGx 2008–12F, TGx 2004–3F, TGx 2007–11F were less affected by drought stress as they showed high yield under both non-drought stress (ND) and drought stress (DS) conditions hence exhibit tolerant to drought stress. This clearly indicated that the respond of different accessions to drought stress varies from one accession to another and identify the following TGx 2004–13F, TGx 1987–62F, TGx 1448–2E, TGx 2010–3F, TGx 1485–1D, Local–107 as drought susceptible. It should be noted that, the narrow genetic diversity in the soybean accessions would likely not provide a wider genetic variability in response to drought stress. The latter suggests further research and use of more accessions from other regions or agro-ecological zones.

Keywords: Drought stress, drought tolerance, susceptibility, soybean genotypes/accessions, morphological parameters, harvest index (HI), and reproductive components.

INTRODUCTION

Background

Soybean [*Glycine max* (L.) Merrill] is an annual legume crop that belongs to the family *Fabaceae* which was cultivated as early as the 11th century in china (Hymonwitz and Shurtleff, 2005). It contain 20-22% essential amino acids, 40% protein and 18-22% oil of which 85% is cholesterol free (Malik *et al*., 2006). At present soybean are grown primarily for oil extraction and for use as a high protein meal for animal and poultry feeds (Singh and Shivakumar, 2010) and the soybean seeds contain high content of protein and oil which are used for making nutritious food products such as soymilk, miso, soyflour, soysauce and tofu (Fabiyi, 2006). Soybean also improves soil fertility by fixing the atmospheric nitrogen via symbiotic N_2 fixation and hence reduces the cost for purchasing inorganic N_2 fertilizer (Sinclair and Vadez, 2012). In addition soybean also has a medicinal value by reducing the risk of blood cancer, osteoporosis and heart diseases. Alternatively, Soybean is also reported to be used as raw material in industries for production of biodiesel, cosmetics, pesticides, hydraulic fluid and lubricants (Wanderi, 2012). Furthermore soybean shows a potential of reducing the *Striga hermontica* infestation in rotational system with cereals and it was reported that it increase maize yield by 90% (Carsky *et al.*, 2000).

Soybean was first introduced to the Sudan in 1910 by the Colonial Garden and in 1949 it was introduced into Southwest Sudan to prevent the severe malnutrition in children, pregnant and lactating women and infants (Ibrahim, 2012). In fact, research in soybean started as early as 1925 at Gezira Research Station farm, Agricultural Research Corporation (Ngalamu *et al.*, 2013).

In spite of the various uses and wide adaptability, soybean is very sensitive to environmental condition especially the environmental factors such as; drought stress, salinity and heat stress that affects the growth and grain yield. Although the effect of various environmental factors interferes with the performance of crops, drought is the main limiting factor to soybean yield (Souza *et al.,* 2013). Drought stress is one of the most common environmental stress affecting plant growth and productivity (Boyer, 1982).

From crop production perspective, drought can be defined as inadequate water availability including precipitation and soil moisture storage capacity in quality and distribution during the life cycle of crop plant which restrict the expression of full genetic potential of the plant (Chopra and Paroda, 1986). Drought tolerance is the ability of crop plant to produce its economic product with minimum loss in drought stress environment relative to the water constraint free management (Mitra, 2001). According to Raheja (1966), 36% of the land area is classed as arid to semi-arid receiving only 5-30 Inch of rainfall annually and the rest under goes temporary drought during the crop season.

Breeding for drought tolerance in legume has become a top priority especially in developing nations with low and erratic rainfall and with high incidence of malnutrition (Global Development Program, 2011). Hench those are the areas targeted for drought tolerance crops to minimize loss in yield by drought stress.

The mechanisms of drought tolerance act whenever plants have little or no means to avoid low water potential (Grace *et al*., 1981). According to Mitra (2001), mechanism of drought resistance can be categorized into three; First, drought escape which is the ability of a plant to complete its life cycle before sever soil and plant water deficits developed, secondly, drought avoidance which is the ability of a plant to maintain relative high tissue water potential despite a soil moisture deficit and thirdly, drought tolerance which is the capability of plant to withstand water deficit with low tissue water potential. Less has been known about the genetic mechanisms that control the molecular, physiological and morphological character of crop plant that are responsible for drought tolerance. The drought resistant trait and genes in crop plant is complicated and its expression is determined by the action and interaction of biochemical, physiological and morphological characters. The genes that are responsible for morphological and physiological trait and their location in chromosomes are not identified but their inheritance pattern and nature of gene action have been reported (Mitra, 2001).

According to Turner *et al*. (2001), yield stability under drought condition depends on the mechanism of drought tolerance that takes into consideration the yield variation in terms of trait affecting water use (WU), water use efficiency (WUE) and harvest index (HI) represented by the formula; Yield = $WU \times WUE \times HI$ (Passioura, 1977; Blum, 2009). Deep rooting, osmotic adjustment and early vigor leading to early ground cover are trait associated with WU and WUE that contribute to greater yield through increase in total biomass which is then converted to yield via higher Harvest Index (HI). The sensitive reproductive process and translocation of reserve to grain trait also influence Harvest Index (HI) under drought condition (Bhatia *et al*., 2013).

However many possible means have been tried and proposed by the researchers to improve crops to drought tolerance but less has been achieved due to the following challenges; little knowledge about the physiological basis of yield in drought condition, limitation in technology for systematic phenotyping (Sinclair, 2011), lack of understanding of plant response to sever moisture stress (Burton, 1964), amount of time required to phenotype a large number of individuals (Verbree, 2012) and involvement of multiple genes at genetic level in the initiation of defensive mechanism makes it difficult to fully understand the genetic basis (Quisenberry and McMichael, 1991).

Due to various biotic and abiotic stresses, food productivity is decreasing and therefore minimizing these losses is one of the top priorities to ensure food security under changing climate (Anjum *et al*., 2011). The losses from drought stress can be minimized by developing drought tolerance crop plants in drought prone environments.

However, there is little evidence or data on physiological response of legume (soybean) to drought stress and its implication on growth performance and grain yield under Greenbelt agro ecological zone or elsewhere in South Sudan. This substantiates the original purpose of conducting research in this area of study to provide insight into understanding the effect of drought stress in soybeans.

Objectives of the study

This study was therefore, initiated to address the following objectives;

General objectives

1. To compare the performance of different genotypes of soybean under non-drought stress (ND) and drought stress condition (DS) during off season under irrigation.
2. The present study was undertaken to identify suitable tolerant genotypes for improving yield of soybean under water stress condition in South Sudan especially in drought prone agro-ecological zones.

Specific objective

To screen 18 different genotypes of soybean for drought tolerance such that genotypes with full genetic potential can be recommended as drought tolerance genotypes for improvement and further production in different parts of South Sudan.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted during the 2016 2^{nd} season (August-December) at University of Juba, Department of Agricultural Sciences Experimental Unit, in Jubek State Southern part of South Sudan located at latitude of 31^{o}35417’E, longitude 4^{o}50529’N and altitude 400 m above sea level with the average annual rainfall 650 mm during the period of April and October within the Green belt agro-ecological zone. The soil of the site was sandy clay loam with the pH range of 7.8–8.5. The climate of the locality was tropical wet and dry with the maximum temperature of 35^{o}C in the summer and around 29^{o}C in cool season (University of Juba research data, 2013).

Experimental design for drought stress assay

Two separate experiments non-drought (ND) site and drought stress (DS) site were conducted based on Randomized Complete Block Design (RCBD) with three replications (Gomez and Gomez, 1984) to screen 18 genotypes of soybean [*Glycine max* (L.) Merrill] for drought tolerance. The total size of the field was 16 m × 20 m (320 m^2) and divided in to two blocks with the size of 160 m^2 consisting of 3 replicates each with the distance of 40 cm between the blocks and each replicate consisted of 18 plots making a total of 54 plots per block. The size of the plot was 2.5 m^2 and the distance between the plots was 40 cm. Two rows of soybean seeds were sown manually on the shoulder of the plots at the distance of 60 cm between the rows and 16 cm between the plants. Each plot had 20 hills and 2 seeds were sown per hill at the depth of 2.5–4 cm manually using small pointed stick. Then latter provides plant density of 40 plants per 2.5 m^2.

Experimental materials and procedures

Plant materials

The plant materials used in this experiment consisted of seeds of 17 soybean genotypes obtained from International Institute for Tropical Agriculture (IITA) and one soybean genotype from the local farmer in Juba, South Sudan. The soybean genotypes obtained from IITA were; TGx 1485–1D (Check early), TGx 2010–3F, TGx 1448–2E (Check medium), TGx 2004–10F, TGx 1987–62F(R-C heck), TGx 2007–11F, TGx 2004–13F, TGX 2008–2F, TGX 2007–8F, TGX 2008–4F, TGX 2006–3F, TGX 2008–12F, TGX 2011–3F, TGX 2011– 7F, TGX 2010 – 15F, TGX 2004 – 3F and TGX 2010–12F. Local–107 (local check) obtained from the local farmer in Juba Munuki.

Cultural practices

Land preparation

The shrubs and the plant debris of the previous crop (cowpea) in the field were cleared with hand tools to open up the field for easy operation and both the secondary and primary tillage which include harrowing, leveling, pulverization, making ridges and tilling was done manually using hand hoes, fork hoe and rake. Ropes, meter ruler and pegs were used in the process of making ridges and plot demarcation. The field was layout into blocks and plots, alleyways was left in between the blocks and plots for easy movement (operation). The field was irrigated one day prior to planting to moisten the soil.

Planting

After seed bed preparation and prior to sowing, the field was flooded with water to give maximum moisture in the soil to initiate seed germination. Sowing was done manually on the 14th/09/2016 during off season on the two rows of the plot with the distance of 60 cm between the rows and 16 cm between the plants. Two soybean seeds were sown per hills at the depth of 2.5–4 cm and then provide plant density of 40 plants per plot and seeds started germinating after 3days from the day of sowing and it took one week for all seeds to emerge.

Replanting /Re-sowing

The genotype TGX 1448–2E (Check medium) was re-sown again on 30/09/2016 due to poor germination and hence less than 1% seeds germinated after re-sowing again.

Weeding

In this experiment, weeding was carried out for three times. The first weeding was done after a 14 days from the day of sowing and was done manually with hoe and hand pulling to rogue unwanted weeds like nut grass and coach grass that compete with the seedling. The second weeding was done after 26 days from the day of planting and the last weeding was done after 48 days from the day of planting and thereafter the canopy was large enough to suppress the weeds and it should be noted that herbicides were not used to control weeds in this experiment.

Irrigation, water management and drought stress induction

Before initiation of drought stress, all plants from the both non-drought stress block and drought stress block were supplied with adequate moisture by using flood irrigation system to maintain the soil moisture favorable for plant growth. Drought stress was induced on plants by withholding the irrigation after 30 days from the date of planting when the plants were at the 5th trifoliate leaf development stage. Irrigation was carried on the drought stress (DS) block only once a week (after six days) and on the non-drought stress (ND) block, irrigation was carried after three (3) days and when necessary to avoid water deficit. And during the period of the experiment, rainfall was experienced from September to November.

Pests and diseases control

In this experiment, no chemicals were used to control pests and diseases, however, pests and disease were controlled mechanically by removing the suspected alternative host plant for pests and diseases around the field and maintaining field sanitation to keep out pests and diseases. In addition occurrence of pests and diseases were recorded.

Harvesting

Harvesting was done when most of the pods turned brown (matured) and it started on 21/12/2016 with the early maturity genotypes and ended on 31/12/2016 with the late maturity genotypes. Harvesting was done manually by uprooting the whole plants from the field and tied in bundles and one sample plant selected randomly from each plots were tied inside the plastic bags, sun-air dried on plastic sheets ($3 \times 5\ m^2$) for obtaining other reproductive parameters (measurement); 100 seed weight, yield/plot, number of seed /plant and biomass (dry weight, DW).

Seed processing

The pods of the harvested plants were threshed manually to obtain the seeds and the seeds were winnowed, sundried to lower the seed moisture content, weighted and packed in a box for temporary storage.

Data collection

The data collected was based on the following parameters described below at harvest stage.

Parameters:

Morphological parameters

Plant height (cm)

One plant was selected randomly from each plot at harvest stage. Plant height (cm) was measured using a tape measure from a point immediately above the soil surface to the top of the plant and then the mean of height per plant was obtained from the average of the single plants collected from each replicate.

Root length (cm)

From the randomly selected plant from each plot three (3) replications per accession, the root length were measured with tap measure from the point below the soil surface to the tip of the root and then the mean length per plant was obtained in centimeter (cm) at harvest.

Biomass (Dry weight, DW)

The whole plants were uproot from each plot three (3) replications per accession, collected, sun- air dried on plastic sheets (3x5 m^2) in the greenhouse and weighted to obtain dry weight (DW).

Reproductive components

Number of pods per plant

Number of pods for the randomly selected plant from each plot three (3) replications per accession was counted at harvest stage and the mean number of pods per plant was obtained from the average of the single plants sampled from each replicate of the experimental unit (plot).

Number of aborted pods per plant

Number of aborted pods from randomly selected plants was counted at harvest from each plot three (3) replications per accession and the mean number of aborted pods per plant was obtained from the single plants collected from each replicate.

Number of seeds per plant

The number of seed was counted from the randomly selected plant from each plot three (3) replications per accession at harvest after the pods were threshed and the seeds per plants were obtained.

Seed weight per plant (g)

From the randomly selected plants 3 reps per accession at harvest, the pods were threshed and the seeds were obtained and weight using electric weighing machine and mean weight per plant was obtained in grams (g).

Seed yield per plot (g)

The whole plant from each plot were harvested from the field, sun –air dried, then the pods were threshed and the seeds were obtained and weight using electric weighing machine and mean weight per plot was obtained in grams (g).

100-seed weight (g)

A sample of 100 seeds was taken randomly from yield of each plot and then weighed to determine 100-seeds weight per each treatment.

Harvest index (HI) (%)

The Harvest Index was calculated using the formula;

HI = $\frac{seed\ yields\ (Grain\ yield)(g)}{Biomass\ (biological\ yield)(g)} \times$ **100.** (Yagoub *et al*., 2015)……….…………Equation 1

Drought intensity index (DII)

Drought Intensity Index was used to qualify the genotypes or accession to drought stress tolerance and it is calculated from the formula; **(DII**$= 1 - \frac{Xd}{Xp}$ **)** …………………Equation 2

Where,

DII = Drought Intensity Index

X_d = Mean yield average across line under stress

X_p = Mean yield average across line under non- stress condition

The DII values exceeding 0.7 indicate the severity of drought condition.

Ranking was done based on yield reduction due to water stress

To determine the most desirable drought tolerant genotype, all soybean genotypes were ranked on the basis of their yield reduction due to water stress over non-stress (Chowdhury *et al.,* 2016).

Statistical Analysis

Data were subjected to Duncan's multiple range test (DMRT) (P < 0.05) for mean separation of the soybean genotypes using the software package (XLSTAT System, 2015) and Excel software was used to construct the graphs.

RESULTS

Drought stress is the major environmental factor affecting plant growth and physiology. The effect of drought stress on plant growth parameters (plant height, root length and biomass (dry weight), reproductive parameters (number of pods), yield parameters (number of seeds/plant, seed weight/plant, 100–seed weight, grain yield/plot, harvest index) and drought stress intensity index were presented as means are separated by DMRT (P < 0.05). The result revealed that all growth, reproductive and yield component were adversely affected by drought stress.

Table 1: Means comparison of plant height, root length and dry weight (biomass) of soybean accessions in non-drought (ND) and drought stress (DS) conditions.

			Means			
Accession	**PH (cm)**		**RL (cm)**		**DW/P (g)**	
	ND	**DS**	**ND**	**DS**	**ND**	**DS**
TGx 1485-1D	36.33fg	32.33cd	32.33a	34.67abc	625.83ab	135.00bc
LOCAL-107	36.33fg	33.33bcd	26.00a	30.67abc	876.10a	136.40bc
TGx 2010-3F	73.33ab	58.67a	25.00a	29.33bc	585.00ab	171.13bc
TGx 1448-2E	30.27g	28.33d	21.87a	30.30abc	72.30b	17.87c
TGx 2004-10F	81.33a	53.00abc	26.67a	30.43abc	855.30a	288.27abc
TGx1987-62F	66.00abcd	39.00abcd	33.17a	41.03ab	607.50ab	135.70bc
TGx 2007-11F	47.33cdefg	39.33abcd	29.17a	38.17abc	539.47ab	286.70abc
TGx 2004-13F	72.67ab	52.17abc	25.80a	32.57abc	924.67a	243.23abc
TG x 2008-12F	54.83bcdef	49.17abc	25.33a	34.50abc	445.80ab	417.33ab
TGx 2007-8F	53.33bcdefg	51.33abc	23.33a	24.67c	896.7a	369.40abc
TGx 2008-4F	40.18efg	38.67abcd	24.67a	28.00bc	540.20ab	360.13abc
TGx 2006-3F	71.67abc	58.33a	25.33a	43.33a	701.93ab	541.53a
TGx 2008-2F	54.83bcdef	51.83abc	30.50a	40.00ab	855.20a	599.50a
TGx 2011-3F	55.33bcdef	56.00a	33.00a	36.00abc	640.07ab	412.80ab
TGx 2011-7F	41.83defg	39.67abcd	30.33a	38.67ab	419.50ab	254.20abc
TGx 2010-15F	61.67abcde	57.33a	27.67a	29.67abc	533.53ab	489.67ab
TGx 2004-3F	56.00bcdef	55.00a	28.67a	32.00abc	480.17ab	456.20ab
TGx 2010-12F	61.33abcde	53.53ab	28.67a	40.00ab	290.00ab	274.33abc

Keys: ND = Non-drought stress, DS = Drought stress, PH = Plant height (cm), RL = Root length (cm), DW = Dry weight (biomass) (g); Similar letters in each column shows non-significant difference according to DMRT (Duncan's Multiple Range Test) at 5% level.

Table 2: Effect of drought stress on the plant height, root length and dry weight of soybean accessions.

Treatment	Plant height (cm)	Root length (cm)	Dry weight (g)
Non drought stress	55.23	27.64	604.93
Drought stress	46.95	33.00	312.62
Decrease (%)	15 (%)		48.3 (%)
Increase (%)		19.4 (%)	

The increase and decrease mean percentage shows that there is sharp increase (19.4%) of root length in response to drought stress. Plant height and the dry weight (biomass) are adversely affected by drought stress.

3.1 Plant height (cm)

The result for plant height (PH) presented in (Table 1) Showed that non - drought stress (ND) had significant difference among the accessions in plant height due to the effect of genotype and it also indicated that, accession TGx 2004–10F (81.33 cm) and TGx 2004–13F (72.67 cm) had the highest plant height while accession TGx 1448–2E (30.27 cm) had the lowest height. Under drought stress (DS) there was also significant difference (P<0.05) recorded among the accessions due to their respond to drought stress and accession TGx 2010–3F (58.67 cm), TGx 2006–3F (58.33 cm), TGx–2010–15F (57.33 cm), TGx 2011–3F (56.00 cm) and TGx 2004–3F (55.00 cm) had the higher plant height and accession TGx 1448–2E had the lowest height. Therefore drought stress caused up to 15 % reduction in plant height (Table 2). This reaction can be caused by mechanism of drought tolerance. When plants are exposed to drought stress, cell enlargement, cell wall and synthesis enzymes are reduced and growth and plant height are decreased, consequently.

4.2 Root length (cm)

Mean root length comparison (Table 1) showed that the accessions under non-drought (ND) stress had no significant differences, all the accessions had the similar root length as under ideal condition the soybean roots grow on the top inches of the soil. The result (Table 1) indicated the significant differences when the accessions are subjected to drought stress. Under drought stress (DS) condition, TGx 2006–3F had the longest root length (43.33 cm) and the shortest root length was obtained in the accession TGx 2007–8F (24.6 cm). Due to the effect of drought stress, the root length was increased by 19.4% deeper under drought stress condition compared to non drought stress condition (Table 2). It is evident that increase in Root length suggested a mechanism of drought tolerance in soybean. The drought stress promotes the expansion of the root system to reach additional deeper moisture zones in the soil profile.

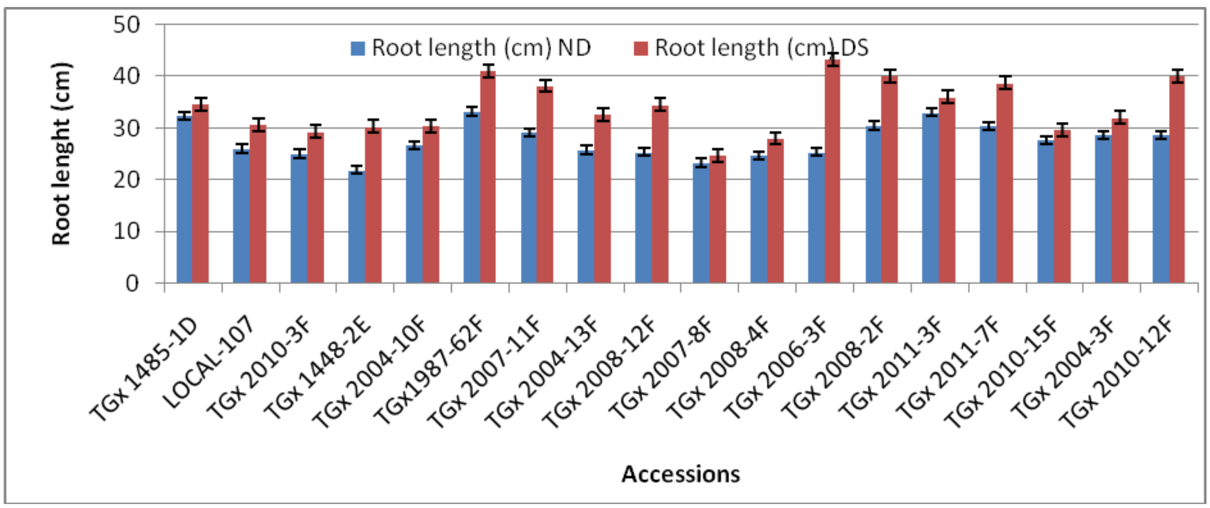

Figure 2: Performance of soybean accessions on the root length (cm) under non-drought (ND) and drought stress (DS) condition**.**

Dry weight /plot (Biomass) (g)

Table 1 also showed the significant differences (p<0.05) among the accession in non-drought stress (ND) condition which is due to the effect of genotype and the highest dry weight was recorded in TGx 2004–13F (924.67 g) followed by TGx 2007–8F (896.7 g), Local–107 (876.10 g), TGx 2004–10F (855.30 g) and TGx 2008–2F (855.20 g) while the lowest dry weight belongs to TGx 1448–2E (72.30 g) and others are similar. The result presented in (Table 1) also indicated that the significant differences exist (P<0.05) among the accessions subjected to drought stress (DS) and the highest dry weight was related to TGx 2008–2F (599.50 g) and TGx 2006–3F (541.53 g) while the lowest was recorded in TGx 1448–2E (17.87 g). The drought stress caused up to 48.3% reduction in the dry weight of soybean when subjected to drought stress condition.

(Table 2) The drought stress inhibits the dry matter production through its inhibitory effect on leaf expansion, leaf development and stem enlargement which consequently reduce the dry weight.

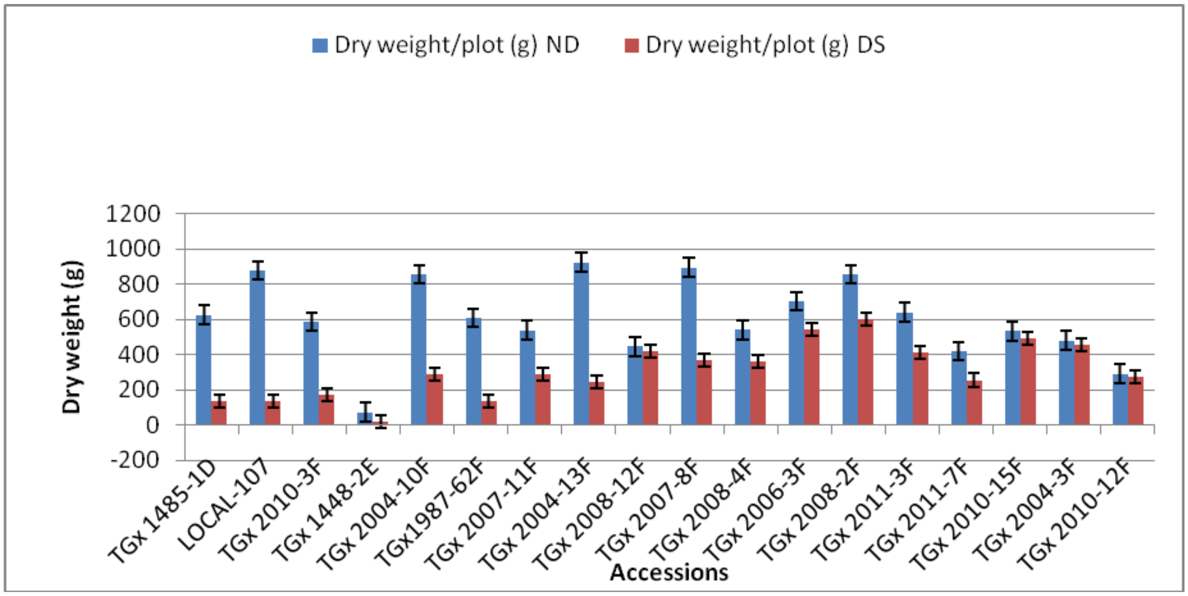

Figure 3: Performance of soybean accessions on dry weight under non-drought (ND) stress and drought stress (DS) condition.

Table 3: Means comparison of number of pods per plant, number of aborted pods per plant, number of seeds per plant and seed weight per plant of soybean accessions in non-drought stress (ND) and drought stress (DS) sites.

Accession	Means							
	NP/PL		NAP/PL		NS/PL		SW/PL	
	ND	DS	ND	DS	ND	DS	ND	DS
TGx 1485-1D	187a	56ab	22abc	7b	278a	54abc	32.67a	6.00bc
Local-107	130ab	54ab	9bc	14ab	188ab	29c	25.23ab	4.23c
TGx 2010-3F	118ab	62ab	12bc	17ab	169ab	54abc	25.23ab	6.73bc
TGx 1448-2E	137ab	55ab	44a	14ab	155ab	42bc	10.83b	4.07c
TGx 2004-10F	165ab	42b	21bc	9b	198ab	34c	23.97ab	4.80c
TGx1987-62F	153ab	52ab	7bc	8b	188ab	47bc	22.30ab	5.87bc
TGx 2007-11F	144ab	117a	29abc	42a	193ab	126ab	22.50ab	16.6ab
TGx 2004-13F	153ab	78ab	28abc	18ab	171ab	53abc	24.13ab	7.57abc
TGx 2008-12F	71b	68ab	9bc	12b	79b	63abc	13.47ab	9.50abc
TGx 2007-8F	100ab	90ab	25abc	24ab	107b	51bc	15.57ab	8.40abc
TGx 2008-4F	124ab	119a	19bc	15ab	150ab	131ab	19.83ab	16.30ab
TGx 2006-3F	124ab	76ab	32ab	6b	81b	66abc	12.47b	11.80abc
TGx 2008-2F	117ab	60ab	15bc	10b	152ab	56abc	19.70ab	8.90abc
TGx 2011-3F	119ab	67ab	8bc	11b	181ab	62abc	21.63ab	7.43abc
TGx 2011-7F	85b	73ab	5c	33ab	138ab	107abc	16.93ab	13.37abc
TGx 2010-15F	143ab	102ab	26abc	20ab	199ab	140a	25.47ab	18.80a
TGx 2004-3F	105ab	48b	11bc	5b	144ab	54abc	17.90ab	8.03abc
TGx 2010-12F	84b	80ab	13bc	32ab	118b	103abc	14.40ab	13.60abc

Keys: ND = Non-drought stress, DS = Drought stress, NP/PL = Number of pods per plant, NAP/PL = Number of aborted pods per plant, NS/PL = Number of seeds per plant, SW/PL = Seed weight per plant; Similar letters in each column shows non-significant difference according to DMRT (Duncan Multiple Range Test) at 5% level.

Table 4: Effect of drought stress on number of pods per plant, number of seeds per plant and seed weight per plant of soybean accessions

Treatment	No of pods	No of seeds/plant	Seed weight/plant
Non drought stress	126	161	20.11
Drought stress	71	67	9.14
Decrease (%)	44%	58.4%	55%

Number of pods/plant

Result of mean comparison (Table 3) showed that both non-drought (ND) stress and drought stress (DS) had significant differences ($p<0.05$) among the accessions on the number of pods/plant and the result also indicated that the highest number of pod was obtained from TGx 1485 –1D (187 pods) and the lowest was recorded in TGx 2008–12F (71 pods), TGx 2010–12F (84 pods), TGx 2011–7F (85 pods) and the rest are all similar under non-drought (ND) stress condition meanwhile under drought stress (DS) condition, the highest number of pods was obtained for TGx 2008–4F (119 pods) and TGx 2007–11F (117 pods) and the lowest was related to TGx 2004–10F (42 pods) and TGx 2004–3F (48 pods) , the rest are all similar. Table 4 showed that the drought stress decreased the number of pods/plant by 44%. The number of pods is reduced especially during flowering and pod filling stage as a result of flower abortion, embryo abortion and reduced nodes due to drought stress.

Number of aborted pods/plant

The results in (Table 3) indicated that both non-drought stress (ND) and drought stress (DS) had significant differences among the accessions in the number of aborted pods/plant and the highest number of aborted pods was recorded in the accession TGx 1448–2E (44 pods) and the lowest was obtained in the accession TGx 2011–7F (5 pods) under non-drought stress (ND) condition meanwhile under drought stress (DS), the highest number of aborted pod was recorded in the accession TGx 2007–11F (42 pods) and the lowest was recorded in the accessions TGx 2004–3F (5 pods). The result showed that the higher number of aborted pods recorded in some accessions under drought stress condition could be related to the effect of drought stress occurring during early pod filling stage which leads to abortion of immature pods. However, the numbers of aborted pods in most of the accessions are higher in the non drought stress condition compare to the drought stress condition which could be attributed to the impact of the insect pest damage in the non drought stress condition as large number of insect pests was observed under the non drought stress condition.

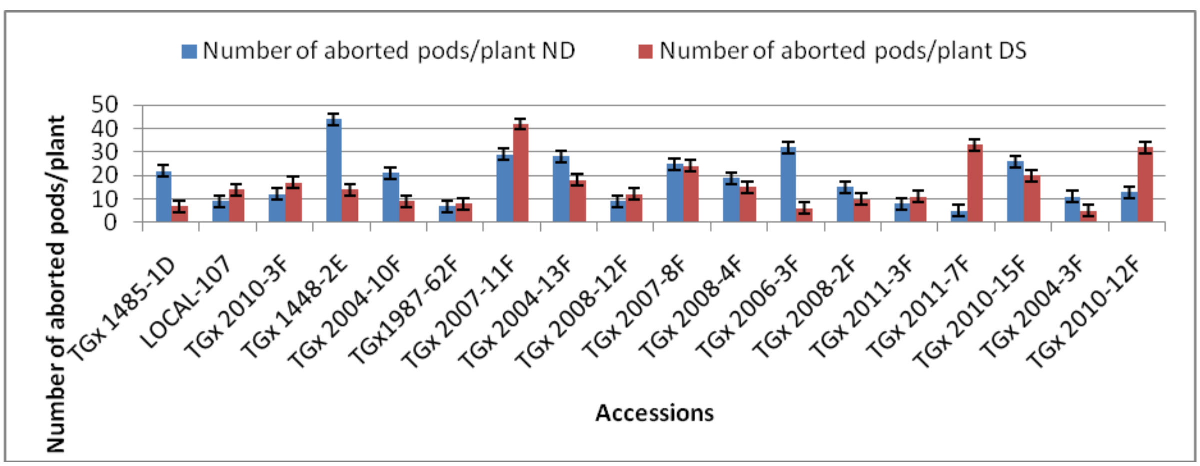

Figure 5: Performance of soybean accessions on the number of aborted pods/plant under non-drought (ND) stress and drought stress (DS) conditions.

Number of seeds/plant

The values obtained for yield component (Number of seeds/plant (Table 3) showed that non-drought stress (ND) had a significant differences at ($p<0.05$) among the accession on the number of seed/plant due to the effect of genotype and the highest number of seed/plant was recorded in TGx 1485–1D (278 seeds) while the lowest number of seeds was obtained in TGx 2008–12F (79 seeds), TGx 2006–3F (81 seeds), TGx 2007–8F (107 seeds) and TGx 2010–12F (118 seeds). Under drought stress (DS) condition, a significant difference at ($p<0.05$) among the accession was also shown due to the effect of drought stress on the accessions. The highest number of seeds was obtained in TGx 2010–15F (140 seeds) and the lowest was related to Local–107 (29 seeds) and TGx 2004–10F (34 seeds). Table 4 indicated that the number of seeds/plant was drastically reduced by 58.4% which might be attributed to the adverse effect of drought stress on the eighteen (18) accessions. The drought stress occurring during flowering and early pod development shorten the period of pod filling hence significantly reduced the number of seeds.

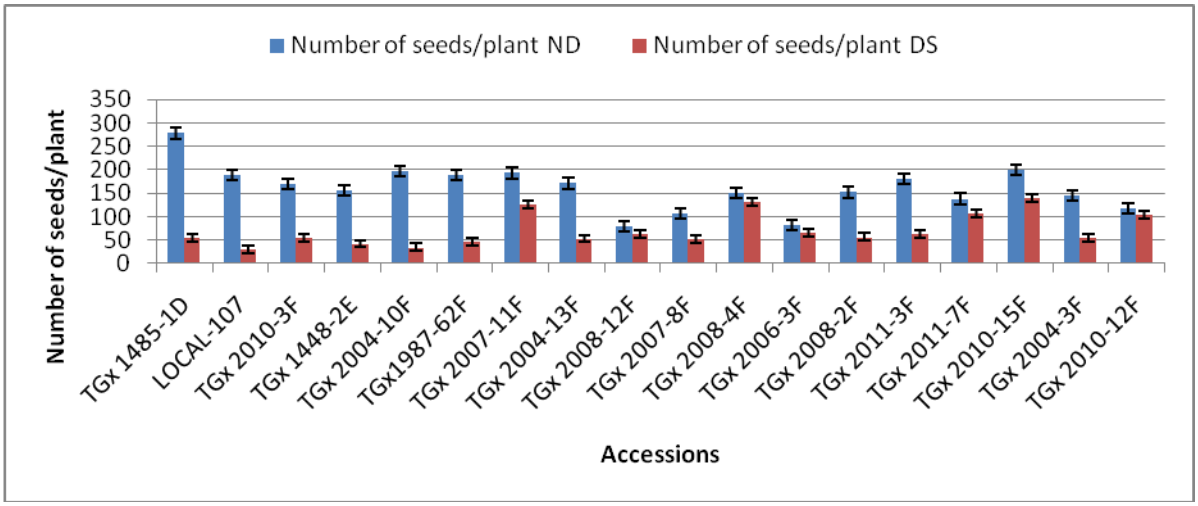

Figure 6: Performance of soybean accessions on number of seeds/plant under non-drought (ND) and drought stress (DS) conditions.

Seed weight/plant

The mean comparison (Table 3) on seed weight/plant showed that both non-drought stress (ND) and drought stress (DS) condition had the significant differences in the seed weight/plant among the accessions due to the effect of genotype and drought stress respectively. Under non-drought (ND) stress the highest seed weight was obtained in TGx 1485–1D (32.67 g) and the lowest seed weight was recorded in TGx 1448–2E (10.83 g) and TGx 2006–3F (12.47 g) while when the accessions are subjected to drought stress (DS) condition the highest seed weight was recorded in TGx 2010 – 15F (18.80 g) and the lowest seed weight was related to TGx 1448–2E (4.07 g) followed by TGx 2004–10F (4.8 g) and Local–107 (4.23 g). Interestingly, seed weight/plant followed the same trend as in the number of seeds/plant in that drought stress caused 55% reduction in the seed weight at harvest (Table 4). The stressed soybean often mature earlier which shorten the grain filling period causing reduced seed weight and yield.

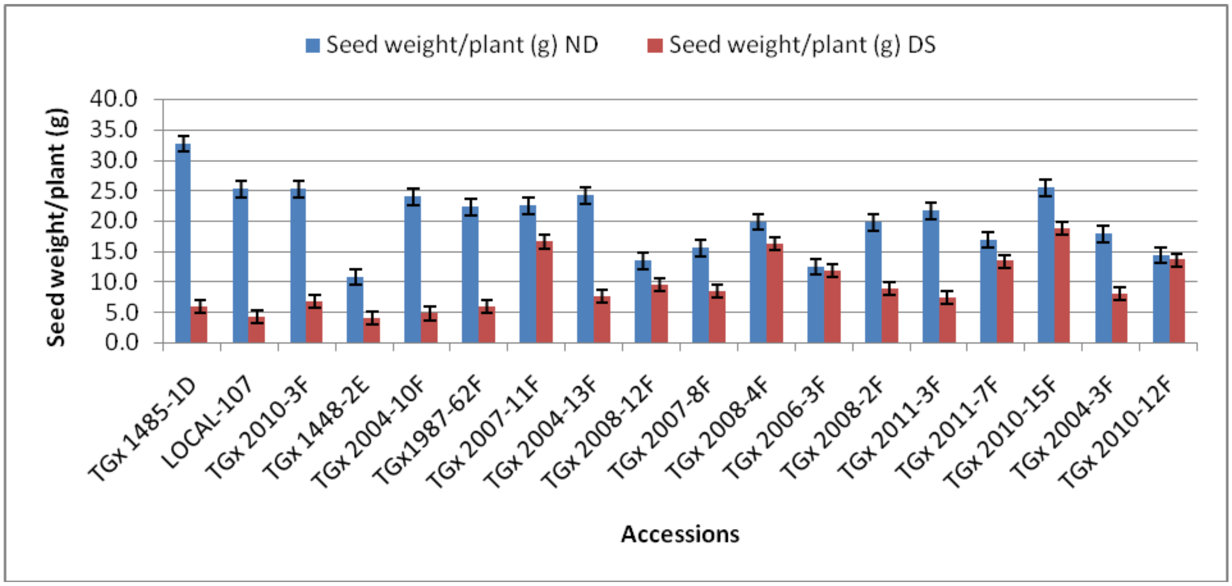

Figure 7: Performance of soybean accessions on seed weight/plant under non-drought (ND) and drought stress (DS) condition

Table 5: Means comparison of yield per plot, 100–seed weight and harvest index (HI) of soybean accessions in non-drought (ND) stress and drought stress (DS) sites

	Means					
Accession	**Y/P (g/plot) m^2**		**100-SW (g)**		**HI (%)**	
	ND	**DS**	**ND**	**DS**	**ND**	**DS**
TGx 1485-1D	279.57ab	44.17abc	14.77ab	10.37bcd	44.37a	31.13a
LOCAL-107	354.33a	34.20bc	16.93a	10.10cd	40.57abc	28.20a
TGx 2010-3F	230.03ab	36.30bc	15.57a	10.53bcd	39.40abc	16.80a
TGx 1448-2E	23.17c	3.80c	7.70c	7.27d	31.83abcd	22.17a
TGx 2004-10F	203.67abc	70.13abc	12.60ab	10.03cd	23.57d	21.00a
TGx1987-62F	189.20abc	52.60abc	10.83bc	7.30d	31.00abcd	25.30a
TGx 2007-11F	164.60abc	87.07abc	13.63ab	10.53bcd	33.50abcd	28.43a
TGx 2004-13F	206.50abc	61.20abc	14.97ab	10.20bcd	26.30cd	25.10a
TGx 2008-12F	168.03abc	101.44abc	15.30ab	14.23ab	34.33abcd	26.27a
TGx 2007-8F	258.33ab	104.10abc	15.37ab	13.20cd	29.53bcd	27.63a
TGx 2008-4F	170.43abc	108.33ab	15.17ab	13.17cd	31.27abcd	28.87a
TGx 2006-3F	193.17abc	141.33a	16.88a	15.61a	29.08bcd	26.77a
TGx 2008-2F	272.50ab	132.13ab	14.73ab	12.30abc	31.833abcd	24.47a
TGx 2011-3F	216.4abc	86.17abc	12.90ab	10.37bcd	33.83abcd	20.50a
TGx 2011-7F	161.0abc	79.30abc	13.70ab	11.37bcd	41.83ab	28.20a
TGx 2010-15F	138.83bc	112.27ab	13.60ab	13.40abc	26.67cd	23.67a
TGx 2004-3F	181.97abc	97.40abc	13.67ab	12.40abc	37.40abcd	21.00a
TGx 2010-12F	125.90bc	80.13abc	12.93ab	12.60abc	31.97abcd	27.43a

Keys: ND = Non drought stress, DS = Drought stress, Y/P =Yield per plot (g/plot), 100–SW; 100 seed weight, (g) and HI = Harvest Index (%); Similar letters in each column shows non-significant difference according to DMRT (Duncan's multiple Range Test) at 5% level.

Table 6: Effect of drought stress on yield per plot, harvest index and 100–seed weight of soybean accessions

Treatment	Yield per plot(g/plot)	100 – seed weight (g)	Harvest Index (%)
Non drought stress	196.5	13.8	33.2
Drought stress	77.96	11.4	25.1
Decrease (%)	60.3 %	17.4%	24.4%

Yield/plot (g)

The result for grain yield (Table 5) indicated that the non-drought stress (ND) condition had significant differences (P<0.05) among the accessions due to the effect of genotype. The highest grain yield was obtained in Local–107 (354.33 g) and the lowest grain yield was related to TGx 1448–2E (23.17 g). The significant differences also existed among the accessions under drought stress (DS) due to the effect of drought stress which reduced the grain yield by 60.3% (Table 6) and the highest grain yield was recorded in TGx 2006–3F (141.33 g) and the lowest grain yield was related to TGx 1448–2E (3.80 g). Drought stress at the reproductive stage reduced the crop yield by decreasing the seed yield and yield components. The reduction could be attributed to the accelerated days to flowering, shorter grain filling duration and lower accumulation of dry matter

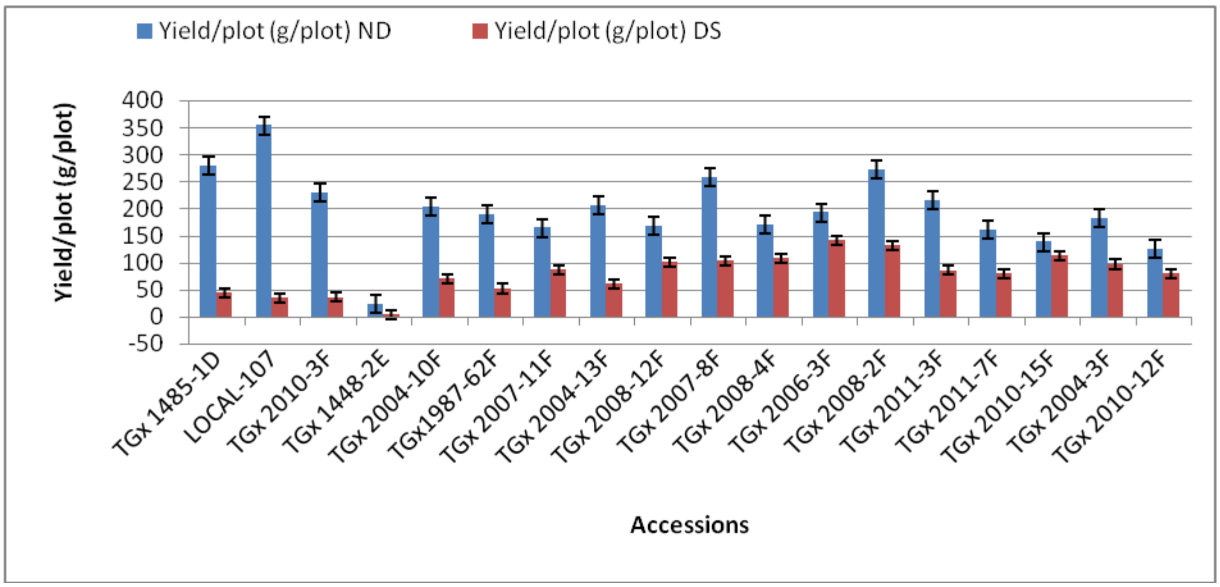

Figure 8: Performance of soybean accessions on the yield/plot under non-drought (ND) and drought stress (DS) condition.

100–seed weight (g)

The mean comparison on the 100–seed weight (Table 5) showed that non-drought (ND) stress condition had significant differences among the accessions due to the effect of genotype and the highest 100–seed weight was obtained in the accessions Local–107 (16.93 g) followed by TGx 2006–3F (16.88 g) and TGx 2010–3F (15.57 g) and the lowest 100– seed weight was recorded in the accession TGx 1448–2E (7.70 g) and the rest are similar. The drought stress (DS) condition also showed significant differences (P<0.05) among the accessions as the effect of drought stress reduced the 100–seed weight by 17.4% (Table 6). The highest 100–seed weight was obtained for accession TGx 2006–3F (15.61 g) and the lowest 100–seed weight was obtained for accession TGx 1448–2E (7.27 g) and TGx 1987– 62F (7.30 g). The grain filling period is shorten by the drought stress which may results in to formation of smaller, shrinkage seeds with a lower seed weight.

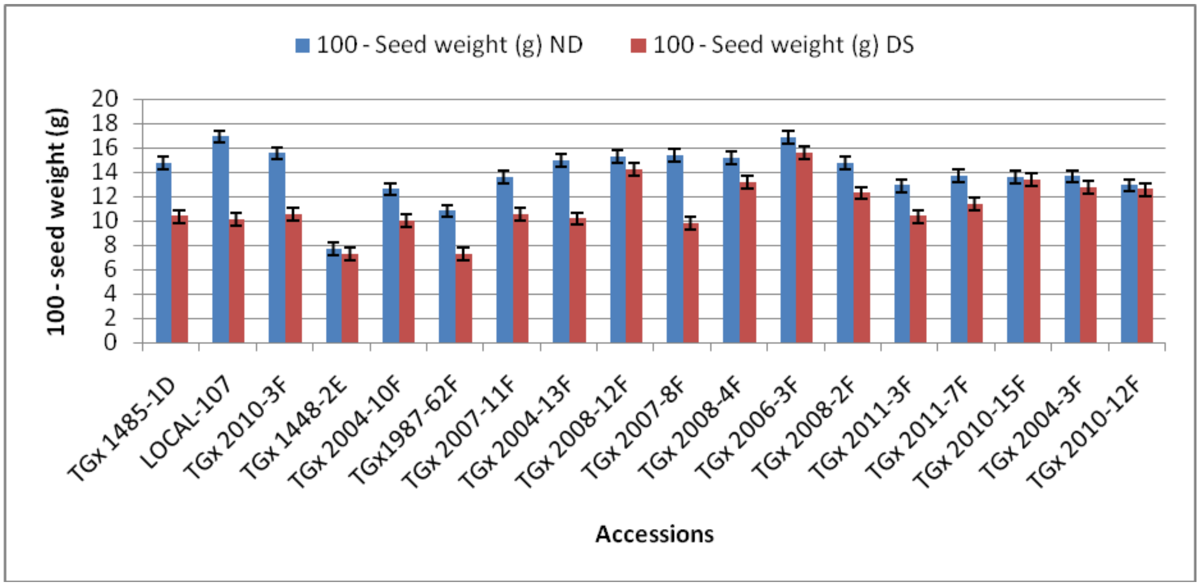

Figure 9: Performance of soybean accessions on 100–seed weight under non-drought (ND) and drought stress (DS) condition.

Harvest index (HI %)

$$\mathbf{HI} = \frac{\textit{seed yields (Grain yield)(g)}}{\textit{Biomass (biological yield)(g)}} \times \mathbf{100.}$$ (Yagoub *et al*., 2015)…………………Equation 1

The result of harvest index (HI %) (Table 5) revealed that the non-drought (ND) stress had the significant differences (P<0.05) among the accession due to the genotype effect and the highest harvest index (HI) was obtained in the accession TGx 1485–1D (44.3%) while the lowest harvest index (HI) was recorded for accession TGx 2004–10F (23.57%) and when the accessions are subjected to drought stress, the harvest index (HI) was slightly reduced by 24.4% (Table 6) and the results showed no significant differences among the accessions due to the effect of drought stress. It can be deduced from this work that harvest index (HI) decreases proportionally or as the result of reduction in the yield and the biomass (dry weight) due to the effect of drought stress on the general development of the crop.

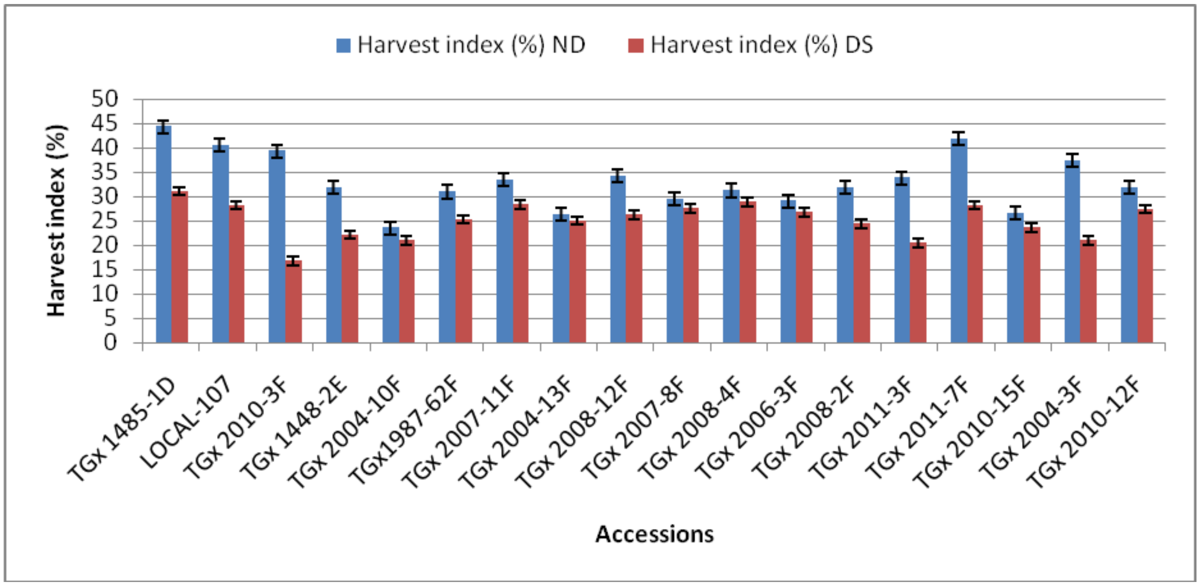

Figure 10: Performance of soybean accessions on harvest index (HI) under non-drought (ND) and drought stress (DS) conditions.

The Drought intensity index (DII)

Table 7: Drought intensity index (DII) to qualify soybean accessions response to drought stress tolerance, any accession with the value of drought intensity index (DII) exceeding 0.7 shows severity of the drought stress.

Accessions	Source	Drought Intensity Index (DII)
TGx 1485-1D	IITA	0.81
Local-107	South Sudan **	0.90
TGx 2010-3F	IITA	0.72
TGx 1448-2E	IITA	0.82
TGx 2004-10F	IITA	0.65
TGx 1987-62F	IITA	0.72
TGx 2007-11F	IITA	0.47
TGx 2004-13F	IITA	0.70
TGx 2008-12F	IITA	0.39
TGx 2007-8F	IITA	0.59
TGx 2008-4F	IITA	0.36
TGx 2006-3F	IITA	0.26
TGx 2008-2F	IITA	0.51
TGx 2011-3F	IITA	0.60
TGx 2011-7F	IITA	0.50
TGx 2010-15F	IITA	0.19
TGx 2004-3F	IITA	0.46
TGx 2010-12F	IITA	0.36

** The variety Local 107 (accession) was courteously provided by a farmer from Hai 107 (Not a released variety). DII; (Drought Intensity Index)
Drought intensity index (DII) was used to qualify the genotypes or accession to drought stress tolerance and it is calculated from the formula;

$$(DII = 1 - \frac{Xd}{Xp})$$ ……………………………………………….Equation 2

Where, **DII** = Drought Intensity Index, X_d = Mean yield average across line under stress, X_p = Mean yield average across line under non- stress condition.

Drought indices which provide a measure of drought tolerance or susceptibility based on loss of yield under drought stress in comparison to non-drought stress have been used for screening drought tolerant genotypes.

The result for DII (Table 8) showed that accession TGx–2010–15F had, in an ascending order the lowest DII value followed by TGx–2006–3F, TGx–2008–4F, TGx–2010–12F, TGx–2004–3F, TGx–2007–11F, TGx–2011–7F, TGx–2008–12F (DII) TGx 2004–10F, TGx 2007–8F, TGx 2008–2F and TGx 2011–3F which exhibited low drought intensity index (DII) and the severe drought intensity was recorded in accessions TGx 1485–1D, Local–107, TGx 2010–3F and TGx 1987–62F because their yields were adversely affected by drought stress as a result of their higher drought intensity index (DII).

Ranking soybean genotypes (accessions)

To determine the most desirable drought tolerant accessions, all soybean accessions were ranked according to Chowdhury *et al.* (2016) on the basis of their yield reduction due to water stress over non-stress (Table 8). According to the yield reduction, accession were ranked into four groups as tolerant (less than 50% yield reduction), moderately tolerant (50.01-60.00% yield reduction), moderately susceptible (60.01-70.00% yield reduction) and susceptible (above 70.01% yield reduction).

Table 8: Ranking of 18 soybean accessions on the basis of their yield reduction under drought stress (DS) condition

Rank order	Yield reduction (%) over non-drought stress	Accessions (18)
Tolerant	Less than 50.00	TGx 2010–15F (19%) TGx 2006–3F (26.8%) TGx 2008–4F (36.4%) TGx 2010–12F (36.4%) TGx 2008–12F (39.6%) TGx 2004–3F (46.5%) TGx 2007–11F (47.1%)
Moderately tolerant	50.01 – 60.00	TGx 2011–7F (50.70%) TGx 2008–2F (52.00%) TGx 2007–8F (59.70%)
Moderately susceptible	60.01 – 70.00	TGx 2011–3F (60.20%) TGx 2004–10F (65.60%)
Susceptible	Above 70.01	TGx 2004–13F (70.40%) TGx 1987–62F (72.20%) TGx 1448–2E (83.60%) TGx 2010–3F (84.20%) TGx 1485–1D (84.20%) Local–107 (90.35%)

Based on the yield reduction, seven accessions were found in tolerant group because they were relatively more productive both under non-stress and water stress conditions, and exhibited low yield reduction due to water stress. Similarly, three accessions were found moderately tolerant as they gave lower yield than the tolerant accessions, but higher yield than the susceptible accession. Two accessions were grouped as moderately susceptible due to higher yield reduction in water stress condition and six accessions were ranked in susceptible group due to their very low yielding ability and very high yield reduction.

DISCUSSION

Results of this study indicated that the significant differences ($P<0.05$) exist among the accessions under non-drought stress (ND) condition (Table 1) at ($P<0.005$) was only attributed to the effect of genotype whilst the accessions subjected to drought stress (DS), the accessions also showed significant differences ($P<0.05$) due to its respond to drought stress condition. It was also observed that the drought stress caused reduction in the plant height by 15% as when plants are exposed to drought stress, cell enlargement, cell wall and synthesis enzymes are reduced, the growth and plant height are decreased. This finding is in agreement with the results of Nielsen and Nelson (1998) who reported on depression of plant height as a result of severe influence from environmental factors such as water stress. Desclaux *et al.* (2000) evaluated the effects of water stress at various stages of development in soybean plants and found that reduction in plant height was associated with water stress induced in the V4 stage. This finding is also in agreement with that of Hiler *et al*. (1972) who found that plant height in cowpea was substantially reduced by water stress. Moreover, (Nonami,1998) reported that drought stress impaired cell elongation and expansion by reduced turgor pressure which results in a decrease in tissue water contents and loss of turgor. Drought stress also impairs photo-assimilation and metabolites required for cell division that result in to reduced plant height, leaf area and crop growth under drought condition. The result of the foregoing study also indicated that due to the effect of drought stress, the root length of soybean is increased by 19.4% (Table 2). It is evident that increase in root length suggests a mechanism of drought tolerance in soybean. The soybean can develop a root system that can reach the deeper layer of the soil for mitigating the effect of water stress as the roots send the signal to the stem such that the dry matter will be accumulated in the root to initiate its grow. Leport *et al.* (2006) also reported that drought stress improves allocation of assimilates to the root system such that the roots can reach the deeper soil layer to enhance water uptake.

When the water vapor atmospheric demand is greater, this requires the plant to have a well developed root system allowing it to reach water in deeper layers of the soil profile (Souza *et al.,* 2013). This result is also in agreement with (Hoogenboom *et al*., 1987) who reported that the increase root growth rate coincided with the water deficit.

Despite the wealthy data on root development under drought or water stress, there are some controversial evidences on effect of drought stress on root growth. For instance, an increase in root growth due to water stress was reported in *Catharathus roseus* (Jaleel *et al*., 2008), the growth rate was not substantially inhibited under water stress in maize (Sacks *et al.*, 1997).

It was also observed that both non-drought stress and drought stress had significant differences among the accessions (Table 1). The results showed that the drought stress resulted to 48.3% reduction in the dry weight (Table 2). This finding is in support of (Sauza *et al.,* 2012) who indicated that, drought stress decreased photosynthetic rates, biomass accumulation, translocation to grain, leaf area and acceleration of the senescence and abscission of leaves could reduce the dry weight by approximately 50% compare to normal plant. These results agree with (Khan *et al*., 2001) and (Zhao *et al.,* 2006) who reported that a common adverse effect of water stress on crop plant was the reduction in fresh and dry biomass production.

The results also revealed that when soybean crops are subjected to water stress, the number of pods/plant and the number of seeds/plant can be reduced up to 44% and 58.4%, respectively, (Table 4) as a result of flower abscission during flowering stages, immature pod abortion and reduced number of nodes due to the adverse effect of drought stress on the soybean during reproductive stages. This result is in agreement with (Sionit and Kramer, 1977) who indicated that water stress during early pod formation caused greatest reduction in the number of pods and seed at harvest.

Lopez *et al.* (1996) also indicated that the number of pods/plant are most affected by the drought stress during flowering and can reduced the final grain yield up to 70% depending on the stress period.

These results are also in line with (Hall and Twidwell, 2002) who stated that moisture stress during the soybean reproductive stages causes floral abortion, reduced pod number, fewer seeds per pod, and reduced seed size. Moreover, this finding is in support of Faroog *et al*. (2009) who indicated that drought stress can reduce the soybean yield by 46%-71% at reproductive stage.

Based on the results of pod abortion (Table 3), the accessions had significant differences both in the non - drought and drought stress condition in the number of aborted pods. The higher rate of pod abortion under drought stress condition could be related to the effect of drought stress as other accession under drought stress aborted higher number of pods compare to the accessions in non drought condition. Dybing *et al*. (1986) reported that drought stress occurring during flowering and early pod development increased the rate of pod abortion in soybean. In support to this finding (Liu *et al*., 2004) also indicated that the abscisic acid (ABA) in flowers and pods was increased by drought stress which leads to pod abortion.

Furthermore, drought stress limits the source and also cause barrenness as it impairs the reproductive sink (pod) from utilizing the incoming assimilates from the source that may result in to pod abortion (Farooq *et al*., 2009).

However, some accessions under non–drought stress condition had higher number of aborted pods compared to drought stress condition which could be attributed to the incident of insect pest damage as a result of higher number of insect pest which was observed in non-drought stress site.

This foregoing study also indicated that when different accessions of soybean are subjected to drought stress, their response to the stress varies which cause the significant differences among the accessions and interaction between genotype and environment in seed weight/plant, grain yield/plot and 100–seed weight. The drought stress also leads to the reduction in seed weight/plant, grain yield/plot and 100–seed weight by 55%, 60.3% and 17.4%, respectively. These findings are in line with El Sabagh *et al.* (2016) who indicated that water stress is a key abiotic limiting factor for soybean production and can reduce the yield of soybean up to 40% or more.

As a result of reduced rate and duration of effective seed filling period (Table 6.), soybeans produced shrinked and smaller seed size with reduced seed weight which leads to decreases soybean final yield in drought stress conditions. These results are in agreement with the previous studies (Gupta, 1995 and Hsiao 1973) that drought stress at reproductive growth stages disrupted photosynthesis and remobilization in plants which can cause reduction in the number and weight of seeds. In support of these results, Dogan *et al*. (2007) also stated that drought stress is important factor in growth and yield reduction especially when drought stress occurs at reproductive stages such as initial pod filling, beginning of seed formation and full seed stages is responsible for yield reduction compared to non drought stress conditions.

Furthermore, based on the results presented in (Table 5) the non-drought stress (ND) had significant differences ($P<0.05$) among the accessions in the harvest index (HI) due to the effect of genotype meanwhile drought stress (DS) showed no significant differences among the accessions but as the result of adverse drought stress, the harvest index (HI) was reduced by 24.4% (Table 6). It seems that, the (HI) was reduced due to the loss of flowers and decrease in seed numbers per plant. The finding of this study is in line with (Mirakhori *et al.,* 2009) who indicated that the harvest index decreases as the result of reduction in yield and biomass yet there are no significant differences in drought stress conditions. Similarly, Abbas *et al*. (2013) also stated that the loss of harvest index (HI) at grain filling stage was due to reduced assimilates transfer, eventually leads to shrinkage and seed weight is reduced as a result of reducing the harvest index (HI).

Nevertheless, the results presented in (Table 7 and Table 8) showed clearly that when different genotype of soybean are subjected to drought stress, their respond to drought stress varies from one genotype to another as other accession exhibit drought tolerant and others susceptible to drought stress based on their performance in both non drought and drought stress condition. Generally, drought stress affects soybean in all the development stages especially during the reproductive stage which adversely reduced crop yield by decreasing seed yield and yield components. The reduction in crop yield could be attributed to the accelerated days to flowering, shorter grain filling duration and lower accumulation of dry matter, reduction in yield components such as; seed weight, number of seeds/plant and number of pods/plant. Therefore the great reduction in the yield can be minimized by growing the soybean genotypes that are classified as drought tolerance and improving the yield component under drought stress condition.

CONCLUSIONS

Drought stress has a great impact on the development of soybean and consequently on final seed yield. However the present study identified some suitable genotypes of soybean to be improved and develop to minimize the adverse soybean yield loss due to the drought stress. Based on the finding, it can be concluded that drought stress affect all the morphological and reproductive parameters and the significant differences exist among the soybean accessions under both non- drought stress (ND) and drought stress (DS) conditions except, root length under non drought stress and the harvest index under drought stress condition. Drought stress also decreased the plant height and dry weight by 15% and 48.3% respectively and increased the root length by 19.4% (Table 2) and also adversely reduced the reproductive parameters such as number of pods/plant (44%), number of seeds/plant (58.4%), seed weight/plant (55%), grain yield/plant (60.3%), 100-seed weight (17.4%) and harvest index (24.4%). The most affected parameter by drought stress was the yield/plot by 60.3% reduction (Table 4 and 6), this indicated clearly that the effect of drought stress on the final yield was due to decreased number of pod/plant, seed number per plant, seed number per pod and decreased seed individual weight. Although drought stress had great impact on the final seed yield reduction, some accessions such as TGx 2010–15F, TGx 2006–3F, TGx 2008–4F, TGx 2010–12F, TGx 2008–12F, TGx 2004–3F, TGx 2007–11F were less affected by drought stress as they showed high yield under both non drought stress and drought stress condition hence exhibit tolerant to drought stress. This clearly indicated that the respond of different accessions to drought stress varies from one accession to another.

RECOMMENDATIONS

Based on the findings, it can be suggested that the accessions such as TGx 2004–13F, TGx 1987–62F, TGx 1448–2E, TGx 2010–3F, TGx 1485–1D, Local–107 that are susceptible to drought stress and TGx 2011–3F, TGx 2004–10F were moderately susceptible and both should not be grown in drought prone agro-ecological zone or during off-season to avoid yield loss due to drought stress but they can be grown during the first season or under irrigation since they exhibit higher yield under normal condition except the accession TGx 1448 – 2E that had the lowest yield though under normal condition.

Similarly, it can be recommended that the accessions; TGx 2010–15F, TGx 2006–3F, TGx 2008–4F, TGx 2010–12F, TGx 2008–12F, TGx 2004–3F, TGx 2007–11F that were identified as drought tolerant and TGx 2011–7F, TGx 2008–2F and TGx 2007–8F were moderately tolerant and both should be subjected to further field trial before they are released as drought tolerant varieties for further commercial production. We also recommended that more research need to be done to determine the most affected growth stage by drought stress that may contribute to the failure to obtain maximum soybean yield such that the frequency of irrigation or planting date can be adjusted to minimize the yield loss due to drought stress.

Finally, despite the effort to screen the soybean accessions concentrating more on the reproductive component, further research on the morphological and physiological parameters such as photosynthetic apparatuses (PAR, stomatal conductance, transpiration), number of leaves/plant, leave area index, (LAI), days to flowering, days to maturity, stem biomass reduction and identifying morphological markers is essential to understand the mechanism underlying drought tolerance and suggest more accessions from other regions or agro-ecological zones.

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