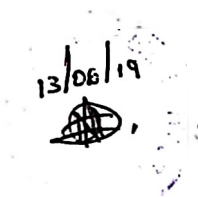


**EVALUATION OF COMMON BEAN (*Phaseolus vulgaris* L.) GENOTYPES
UNDER DROUGHT STRESS CONDITIONS IN THE SOUTHERN
HIGHLANDS OF TANZANIA**



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**DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
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ABSTRACT

A study was conducted to evaluate common bean (*Phaseolus vulgaris* L.) genotypes for drought tolerance in Southern Highlands of Tanzania. Eighteen genotypes were selected for conducting experiments in the field and screen house, on June, 2015. The field experiment was conducted at Inyala Agricultural Training Institute while the screen house experiment was laid out at Uyole Agricultural Research Institute. Experiments were laid out in a 3x18 split plot arranged in randomized complete block design (RCBD) with 3 replications. Results for seed yield under stress and non-stress condition were used to calculate yield indices which were used to predict tolerant bean genotypes. Results showed significant differences ($p \leq 0.05$) of yields across genotypes and water treatments. Genotypes BFS60, KG104-72 and SER16 yielded highest under stress at flowering while genotype KG4-30, RCB266, KG25-21 and KG104-72 yielded highest under stress at mid pod filling. Selection indices, such as yield index (YI) selected BFS60 as most tolerant genotype followed by KG104-72 and SER16 while Stress tolerance index (STI) selected SER16 followed by BFS60 and KG104-72; Stress susceptibility percent index (SSPI) selected RCB266 followed by SER16, 41-EX-VAM and SER83 as most tolerant genotypes. Genotypes SER16, BFS60, KG104-72 and CZ109-22 were found as most tolerant genotypes when the means of rankings of yield indices ranked. Correlation analysis showed that yields under non stress condition (Y_p) were significant and positively correlated with YI, STI and SSPI, while yields under stressed condition (Y_s) were significant and positively correlated with YI and STI. On the other hand, yields under (Y_s) were not significant and negatively correlated with SSPI. Genotypes (SER16, BFS60 and KG104-72) are among of the most tolerant to drought conditions, therefore, can be used as parental materials in breeding for drought tolerance.

DECLARATION

I, KARANTIN DAVID MAZENGO, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has neither been submitted nor concurrently submitted for degree award in any other institution.



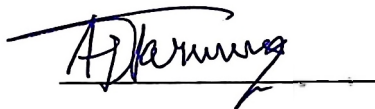
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DEDICATION

I dedicate this piece of work to my beloved son James Mazengo, my beloved mother and Father, Vaileth Mazengo and David Mazengo, respectively, as well as my Lovely wife Rehema Mazengo. I drew a lot of inspiration from them and I pray that the Almighty God be with them for the rest of their lives.

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LIST OF ABBREVIATION AND SYMBOLS

%	Percent
/	Per
<	Less than
>	Greater than
≤	Less or equal to
ANOVA	Analysis of Variance
ARI	Agricultural Research Institute
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
CIAT	Centro Internacional de Agricultura Tropical
cmol _c (+)kg ⁻¹	Cent mole concentration per kilogram
CV	Coefficient of Variation
DAP	Days After Planting
DNMRT	Duncan's New Multiple Range Test
ECSA	Eastern Central and Southern Africa
FAO	Food and Agriculture Organization of the United Nations
MJm ⁻² day ⁻¹	Mega joules per meter square per day
pH	Hydrogen ion concentration
RCBD	Randomized Complete Block Design
s/n	Serial number
SHTZ	Southern Highlands of Tanzania
SP0	Without stress treatments
SPI	Stress at flowering
SPII	Stress at mid pod filling

SSPI	Stress Susceptibility Percent Index
STI	Stress Tolerance Index
TSP	Triple super phosphate
YI	Yield Index
Y_p	Yields without stress
$\bar{Y}_p$	Mean yields without stress
Y_s	Yield with stress
$\bar{Y}_s$	Mean yield under stress

CHAPTER ONE

1.0 INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is one of the widely cultivated crops. It is considered to be one of the most important legumes for human consumptions (CIAT, 2001; Emam *et al.*, 2010) and is an important source of dietary protein, calories, dietary fibers, and minerals, especially iron and zinc in Africa, and it is a primary staple in parts of the Great Lake Regions (Singh *et al.*, 2000; Tryphone and Nchimbi-Msolla, 2010). Beans consumption also has medicinal benefits to human health; eating beans may provide protection from cardiovascular disease by a small depression in blood cholesterol (Kabagambe *et al.*, 2005). In epidemiological studies of colon cancer, low incidence was observed in many Latin American countries where the consumption of common beans is high (Hangen and Bennink, 2006). Clinical studies consistently showed that when consumed on behalf of other carbohydrate-rich foods, beans reduced postprandial glucose elevations in both diabetic and non diabetic participants (Tomson *et al.*, 2012).

It is estimated that over 75% of rural households in Tanzania depend on it for daily dietary requirements (CIAT, 2008). Bean is a cash income earner in the sense that, dry seeds and fresh pods attract higher market prices (Broughton *et al.*, 2003). Beans have the ability to fix atmospheric nitrogen in the soil in association with *Rhizobium* bacteria (Kay, 1979). The fixation of atmospheric nitrogen improves soil nitrogen level and hence benefiting the crop that is grown thereafter, and also minimizes the production costs. Furthermore, common bean residues left on the field improve soil structure (Barrett, 1990).

Despite the importance of common beans in Tanzania and other developing countries, its production mostly relies on local cultivars (Chataika *et al.*, 2010). Like other plants, the development and productivity of beans is adversely affected by biotic and abiotic factors (Jaleel *et al.*, 2009). Biotic factors that contribute to low yields are poor seed quality, insect pests, weeds and diseases whereas abiotic factors; are low soil fertility and recurrent droughts. Among the abiotic factors, drought is perhaps the major factor limiting crop production worldwide (Jones and Corlett, 1992). Water stress is ranked second from insect pests and diseases that cause grain yield losses with about 60% of world bean production area. With the evolving phenomena of climate change, it is anticipated that drought will exert increasing impacts on crop productivity (Man *et al.*, 2011).

The production of beans is usually under rainfed conditions and consequently insufficient or unpredictable rainfall may limit the yield (Acosta-gallegos and Domingo, 2009). In recent years the average bean yields in Tanzania is about 500 kg/ha while the potential yield is 1500-3000 kg/ha (Hillocks *et al.*, 2006). Drought causes reduction in yield, yield components and biomass accumulation of common beans (Munoz-Perea *et al.*, 2006). In the Southern High lands of Tanzania, the bulk of bean production is done by small scale farmers who depend entirely on rainfall. In these areas, intermittent and or terminal droughts are experienced in some years, whilst crop management practices such as supplementing the crops with irrigation during drought periods is not common and unaffordable for small scale farmers. For this situations therefore, deployment of common bean germplasm that are drought tolerant is necessary in those areas. Variety evaluation for drought tolerance in common beans is the appropriate approach for plant breeders to identify superior

genotypes for varieties development programs (Abebe *et al.*, 1998). The main objective of a study was to establish the drought stress tolerance indices and identification of genotypes to be used for future hybridization activities in the Southern Highlands of Tanzania.

The specific objectives were;

- (i) To determine the growth and yield characteristics among selected common bean genotypes
- (ii) To identify suitable selection indices for drought tolerance of common bean genotypes.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, Domestication and Distribution

The common bean is a cultivated crop that originated in the New World. The first domestication of *P. vulgaris* by humans is said to have started slightly more than 4,000 years ago in Mesoamerica and South America (Kaplan and Lynch, 1999). The work of Kami *et al.* (1995) suggested that in South America, starting from the core area of the western slopes of the Andes in northern Peru and Ecuador, the bean was dispersed to northern parts of South America continent (Colombia, Central America, and Mexico) and to the southern regions of the same continent (Southern Peru, Bolivia, and Argentina), and these two opposite directions of common bean spreading were the source of the emergence of Mesoamerican and Andean gene pools and their races. In Europe and Africa common bean was spread during the European exploration of the Americas (Gepts and Bliss, 1988).

2.2 Botanical Description

The common bean is an annual leguminous plant with pinnately compound trifoliate large leaves (Katungi *et al.*, 2009). The common bean is largely a self pollinated plant though cross-pollination does occur if the stigma is exposed to foreign pollen. Seeds are non-endospermic and vary greatly in size and colour from the small black wild type to the large white, brown, red, black or mottled types, and their sizes may range from 7-16 mm long (Cobley and Steele, 1976). Common bean shows variation in growth habits from determinate bush to indeterminate, extreme climbing types.

Bush varieties form erect bushes with 20–60 cm in height, while pole or climbing varieties form vines with 2–3 m long. In addition, studies conducted by Singh (1999) classified the bean growth habits into four major classes (type I for determinate upright or bush; type II for indeterminate upright bush; type III for indeterminate prostrate, non climbing and type IV for indeterminate strong climbers) and suggested a key for their identification based on the type of terminal bud, stem strength, climbing ability and fruiting patterns. All varieties of common bean bear alternate, green or purple leaves, divided into three oval, smooth edged leaflets, each with 6–15cm length and 3–11cm width and they are somewhat hairy and each has a well developed pulvinus at the base (Summerfield and Roberts, 1984). Common bean stems and branches are slender, twisted, angled and ribbed, and for the climbing forms, have more nodes which are further apart than determinate bush types.

The development of bean (determinate and indeterminate plant types), passes through two main stages of vegetative (V), (7 to 40 days) to reproductive (R), (40 to 94 days) as indicated in Table 1. Vegetative stages are determined by counting the number of fully expanded trifoliolate leaves on the main stem while the reproductive stages are described by pod and seed characters. The first pod developing on the plant is described and followed to full size. At the time of first bloom (R1 stage), secondary branching begins in the axis of lower nodes which will produce secondary groups of blooms or pods. To determine the growth state, the main stem is followed, which is readily discernible on both determinate and indeterminate plants. A trifoliolate leaf is counted when it is fully unfolded (Kandel, 2010).

Table 1: Stages of vegetative and reproductive development in an indeterminate (Type III) dry bean

Stages	General description/vegetative stages	Days from planting
VE	Hypocotyl emergence.	7
VC	Cotyledonary and unifoliolate leaves visible.	10
V1	First trifoliolate leaf unfolded	14
V2	Second trifoliolate leaf unfolded.	20
V3	Third trifoliolate leaf unfolded Secondary branching begins to show from node of V1.	26
V(n)	ntrifoliolates on the main stem, after every 3 days, a new node is formed but with blossom clusters still not visibly opened.	29-37
V8	Vine (indeterminate) plants may begin to exhibit blossom and become stage R1.	40
Reproductive Stages		
R1	One blossom opens at any node. Tendril will begin to show	40
R2	Pods 1.27 cm long at first blossom position (node 2 to 5 most plants).	43
R3	Pods 2.54 cm long at first blossom position	46
R4	Pods 5.1 cm long at first blossom position.	50
R5	Pods 7.6 cm long, seeds discernible by feel.	56
R6	Pods 11.4 cm long with spurs (maximum length). Seeds at least 0.6 cm long axis.	60
R7	Oldest pods have fully developed green seeds. Other parts of plant will have full length pods with seeds near same size. Pods to the top and blossom on tendril, nodes 10-13.	70
R8	Leaves yellowing over half of plant, very few small new pods/blossom developing, and small pods may be drying. Point of maximum production has been reached.	82
R9	Mature, at least 80% of the pods showing yellow and mostly ripe. Only 30% of leaves are still green.	94

Source: Kandel (2010)

2.3 Taxonomy

Common bean is also known as dry bean. It is a species of the genus *Phaseolus* belonging to leguminaceae (fabaceae) family (Raemaekers, 2001). This genus comprises over 50 species (Debouck, 1991). However the genus has many number of species, only five of these species are cultivated, namely *P. acutifolious* L. (tepary

bean); *P. coccineus* L. (runner or scarlet bean); *P. lunatus* L. (lima, butter or Madagascar bean); *P. polyanthus* Greenman (year-long bean) and *P. vulgaris* L. (common bean, haricot, navy, French or snap bean) (Singh, 2001). Among these species; *P. vulgaris* L. is the most widely cultivated in the world, over 85% of all production areas is dedicated to *Phaseolus* species, and has the broadest range of genetic resources (Singh, 2001).

Apart from these number of species of the genus *Phaseolus*, the species of common bean has two major gene pools known as Mesoamerican and Andean (Blair *et al.*, 2006), which resulted due to multiple domestication (Beebe *et al.*, 2000; Singh, 2001). The evidence of existence of this division was based on morphological traits (Singh *et al.*, 1991a), phaseolin seed protein (Gepts *et al.*, 1986), isozymes (Koenig and Gepts, 1989) and molecular markers (Freyre *et al.*, 1996). Furthermore, the Mesoamerican gene pool found to consist four major races, namely Durango, Jalisco, Mesoamerica and Guatemala (Beebe *et al.*, 2001), whereas the Andean gene pool has three races which are Peru, Nueva Granada and Chile. In the differentiation process of these races within gene pools, molecular markers were used (Singh *et al.*, 1991).

2.4 Production Requirements and Adaptation of Common Bean

Common bean is adapted to deep well drained, sandy loam, sandy clay loam or clay loam soils with clay content of between 15 and 35% with no nutrient deficiencies (Thung and Rao, 1999). The optimum soil pH range for common bean production is pH 4.6 - 5.0 (CaCl₂). Heavy clay soils with poor oxygenation and capping clay sands are not suitable. Thus, it will not grow well in soils that are compacted, too alkaline or poorly drained (Lunze, 2001). It grows optimally at temperatures of 15.6 to 21.1

°C. The maximum temperature should be 27° C, while the minimum should be 10°C. The temperature above 30 °C at flowering result in serious blossom-drop, leading to formation of fewer pods (Gross and Kigel, 1994), and when the temperatures reaches 33°C and above during maturation may lead to a lower percentage of seeds producing normal seedlings than lower temperatures (10°C) (Siddique and Goodwin, 1980). Common bean is susceptible to low temperature at all stages of growth (Silbernagel, 1986). Temperatures at or below 10°C during imbibition and germination may result in permanent injury and vigour reduction, while prolonged temperatures at or below 15 °C can result in stunted plant with no seeds (Dickson and Petzoldt 1987). Cold stress at reproductive phase is largely associated with abnormal development of flowers at flowering stage and failure of pods to set seeds at pod filling stage (Blum, 1987).

Under rain-fed conditions, the crop requires moderate amounts of rainfall (300 – 600 mm) but adequate amounts are essential during and immediately after the flowering stage (Katungi *et al.*, 2009). Generally, common bean is considered as a short-season crop with most varieties maturing in a range of 65 to 110 days from emergence to physiological maturing (Buruchara, 2007). Maturity period can continue up to 200 days after planting amongst climbers that are used in cooler upland elevations (Graham and Ranalli, 1997 in Gomez, 2004). In Africa, common bean cultivation is concentrated at altitude above 1000 meters above sea level, with adequate amounts of precipitation (greater than 400 mm of rain) during crop growing season and soil pH above 5.5. These are the cooler highlands and the warmer mid-elevation areas of East, Central and Southern Africa. In Tanzania, most of the bean crop is produced in

the higher altitudes, cooler and high rainfall zones because of the reliable distribution of annual rainfall and relatively cool day time temperatures ranging from 17 to 22 °C.

2.5 Importance of Common Bean

Common bean is the world's most important grain legume for direct human consumption (Broughton *et al.*, 2003). In 2010, global bean production was approximately 23,816,123 tons, with 24.4 and 17.7% of the world production in Latin America and Caribbean (LAC) and Africa, respectively (FAO, 2014).

In Africa, beans are grown mainly for subsistence, in which the Great Lakes Region has the highest per capita consumption in the world. Beans are a major source of dietary protein in Kenya, Tanzania, Malawi, Uganda, and Zambia (CIAT *et al.*, 1999). Common bean has also been reported by Lunze (2001) as an important grain legume grown on over 3.7 million of hectares every year in Eastern, Central and Southern Africa (ECSA), where bean consumption per capita exceeds 50 kg/year and reaching over 66 kg in densely populated western Kenya (Wortmann *et al.*, 1998). Apart from the high protein content, common bean is also a good source of energy and provides folic acid, dietary fiber and complex carbohydrates. Common bean protein is high in lysine, which is relatively deficient in maize, cassava and rice, making it a good complement to these staples in the diet. It is also an excellent low-fat source of complex carbohydrates, fiber, folate, potassium and B vitamins (Canada, 2003). It is consumed through its green leaves, green pods, immature grains and dry seeds. Beans are appreciated throughout the Eastern and Southern Africa because they have a long storage life, good nutritional properties and can be easily

stored and prepared for eating (CIAT, 1999). The cost of common bean is low as compared to meat products, thus leads to its high consumption in Africa. Beyond promoting food, health and nutritional security, beans provide a steady and lucrative source of income for many rural households with the value of sales exceeding US \$ 500 million annually (FAO, 2011). Common bean is usually grown either in a pure stand or in rotation with cereals or in crop mixtures usually with maize; and bean fixes nitrogen which benefits the next crops. In this way, the poor resource farmer is enabled to increase land productivity and minimize fertilizers application. After harvesting, crop residues, such as dried pods and stems (straw) and processing by-products (discarded pods, pod extremities), can be used for livestock fodder (Wortmann, 2006).

2.6 Importance of Water in Common Bean Growth and Development

During the vegetative stage of the bean growth, it requires adequate water for germination and root development. Inadequate soil water during the early growth stages results in reduced plant populations and biomass yield, which, in turn, reduces final yield (Efetha, 2011). A study to compare drought-resistant and drought-sensitive cultivars of field beans and field peas to water stress was conducted and significant decrease in number of developed harvestable parts, total yield and dry matter was observed. The reduction was reported to be smaller in drought tolerant cultivars than in the drought sensitive cultivars (Grzesiak *et al.*, 1997).

The effect of water deficit on leaf of beans occurs in two ways; early deficit during phase 1 reduces leaf area through an effect on cell division, while late deficit during phase 2 reduces leaf area by reducing cell size (Jeuffroy and Ney, 1997). The bean

requires moderate amounts of water (300-600 mm) from planting to physiological maturity. Adequate amounts of water in the early season is essential, but particularly so during pod-filling stage (during and immediately after flowering). Water stress at growth and development of the bean excluding during flowering and immediately after flowering has little effect on grain yield (Science, 2004). Jeuffroy and Ney (1997) reported that the main effect of water stress was an earlier cessation of flowering and thus results to a smaller number of flowering nodes, which potentially bear pods and seeds. Jeuffroy and Ney (1997) showed that drought stress reduced seed yield by 80%; and this was associated with reduction in pod numbers per plant by 60 %, seeds number per pod by 26 % and 100-seed weight by 13 %.

2.7 Production Constraints of Common Bean

Bean production is constrained by both abiotic and biotic factors that adversely affect grain yield. Almost all bean production occurs under low input agriculture on small-scale farms in developing countries (Miklas *et al.*, 2006). Beans produced by these resource-poor farmers are more vulnerable to diseases, insect pests and to abiotic stresses, including water stress and low soil fertility. Commercial farmers can minimize these stresses through the use of external inputs such as fertilizers, irrigation and pesticides. Utilization of such inputs, however, can seriously reduce profitability and threaten the environment; Field irrigation is unaffordable for household farmers and there is no effective fertilizer application. The use of pesticide to reduce pests has not yet met the requirements, thus why biotic and abiotic stresses continue to be the major constraints in both subsistence and commercial production of common bean.

2.7.1 Insects

The most common insects that affect bean plants are aphids (*Aphis fabae*), bean stem maggot (*Ophiomyia Spp*), flower thrips (*Frankliniella occidentalis*), *Ootheca bennigseni* (a beetle which eats the leaves of bean plants), bean flies (*Ophiomyia phaseoli*), pod borers (*Muruca vitrata*). Insects also cause significant losses in yield. Bean stem maggot alone attributes an estimate loss of 297,100 ton yr⁻¹ (Wortmann *et al.*, 1998). However, many insects, cause damage to the bean plant, some, such as spiders, lady birds and ants, are natural enemies of harmful insects (Buruchara *et al.*, 2011).

2.7.2 Diseases

Common bean is susceptible to a number of diseases. The common diseases in the tropics and sub-tropics that affect bean production are:- common blight (*Xanthomonas axonopodis* pv. *phaseoli*), fusarium root rot (*Fusarium solani* f. *sp. phaseoli*), rust (*Uromyces appendiculatus* var. *appendiculatus*), anthracnose (*Colletotrichum lindomuthianum*), The bean common mosaic virus (BCMV), angular leaf spot (*Phasoisariopsis griseola*), halo blight (*Pseudomonas syringae* pv. *phaseolicola*), powdery mildew (*Erysiphe polygoni*) and root knot (*Meloidogyne spp.*). Wortmann *et al.*, (1988) reported yield losses due to angular leaf spot and anthracnose of 384,200 and 328,000 ton yr⁻¹ respectively.

2.7.3 Abiotic stress

Common bean is often grown on marginal lands under unfavourable environmental conditions (Broughton *et al.*, 2003) with minimal soil and crop management inputs

(Beebe *et al.*, 2008, 2009). Low soil fertility in those areas is due to phosphorus (P) deficiency or aluminium (Al) toxicity (Beebe *et al.*, 2009). Another unfavourable condition that affect common bean is drought, which may be intermittent or terminal drought. (Munoz-Perea *et al.*, 2006). These types of drought are among the most common abiotic stresses. In Africa and Latin America, production constraints caused the yield to be 0.70 ton ha⁻¹ in 2008 (FAOSTAT, 2010), while, experimental dry bean yield potential exceeds 3.00 ton ha⁻¹ (Beebe *et al.*, 2006). Among the abiotic stresses, poor soil fertility are long term and predictable problem (Lunze *et al.*, 2011), but drought events are not predictable, thus why it causes a serious threat to agriculture and frequent hunger. Factors that contribute to low soil fertility are like land degradation exacerbated by the effects of climate change (Christensen *et al.*, 2007) and crop intensification. Erratic weather and crop intensification destroys landscape and cause fertility decline and surges in pest and disease pressure. For example, according to the Atlas of common bean production in Africa (Wortmann *et al.*, 1998), P is deficient at 65 to 80 % of soils and N at 60 % of soils in bean producing areas of Eastern and Southern Africa, while about 45 to 50 % of soils are acidic with a pH less than 5.2, containing high levels of either Al or Mn.

2.8 Drought and Its Occurrence

Drought may be defined as “the inadequacy of water availability (including precipitation and soil moisture storage capacity) in quantity and distribution during the life cycle of a crop, thus restricting the expression of its full genetic yield potential”. Drought is a multidimensional stress affecting plants at various levels of their organization (Yordanov *et al.*, 2000). Drought can be imposed when a plant is

unable to meet its evapotranspirational demands. Drought environments are characterized by wide fluctuations in precipitation, quantity of precipitation, and its distribution within and across seasons. There are different types of drought; a drought may be meteorological when precipitation is significantly below expectation for the time of year and location. An agricultural drought is said to exist when water from all sources is sufficiently low enough to cause serious shortfalls in crop yield. Plants can also experience drought when water is present in the soil, but the plant fails to withdraw it due to lower osmotic potential of the soil caused by salts (Rauf, 2008), this type of drought is called physiological drought. Hydrological drought is another type of drought which occurs when the water reserves available in sources such as aquifers, lakes and reservoirs fall below the statistical average. Hydrological drought tends to show up more slowly because it involves stored water that is used but not replenished. Like an agricultural drought, this can be triggered by more than just a lack of rainfall.

The effect of stress is usually manifested as a decrease in photosynthesis and growth (Yordanov *et al.*, 2000). Drought stress is a worldwide production constraint of common bean (Teran and Singh, 2002). Pandey *et al.* (1984) reported that common beans are extremely sensitive to drought, and significant yield reductions due to drought are common in the tropics. There are two kinds of drought associated with limited rainfall; intermittent and terminal drought. Intermittent drought occurs due to climatic patterns of sporadic rainfall that causes intervals of drought and can occur at any time during the growing season (Schneider *et al.*, 1997). The nature of this rainfall which causes intermittent drought is unpredictable and leads to marginal

yields in crops. In contrast, terminal drought occurs when plants suffer lack of water during later stages of reproductive growth or when crops are planted at the beginning of a dry season (Frahm *et al.*, 2004). Terminal drought occurs when beans are planted during a short period of precipitation or toward the end of the rainy season without the option of irrigation.

2.9 Drought Resistance of Plants

Drought resistance in modern farming is based on the plant's ability to obtain limited water or to use the limited water caused by drought efficiently; when it is limited by drought. Drought resistance is also defined as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Rather, drought resistance appears to result from a combination of mechanisms including a deeper root system, stomatal control and improved photosynthate remobilization under stress (CIAT, 2007; CIAT, 2008).

There are two main components of drought resistance; these are drought avoidance and drought tolerance. In common beans, the mechanisms of drought avoidance include principally the development of an extensive root system and an efficient stomatal closure, while drought tolerance in agronomic terms means the ability of the crop to produce a satisfactory yield when subjected to water deficit (Madata, 1991). Drought tolerance in common beans encompasses all mechanisms that allow greater yield under soil moisture deficit (Maghembe, 1999) like thick cuticle with hairs, narrow leaves and deep roots. It is associated with many different morphological and physiological traits or responses, including stomatal regulation, variation in leaf cuticle thickness, root morphology and depth, osmotic adjustment, antioxidant

capacity, desiccation tolerance (membrane and protein stability), maintenance of photosynthesis and the timing of events during reproduction (Nguyen *et al.*, 1997; Klueva *et al.*, 1998). Mechanisms of drought tolerance, especially at low plant water status, involve processes at the cellular level, and the most important being osmotic adjustment and protection of the membrane system. The osmotic adjustment can allow the maintenance of root or shoot growth under stress conditions, through a control on cellular turgour (Creelman *et al.*, 1990).

Various morphological characteristics have been found to contribute to the drought resistance. Among the morphological characteristics include leaf characteristics such as leaf angle movements (Kristin *et al.*, 1997) and greater root growth (White and Castillo 1989). Another mechanism contributing to increased performance in beans under drought is the phenotypic plasticity, which allows shortening of the growth cycle.

2.10 Evaluation of Common Bean Genotypes for Drought Tolerance Using Selection Indices

Identification of drought tolerant genotypes by using one method such as analysis of variance of yields under stressed and unstressed condition may be contradictory. Therefore, plant breeders who are interested on genotypes which produce high yields under stressed condition came out with the use of drought tolerance selection indices for identifying high yielding genotypes. Thus, selection indices which provide a measure of drought based on loss of yield under drought and normal conditions have been used for screening drought tolerant genotypes (Mitra, 2001). Various

researchers have used different methods to evaluate genetic differences in drought tolerance. According to Fernandez (1992) the best measure for selection in drought condition is the one that could be able to separate genotypes which have desirable and similar yield in stress and non-stress conditions. In the contrary, drought resistance has been defined by Hall (1993) as the relative yield of a genotype compared to another subjected to similar drought stress conditions. Till now there are several selection criteria that have been proposed for selecting genotypes based on performance under stressed and non stressed environments. Rosielle and Hamblin (1981), for example, demonstrated stress tolerance index (STI) by using hybrid maize and the result showed that a hybrid yield in normal irrigation and drought condition is close to each other or plant is resistant to drought. Further stress tolerance index was defined as a useful tool for determining greater yield and stress tolerance potential of genotypes (Fernandez, 1992). To improve the efficiency of STI, a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which corrected the STI as a weight, and Moosavi *et al.* (2008) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes under stress and non-stressed conditions.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

In this study, two experiments were conducted in field and screen house. The field experiment was conducted at Inyala Agricultural Training Institute which is located at latitude 8°86'67" S, longitude 33°66'33" E and altitude of 1539 meters above sea level (m. a. s. l) and at Uyole Agricultural Research Institute (ARI-Uyole) which is located at Latitude 8°53'02" S, longitude 33°39'11" E and altitude 1750 m. a .s. l. for the screen house experiment. The two locations are found in Mbeya district and experience a unimodal rainfall pattern between November and May every year. The area has a subtropical highland climate. The overall average temperature is 17.5 °C. The heaviest rainfall occurs from December to March. The soil characteristics of this area are loam, slightly acidic with a pH of 5.54.

3.2 Materials

A total of eighteen common bean genotypes in which seventeen were known to be resistant to drought conditions, namely; SER125, MR13905-6,41-EX- VAM, BFS20, RCB233, CZ109-22, CZ104-61, KG25-21, SER82, SER83, KG104-72, SER16, KG4-30, SER45 SER124, BFS60, RCB266 and a susceptible check PASS, which were collected at ARI – Uyole. These genotypes were planted in both field and in screen house. The selection criteria were based on seed size, yield, shoot types, field performance, resistance to drought and diseases. These characteristics are also used by farmers to select suitable varieties for cultivation. Fertilizers used were; Triple Super Phosphate (TSP) (46% P₂O₅) and Urea (46 % N).

3.3 Methods

3.3.1 Experimental design

The experiment was laid out in 3 by 18 split plots arranged in a randomized complete block design (RCBD) with three replications for both field and screen house experiments. In the field experiment, plot size was 2 m x 2 m and the spacing used was 0.50 m x 0.10 m making a plant population of 84 plants per plot. The main plot (factor A) was watering regimes with three levels (without water stress and with water stress at flowering and mid pod filling). The stressing duration to the two main plots (stress at flowering and mid pod) was 20 days, and sub plot (factor B) was 18 common bean genotypes.

3.3.2 Land preparation and crop management

For the field experiment, land clearing, ploughing and harrowing was done using oxen-pulled equipments. The experiment was conducted during off season (June 2015) to avoid rain water intervention during stress periods. Planting was done by putting two seeds per hole at 5cm depth in each row. Fertilizers were applied uniformly at a rate of 25.3 kg P/ha and 22.5 kg N/ha. Seven days after planting seedlings were thinned to one plant per hill. Spraying with Profenofos 720 g/l insecticide at the rate of 2 ml/l was carried out to control bean stem maggot, termites and other insects by using a knap sack sprayer. Weeding was done three times using a hand hoe to make sure that no weeds in the plots. For the pot experiment, nearby land close to the field experiment was cleared and the top soil (0-20cm depth) was dug and 8 kg of this soil was filled into 10 liter pots. Watering was done once per week by applying 0.4 liters which was equivalent to 50% field capacity of a soil per pot. Planting was also done on June 2015 by sowing four

seeds per pot at a depth of 5cm. At seven days after planting seedlings were thinned to two seedlings per pot at a spacing of 0.2 m. In this experiment, watering was done once a week until, when the stress period introduced, Weeding was done only by hand pulling.

3.3.3 Inducement of water stress treatments

Water stress was introduced at flowering as well as at mid-pod filling stages to the main plots basing on the experimental layout. Water stress was induced to main plots assigned for stress at flowering when the population had flowered by 50%. To the main plots assigned for water stress at mid-pod filling, stress was also introduced when 50% of the population assigned for stress at mid pod filling had attained their mid-pod filling stage. The level (without water stress) was not stressed by water shortage. In the field experiment, water supply was conducted through flooding, whereas in screen house, crops were irrigated by using a watering can.

3.4 Data Collected from field experiment

(a) Soil physical and chemical characteristics

Composite soil samples were collected randomly from top soil (0-20 cm depth) in June 2015 before setting the experiment. Soil physical and chemical properties were determined at ARI-Uyole soil laboratory using analytical methods presented in Table 2.

(b) Weather data

For field experiment, weather data such as maximum and minimum temperature ($^{\circ}\text{C}$), relative humidity (RH %) and solar radiation ($\text{MJm}^{-2}\text{d}^{-1}$) were collected from

ARI-Uyole meteorological station. Data for temperature ($^{\circ}\text{C}$) and relative humidity (RH %) for the screen house experiment were also recorded. Temperature was recorded using maximum and minimum thermometer whereas, relative humidity was measured using hygrometer, and the solar radiation was recorded using radiometer.

Table 2: Various analytical methods used to analyse soil sample collected at Inyala

Variable	Method of analysis	Reference
Soil texture	Dispersal and hydrometric method	Anderson and Ingram (1993)
Total nitrogen	Micro-kjedahl digestion distillation	Bremner and Mulvanay (1982)
Soil pH	Soil pH meter	Maclean(1982)
Available phosphorus($\text{P}_2\text{O}_5^{2-}$)	Bray - Kurtz-1	Olsen and Sommers (1982)
Organic carbon(OC)	Wakley and Black	Nelson and Sommers (1982)
Exchangeable bases (K, Ca and Mg)	Flame photometer	Moberg (2000)
Cation exchange capacity(CEC)	Ammonium acetate saturation	Chapman(1965)

0630525

(c) Days to 50% flowering

Days to 50% were recorded following CIAT protocol for Field Evaluation of Common Beans for Adaptation to Drought. Days to 50% flowering was measured as days after planting to the time coinciding with initiation of developmental stage R6 (seeds at least 0.6 cm on long axis) when 50% of the plants had one or more flowers.

(d) Days to 85% physiological maturity

Number of days to physiological maturity was determined at developmental stage R8 (when leaves started yellowing over half of the plant).



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(d) Days to 85% physiological maturity

Number of days to physiological maturity was determined at developmental stage R8 (when leaves started yellowing over half of the plant).



(e) Number of pods per plant

Number of pods per plant was determined by counting total number of pods from five tagged plants per plot from the central rows.

(f) Seeds weight per plant (g)

Seeds collected from all pods in a single plant were measured using electronic balance and the exercise was repeated involving all five samples and the mean seed weight per plant was determined and recorded

(g) Number of seeds per pod

Number of seeds per pod was taken by counting total number of seeds from five sampled pods from the field and the mean value was computed and recorded.

(h) Weight of 100 seeds (g)

The 100 seeds weights were measured by taking 100 seeds from each treatment and measured from representative sample of each plot.

(i) Seed yield (kg/ha)

Seed yields were taken by weighing all seeds harvested from an area of 1.7m^2 from within experimental plots, sun dried and weighed using an electronic balance and the values were converted into kg/ha.

3.5 Data Collected from the Screen House Experiment

Data collected from the screen house were similar to those collected from the field experiment (section 3.4) except for the growth data which were collected as follows:-

(a) Number of leaves per plant

Number of leaves per plant was taken by counting all leaves from five tagged plants and mean value was recorded.

(b) Shoot dry weight (g)

Oven dried samples of shoot were weighed using an electronic balance and computed the mean value was recorded.

(c) Root dry weight (g)

Oven dried samples of roots were weighed using an electronic balance and the mean value was computed and recorded.

3.6 Derived Data for Drought Tolerance Indices**3.6.1 Stress susceptibility percentage index**

Moosavi *et al.*, (2008) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stressed conditions, Therefore data for yield under non stressed conditions and stressed conditions of this study were inserted in the formula below for obtaining SSPI.

$$SSPI = (Y_p - Y_s / 2 (\bar{Y}_p)) * 100$$

Where:-

Y_p , Y_s , and $\bar{Y}_p$ represent yield under no-stress, yield under stress, for each cultivar and mean yield in non-stressed conditions for all genotypes.

3.6.2 Stress tolerance index

Fernandez (1992) defined a new advanced index, stress tolerance index (STI), which is used to identify genotypes that produce high yield under both stress and non-stressed conditions. STI is considered as a useful tool for determining high yield and stress tolerance potential of genotypes, and is provided by the following formula.

$$STI = (Y_s * Y_p) / Y_p$$

Where:-

Y_s , and Y_p , represent yield under stress and yield under no-stress respectively for each cultivar.

3.6.3 Yield index

Gavuzzi *et al.*, (1997) suggested yield Index (YI) for evaluation of the stability of genotypes in both stress and no-stress conditions. Yield index for determining drought tolerant genotypes is given by the following formula;

$$YI = (Y_s) / (\bar{Y}_s)$$

Where:-

Y_s and $\bar{Y}_s$ represent yield under stress for each cultivar and mean yield in stressed conditions for all cultivars.

3.6.4 Harvest Index

Harvest index (HI) was determined using the following formula;

$$HI = \frac{\text{Weight of harvested product (grains) (g)}}{\text{Total plant weight (stover + grain) above ground (g)}}$$

3.6.5 Identification of drought tolerant genotypes using selection indices

The mean of yields of genotypes under stress and non-stress condition were converted into yield indices by using selection indices formulae. Genotypes were ranked based on the value of the yield indices within the selection method.

3.6.6 Identification of suitable drought tolerance selection index

The identification of suitable drought tolerance selection index was based on conducting correlation analysis between yield under non water stress and yield under water stress. Selection indices that were highly significant and positively correlated with yield were selected as best drought tolerance selection indices for evaluation of common beans for drought tolerance.

3.7 Data Analysis

3.7.1 Analysis of variance

Data were analyzed statistically using ANOVA as described by Gomez, K and Gomez, A (1984) statistical procedure for split plots arranged in RCBD. The statistical linear model used was:-

$$Y_{ijh} = \mu + \theta_h + \alpha_i + \epsilon_{ih} + \beta_j + \alpha\beta_{ij} + \epsilon_{ijh}$$

Where:-

Y_{ijh} is the observed value of h^{th} replicate, i^{th} levels of factor A and the j^{th} levels of factor B. μ is the general mean, α_i is the effect of i^{th} levels of factor A and β_j is the effect for the j^{th} levels of factor B. θ_h is the block effect for the h^{th} blocks, ϵ_{ih} is the whole plot random error effects for the i^{th} levels of factor A and the h^{th} of blocks. $\alpha\beta_{ij}$ is the interaction effect of the i^{th} levels of factor A with the j^{th} levels of factor

B. ϵ_{ijh} is the subplot random error effect. Means were compared using Duncan's New Multiple Range Test (DNMRT) at $P \leq 0.05$ level.

3.7.2 Correlation analysis

The drought tolerance selection indices (YI, SSPI and STI) and yield of genotypes under water stress and non-water stressed conditions were subjected to correlation analysis ($P \leq 0.05$) using GenStat software 14th edition.

CHAPTER FOUR

4.0 RESULTS

4.1 Soil Analysis

Physical and chemical properties of soil presented are in Table 3. The soil was sandy loam, with a slightly acidic condition (pH 5.3), and cation exchange capacity (CEC) of 15.41 cmol_c (+)/kg, which was rated as high. The quantity of exchangeable bases for potassium and calcium were low (0.12 cmol_c (+)/kg) and medium (4.49 cmol_c (+)/kg) respectively, while for magnesium was 2.14 cmol_c (+)/kg, which was rated as also medium. Total nitrogen of the soil was medium (0.13%), while phosphorus was 15.30 mg/kg, which was also medium and percent organic carbon was low (0.82%).

4.2 Weather Condition

Weather data were collected in 2015, however there were no precipitations data since the experiments were conducted during off season. Data collected were mean monthly maximum temperature, which ranged from 17.06°C in September to 27.23°C in October and minimum temperature, which ranged from 5.20°C in May to 14.05°C in November. The mean relative humidity (R.H) was lowest in August (57.93%) and highest in July (72.7%). Solar radiation was lowest in June (17.72 MJm⁻²day⁻¹), and highest in September (18.73 MJm⁻²day⁻¹) (Appendix 1). Under screen house conditions, mean monthly maximum temperature ranged from 27.55°C in October to 19.11°C in September while the mean monthly minimum temperature ranged from 7.31°C in May to 15.13°C in November, and the R.H was highest in June (82.4%) and lowest in August (63.30%).

Table 3: Physical and chemical characteristics of soil in the experimental site

Parameter	Unit	Quantity	Remarks	Reference
Physical characteristics				
Clay	%	28.43	Sandy loam	Anderson and Ingram (1993)
Silt	%	33.01		
Sand	%	48.59		
Chemical characteristics				
Soil pH(1:25) H2O	pH	5.3	Slightly acidic	Maclean (1982)
CEC	cmol _c (+)/kg	15.41	High	Chapman (1965)
K	mg/l	0.12	Low	Moberg (2000)
Ca	cmol _c (+)/kg	4.49	Medium	Moberg (2000)
Mg	cmol _c (+)/kg	2.14	Medium	Moberg (2000)
TN	%	0.13	Low	Bremner and Mulvanay (1982)
OC	%	0.82	Low	Nelson and Sommers (1982)
P	mg/kg	15.3	Medium	Olsen and Sommers (1982)

4.3 Results of Analysis of Variance (ANOVA) for Screen House Experiment

The results of ANOVA at 0.05 level of probability for growth characteristics are presented in Table 4.

4.3.1 Effects of water stress treatments and common bean genotypes on growth characteristics

The growth characteristics observed were number of leaves per plant, shoots dry weight, root length, roots dry weight and number of days of the bean genotypes to attain 50% flowering and 85% physiological maturity.

4.3.1.1 Number of leaves per plant

There were highly significant differences ($P \leq 0.001$) of number of leaves per plant among bean genotypes (Table 4). Highest number of leaves per plant was observed from 41-EX-VAM (25.45) followed by CZ104-61 (25.22), PASS (22.22), SER45 (21.89), RCB 233 (20.44), BFS60 (19.78) and BFS20 (18.44). Lowest number of leaves was observed from KG25-21 and SER124 both with 13.11 number of leaves per plant, followed by SER16 with 16 numbers of leaves. Other genotypes had moderate number of leaves per plant (Table 4)

Table 4: Effects of water treatments and common bean genotypes on growth characteristics

Water treatments (a)	Number of leaves	Shoot dry weight(g)	Root length(cm)	Roots dry weight(g)	50% Flowering	85% maturity
SP0	22.89c	19.49c	43.41a	0.8807c	59.59a	96.30c
SPI	12.5a	14.2a	43.87a	0.3831a	58.93a	87.91a
SPII	17.59b	17.25b	41.66a	0.5817b	60.04a	91.00b
Mean	17.66	16.98	42.98	0.62	59.52	91.74
F.test_{0.05}	***	***	ns	***	ns	***
CV%	9.0	2.2	2.4	9.8	5.5	11
Genotype (b)						
SER82	14.11a-d	13.45ab	36ab	0.46ab	52.00a	86.33a
SER16	13.33abc	19.29ghi	40.06a-e	0.49ab	52.11a	88.56abc
KG104-72	17.67d-h	14.9a-d	46.71ghi	0.46ab	52.56a	86.56ab
RCB266	17.56d-h	14.96a-e	36.58abc	0.35a	55.00ab	87.78abc
SER125	14.22a-e	15.42b-f	45.61d-h	0.5ab	55.00ab	88.22abc
KG25-21	13.11ab	18.02f-i	44.93d-h	0.76abc	55.44abc	92.11def
PASS	22.22hij	15.43b-f	53.31i	0.88bc	57.44bcd	97.00h
SER124	13.11ab	17.65d-h	45.97e-h	0.69ab	58.56cd	90.00b-e
BFS20	18.44e-h	17.39d-h	45.57d-h	0.8bc	59.56de	95.11fgh
CZ104-61	25.22ij	14.76abc	43.67b-f	0.54ab	60.44de	95.22fgh
KG4-30	15.78b-f	19.25ghi	41.35a-f	0.65ab	60.67de	89.22a-d
CZ109-22	16.89c-g	16.78c-g	32.76a	0.62ab	62.33ef	93.33efg
MR13905-6	12.89a	15.63b-g	46.62e-i	0.87bc	62.56efg	93.00efg
RCB233	20.44f-j	21.3i	46.56e-i	0.46ab	62.67efg	96.33gh
SER83	15.78b-f	17.99e-i	44.77d-g	0.47abc	64.33fgh	93.11efg
BFS60	19.78f-i	20.54hi	48.72hi	0.7abc	65.78ghi	90.78cde
41-EX-VAM	25.45j	12.25a	38.51abcd	0.52ab	66.89hi	93.11efg
SER45	21.89g-j	20.6hi	36ab	0.84bc	68.00i	95.44fgh
Mean	17.66	16.98	42.98	0.62	59.52	91.74
F.test_{0.05}	***	***	*	ns	**	**
CV%	9.9	1.7	12.8	26.7	6.4	8.3

Means in the same column followed by the same letter(s) are not statistically different ($P \leq 0.05$) by Duncan's New Multiple Range Test. ns = Non-significant, * = Significant at 0.05, ** = Significant at 0.01, *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

There were significant differences ($P \leq 0.05$) of number leaves per plant produced under the different stress periods (Table 4). Highest number of leaves across stress periods were produced from those genotypes stressed at mid pod-filling (SPII) (22.89) followed by those produced under unstressed condition (SP0) (17.57) while lowest number of leaves were produced by those stressed at flowering (SPI) (12.5) (Table 4).

4.3.1.2 Shoot dry weight

There were highly significant differences ($P \leq 0.001$) of shoot dry weight among the bean genotypes (Table 4). Genotype with highest weight of shoots per plant was SER45 (23.4 g) followed by RCB233 (21.30 g), BFS60 (20.54g) KG4-30 (19.25g) and SER16 (19.29 g); however KG4-30 and SER16 were statistically similar in terms of shoots dry weight. Lowest weight of shoots among bean genotypes was recorded from SER82 (13.45 g) followed by CZ104-6 (14.76 g), KG104-72 (14.90 g), RCB266 (14.96 g), SER 125 (15.42 g) and PASS (15.43 g), although, SER125 and PASS were statistically not different. The remaining genotypes had a moderate shoot dry weight (Table 4).

The response of genotypes across water stress periods showed highly significant differences ($P \leq 0.001$) on shoots dry weight (Table 4), and the highest weight was from unstressed treatment (19.49 g) followed by those stressed at mid-pod filling (17.25 g) and the lowest shoot dry weight was recorded from those genotypes stressed at flowering (14.2 g) (Table 4).

4.3.1.3 Root length

There were significant differences ($P \leq 0.05$) of root length among common bean genotypes (Table 4). Genotype with longest roots was PASS (53.31cm) followed by KG104-72 (46.71cm), MR13905-6 (46.62cm), RCB23 (56 cm), SER124 (45.97 cm) and BFS20 (45.59 cm). Shortest roots was observed from CZ109-22 (32.76 cm) followed by SER 82 (36.00 cm) RCB 266 (36.58cm) and 41-EX-VAM (38.51cm). The remaining genotype had moderate root length (Table 4)

The response of genotypes across water treatments showed no statistical difference of root length (Table 4); however, the longest root was recorded from plants stressed at flowering (43.87 cm) followed by those with unstressed condition (43.41 cm) and the shortest roots was from those stressed at mid-pod filling (41.66 cm) (Table 4)

4.3.1.4 Roots dry weight

There were no statistical differences of roots dry weight among bean genotypes (Table 4), Highest roots dry weight was recorded from PASS (0.88 g) followed by MR 13905-6 (0.87 g), SER45 (0.84g) and KG25-21 (0.76 g). Genotype with moderate roots dry weight were BFS60 (0.7g), SER 24 (0.69g) KG 4-30 (0.65 g) and Z109-22 (0.62g). Lowest root dry weight was observed from RCB266 (0.35 g) followed by a weight of 0.46 g which was observed from SER82, KG 104-72, RCB 233 and SER 83 (0.47 g).

Across stress periods, results showed highly significant differences ($P \leq 0.001$) of roots dry weight of common bean genotypes (Table 4). The mean roots dry weight was largest with those genotypes grown under unstressed condition (0.8 g) followed by those stressed at mid-pod filling (0.58g) and the lightest was from those stressed at flowering (0.38g) (Table 4).

4.3.1.5 Days to 50% flowering

There were highly significant differences ($P \leq 0.01$) of number of days to attain 50% flowering among common bean genotypes (Table 4). Genotypes with lowest number of day to attain 50% flowering was SER82 (52.0) DAP followed by SER16 (52.11)

DAP, KG104-72 (52.56) DAP and 55 DAP of bean genotypes was recorded from RCB266 and SER125. Genotypes with intermediate number of days to attain 50% flowering were KG25-21 (55.44) DAP, PASS (57.44) DAP, SER124 (58.56) DAP and SER124 (58.56) DAP. Genotypes with longest days to 50% flowering was SER45 (68) DAP followed by 41-EX-VAM (66.8) DAP, BFS60 (65.78) DAP. SER83 (64.33) DAP, RCB233 (62.67) DAP, MR 13905-6 (62.56) DAP and CZ 109-22 (62.33) DAP (Table 4). The remaining genotype had moderate number of days to attain 50% flowering.

On the other hand, there were no significant differences based on water stress periods, and their interaction (Table 4) since the application of stress periods started at flowering stage (when 50% of the whole plot attained flowering).

4.3.1.6 Days to 85% maturity

Common bean genotypes showed highly significant differences ($P \leq 0.001$) on days to attain 85% physiological maturity (Table 4). Genotype with shortest number of days to reach 85% maturity was SER82 (86.33) DAP followed by KG104-72 (86.56) DAP, RCB266 (87.78) DAP, SER125 (88.22) DAP and SER16 (88.56). Genotypes with longest number of days to reach 85% physiological maturity was PASS (97.00) DAP, RCB233 (96.33) DAP, SER45 (95.44) DAP, CZ104-61 (95.22) DAP, and BFS20 (95.11) DAP. However SER45, CZ104-61 and BFS20 were statistically similar. The remaining genotypes had moderate number of days to reach 85% maturity (Table 4).

The general response of genotypes on days to attain 85% physiological maturity was significant ($p \leq 0.05$) across water treatment (Table 4). Genotypes matured earlier, were those stressed at flowering (87.91) DAP followed by those stressed at mid pod filling (91.00) DAP, and the latest to attain 85% maturity appeared to the unstressed condition (96.3) DAP (Table 4).

4.3.2 Effects of interaction between water stress treatments and common bean genotypes on yields and yield components (Screen House Experiment)

4.3.2.1 Effects of interaction on number of leaves per plant

However, the interaction effect was not significant (Table 5), genotype PASS (33) produced highest number of leaves in the unstressed treatment followed by 41-EX-VAM (30.67), BFS60 (30.33), CZ104-61 (27.07), RCB233 (27.00) and SER45 (26.67), although, genotype 41-EX-VAM (30.67) and BFS60 (30.33) produced statistically the same number of leaves (Table 5). Highest number of leaves per plant among genotypes stressed at mid-pod filling was produced from 41-EX-VAM (28.00) followed by SER45 (26), CZ104-61 (24.33) and RCB 233 (24.00) while lowest number of leaves under the unstressed condition were produced from SER16 (16.00) followed by SER82 (16.67), SER124 (17.33) and KG25-21(18.67). Other genotypes produced lowest number of leaves were MR13905-6 and KG125 with 19.00 each (Table 5). The lowest number of leaves among genotypes stressed at flowering was from KG25-21 (7.67), followed by MR13905-6 (8.33) and SER125 (8.67), while low number of leaves among genotypes stressed at mid-pod filling was observed from MR13905-6 (11.33) followed by SER16 (12.33) and KG25-21 (13.00) (Table 5).

Table 5: Effects of interaction between water stress treatments and common bean genotypes on growth characteristics

Water treatments X Genotype	Number of leaves	Shoot dry weight(g)	Root length(cm)	Roots dry weight(g)	50% Flowering	85% maturity
SP0 X SER82	16.67c-n	12.53a-g	30.17abc	0.5543a-l	52.00b	89.00a-i
SP0 X SER16	16.00b-m	21.41n-q	42.83a-e	0.7763g-q	56.67b-i	93.67f-p
SP0 X KG104-72	24.00m-s	14.19b-k	55.00de	0.6667b-n	52.33bcd	89.00a-i
SP0 X RCB266	19.67h-q	16.57d-o	37.40a-e	0.6863c-n	54.00b-c	90.33b-j
SP0 X SER125	19.00g-p	15.67d-m	47.33a-c	0.7050d-n	55.00b-f	90.67b-l
SP0 X KG25-21	18.67f-o	21.56n-q	43.33a-e	1.1690opq	55.33b-g	98.00k-r
SP0 X PASS	33.00t	17.91g-o	57.77e	1.0937m-q	57.67b-j	100.67pqr
SP0 X SER124	17.33d-n	21.18m-q	49.67b-e	0.9823l-q	58.33b-j	95.67i-q
SP0 X BFS20	22.33j-r	18.34h-o	42.37a-e	1.0764m-q	59.00d-k	101.00qr
SP0 X CZ104-61	27.67rst	18.10g-o	43.00a-e	0.8377j-q	60.33e-m	101.33qr
SP0 X KG4-30	20.67i-r	17.03d-o	42.73a-e	1.1163n-q	60.33e-m	92.33c-n
SP0 X CZ109-22	19.67h-q	21.14m-q	24.27a	0.7460f-p	62.33h-q	98.00k-r
SP0 X MR13905-6	19.00g-p	17.16e-o	52.17b-e	1.1830pq	63.00i-q	99.33no-r
SP0 X RCB233	27.00q-t	24.19pqr	39.67a-e	0.7050d-n	62.33h-q	103.00r
SP0 X SER83	23.67l-s	19.76k-o	50.77b-e	0.7070d-n	63.00i-q	95.33h-q
SP0 X BFS60	30.33st	27.33r	50.33b-e	0.8907k-q	65.67k-q	98.00k-r
SP0 X 41-EX-VAM	30.67st	18.70h-o	41.00a-e	0.7433f-p	67.33npq	98.00k-r
SP0 X SER45	26.67p-t	28.00r	31.67a-d	1.2135q	68.00q	99.67o-r
SPI X SER82	12.00a-h	11.62a-e	37.17a-e	0.3240a-h	52.00b	84.00abc
SPI X SER16	11.67a-h	16.94d-o	39.67a-e	0.2467a-d	43.00a	83.00a
SPI X KG104-72	13.67a-i	15.67c-m	42.47a-e	0.2887a-f	52.67bcd	84.67a-d
SPI X RCB266	14.67a-j	15.08b-l	33.33a-d	0.1663a	54.00b-e	84.00abc
SPI X SER125	8.67abc	13.29a-i	43.50a-e	0.3577a-i	55.00b-f	86.67a-f
SPI X KG25-21	7.67a	17.83f-o	50.60b-e	0.3127a-g	55.67b-h	86.33a-f
SPI X PASS	10.67a-f	11.45a-d	49.67b-e	0.7403f-p	57.33b-j	93.67f-p
SPI X SER124	8.33ab	16.33d-o	41.57a-e	0.3750a-j	58.67b-j	83.67ab
SPI X BFS20	15.67a-l	13.17a-h	53.33cde	0.5293a-l	59.67e-l	90.67b-l
SPI X CZ104-61	23.67l-s	10.09abc	41.67a-e	0.2693a-e	60.33e-m	90.00a-j
SPI X KG4-30	13.00a-i	19.06j-p	52.33b-e	0.2983a-f	60.67e-n	87.33a-g
SPI X CZ109-22	13.33a-i	12.17a-f	34.00a-e	0.4043a-j	62.00g-q	90.00a-j
SPI X MR13905-6	8.33ab	13.42a-j	50.37b-c	0.5413a-l	62.00g-q	86.00a-c
SPI X RCB233	10.33a-e	15.08b-l	48.17a-e	0.2357abc	62.33h-q	90.67b-l
SPI X SER83	9.67a-d	18.92i-p	37.53a-e	0.2880a-f	64.00j-q	92.67e-o
SPI X BFS60	13.00a-i	12.44a-g	47.17a-e	0.5557a-l	65.67k-q	84.00abc
SPI X 41-EX-VAM	17.67d-n	8.04a	42.20a-e	0.3257a-h	67.00m-q	90.67b-k
SPI X SER45	13.00a-i	15.01b-l	45.00a-e	0.6370b-m	68.33q	92.33e-n
SPII X SER82	13.67a-i	16.20d-o	40.67a-e	0.5047a-k	52.00bc	86.00a-e
SPII X SER16	12.33a-h	19.52k-q	37.67a-e	0.4617a-k	56.67b-i	89.00a-i
SPII X KG104-72	15.33a-k	14.84b-k	42.67a-e	0.4283a-k	52.67bcd	86.00a-e
SPII X RCB266	18.33e-o	13.22a-h	39.00a-e	0.2063ab	57.00b-i	89.00a-i
SPII X SER125	15.00a-k	17.30e-o	46.00a-e	0.4307a-k	55.00b-f	87.00a-g
SPII X KG25-21	13.00a-i	14.66b-k	40.87a-e	0.8117i-q	55.33b-g	90.67b-l
SPII X PASS	23.00k-s	16.92d-o	52.50b-e	0.7920h-q	57.33b-j	96.67j-r
SPII X SER124	13.67a-i	15.44b-l	46.67a-e	0.7227e-o	58.67b-j	90.67b-k
SPII X BFS20	17.33d-n	20.65l-q	41.00a-e	0.8063i-q	60.00e-l	92.67e-o
SPII X CZ104-61	24.33n-s	16.10d-n	46.33a-e	0.5253a-l	60.67e-o	94.33g-q
SPII X KG4-30	13.67a-i	21.65n-q	29.00ab	0.5297a-l	61.00f-p	88.00a-h
SPII X CZ109-22	17.67d-n	17.03d-o	40.00a-e	0.7090d-n	62.67i-q	90.67b-l
SPII X MR13905-6	11.33a-g	16.32d-o	37.33a-e	0.8813k-q	62.67i-q	93.67f-p
SPII X RCB233	24.00m-s	24.64qr	51.83b-e	0.4430a-k	63.33i-q	94.33g-q
SPII X SER83	14.00a-i	15.30b-l	46.00a-e	0.4053a-j	66.00l-q	90.67b-l
SPII X BFS60	16.00b-m	21.84opq	48.67b-e	0.6510b-m	66.00l-q	90.33a-j
SPII X 41-EX-VAM	28.00rst	10.00ab	32.33a-d	0.4887a-k	66.33i-q	90.67b-l
SPII X SER45	26.00o-t	18.80h-p	31.33a-d	0.6723b-n	67.67q	94.33g-q
Mean	17.66	16.98	42.98	0.61	59.52	91.74
F.test 0.05	ns	ns	ns	ns	ns	ns
C.V%	43.1	43.8	30.3	33.4	28.7	24.1

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test, ns= non-significant, *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

4.3.2.2 Effects of interaction on shoot dry weight

With regard to interaction of genotypes and water stress periods, there were no significant effects (Table 5) on shoot dry weight, although, highest shoot dry weight in the unstressed treatment was observed from SER45 (28.00 g) followed by BFS60 (27.33 g), RCB233 (24.19 g), KG25-21 (21.56 g), SER124 (21.18 g) and a weight of 21.14 g was observed from both SER16 and CZ109-22 (Table 4). On the other hand, highest shoot dry weight among genotypes stressed at mid-pod filling was from RCB233 (24.64 g) followed by BFS60 (21.84 g), KG4-30 (21.65 g), BFS20 (20.65 g) and SER16 (19.52 g) (Table 4); However genotypes produced heaviest shoots when stressed at flowering were KG 4-30 (19.06 g) and SER83 (18.92 g). The lightest shoot dry weight in the unstressed treatments was from SER82 (12.53 g) followed by KG104-72 (14.91 g), SER125 (15.67 g), RCB266 (16.57 g) and KG 4-30 (17.03 g). Also the lightest shoots among genotypes stressed at flowering was from 41-EX-VAM (8.04 g) followed by SER124 (11.45 g) and SER82 (11.62 g). while the lowest shoot dry weight among genotypes stressed at mid-pod filling, was recorded from RCB266 (13.22 g) followed by KG25-21(14.66 g) and KG104-72 (14.84 g).

4.3.2.3 Effects of interaction on root length

The interaction effect was not significant on root length among genotypes (Table 5); however, PASS (57.77 cm) produced longest roots in the non-stressed treatment, followed by KG104-72 (55 cm) and MR13905-6 (52.17 cm), although, root length of MR13905-6 was statistically similar to SER 83, BFS60 and SER124, with a root length of 50.77 cm, 50.33 cm and 49.67 cm respectively (Table 5). On the other

hand, longest roots among genotypes stressed at flowering was from BFS20 (53.33 cm) followed by KG4-30 (52.33 cm), KG25-21 (50.6 cm) and MR13905-6 (50.37 cm) (Table 4), while PASS (52.50 cm) had the longest roots among genotypes stressed at mid-pod filling followed by RCB237 (51.83 cm), BFS60 (48.67 cm) and CZ104-61 (46.33 cm). Other genotypes with longest roots but statistically similar in this condition were SER125 and SER83 with 46.00 cm each. In the unstressed treatments, shortest roots among genotypes was from CZ109-22 (24.27 cm) followed by SER82 (30.17 cm) and SER45 (31.67 cm). The shortest roots across genotypes stressed at flowering were from RCB266 (33.33 cm) followed by Z109-22 (34 cm), SER83 (37.53 cm), SER82 (37.17 cm) and SER16 (39.67 cm) while the shortest roots among bean genotypes stressed at mid-pod filling was from KG4-30 (29 cm) followed by SER45 (31.33 cm) and 41-EX-VAM (32.33 cm), although, SER45 and 41-EX-VAM were statistically similar in root length.

4.3.2.4 Effects of interaction on roots dry weight

There were also no significant differences of roots dry weight caused by the interaction effect, (Table 5), although, the highest weight observed from non-water stressed condition was from SER45 (1.24 g) followed by MR13905-6 (1.18 g), KG25-21 (1.17 g), KG4-30 (1.12 g), BFS20 (1.10 g) and SER124 (0.98 g) (Table 4). On the other hand highest roots dry weight among genotypes stressed at mid-pod filling was from MR13905-6 (0.88g) followed by KG25-25 (0.81g), BFS20 (0.80g), PASS (0.80g) and SER124 (0.72g), although, genotypes KG25-21 and BFS20 were statistically similar (Table 4). The highest roots dry weight among genotypes stressed at flowering was from PASS (0.74g) followed by SER45 (0.64g), BFS60

(0.56g), MR13905-6 (0.54g) and BFS20 (0.53g) while the lowest roots dry weight among genotypes stressed at flowering was from RCB266 (0.17g) followed by SER16 (0.25g) and CZ104-61(0.327g). On the other hand, lowest roots dry weight among genotypes stressed at mid pod filling was from RCB266 (0.21g) followed by KG104-72 (0.43g) and SER125 (0.42g).

4.3.2.5 Effects of interaction on number of days to attain 85% maturity

Days to reach 85% maturity of common bean genotypes were not significantly influenced by the interaction effect (Table 5); however, under unstressed condition earliest genotypes to attain 85% maturity were SER82 and KG104-72, with (89) DAP each, followed by RCB266 and SER125 with (90) DAP each. On the other hand, earliest genotypes to attain 85% physiological maturity under stress at flowering was from SER16 (83) DAP followed by SER124 (83.67) DAP (Table 4). Other genotypes were RCB266 and BFS60 with (84) DAP each, while the earliest genotypes to attain 85% maturity under stress at mid-pod filling were SER82 and KG104-72 with 86.00 DAP each, followed by SER125 (87) DAP and KG4-30 (88) DAP. Also, the latest genotypes to attain 85% physiological maturity when grown in the unstressed environment was RCB233 (103) DAP followed by BFS20 and CZ104-61 with (101) DAP each. Genotypes which took longest days to reach 85% maturity were those stressed at flowering such as SER83 which took 92.67 DAP followed by BFS20, RCB233 and 41-EX-VAM which had 90.67 DAP each, while BFS20 and CZ109-6 had 90.00 DAP each. The latest genotype to attain 85% maturity stressed at mid-pod filling was PASS (96.67) followed by CZ104-61, RCB233 and SER45 with 94.33 DAP each.

4.3.3 Effects of water stress treatments and common bean genotypes on and yield components (Screen House Experiment)

The observed yield components were number of pods per plant, weight of pods per plant, number seeds per pod, number of seeds per plant and harvest index.

4.3.3.1 Number of pods per plant

Highly significant differences ($P \leq 0.001$) of number of pods per plant were noted among common bean genotypes (Table 6). Highest number of pods per plant was noted from SER45 (19.83) followed by RCB283 (15.03), KG104-72 (14.56) and SER124 (14.0); however RCB233 and KG104-72 were statistically similar (Table 6). Genotype with lowest number of pods was PASS (9.11) and KG4-30 (10.17). Other genotypes had moderate number of pods and they were also statistically the same (Table 6).

Across water treatments, significance differences of number of pods of bean genotypes were observed. Highest number of pods was from unstressed treatment (17.25) followed by stress at mid-pod filling (11.4) and the lowest number of pods was from stress at flowering (9.76) (Table 6).

4.3.3.2 Weight of pods per plant

Highly significant differences ($P \leq 0.001$) of weights of pods per plant were observed among bean genotypes (Table 6). Highest weight of pods per plant was recorded from SER16 (21.41 g) followed by SER45 (19.92 g), KG4-30 (17.09 g), SER124 (16.22 g), and KG104-72 (15.09 g). Genotypes with moderate weight of pods were RCB233

Table 6: Effects of water stress treatments and common bean genotypes on yield components.

Water treatments (a)	Number of pods per plant	Weight of pods per plant(kg)	Number of seeds per pod	Weight of seeds per plant(g)	Harvest index
SP0	17.25b	15.65c	5.12a	12.67c	0.64c
SPI	10.79a	10.82a	4.59a	7.82a	0.53a
SPII	10.37a	13.80b	5.09a	10.29b	0.58b
Mean	12.8	13.42	4.934	10.26	0.5836
F.test _{0.05}	**	***	ns	***	**
CV%	1.9	1.8	1.2	1.7	2.3
Genotype (b)					
PASS	9.11a	12.18bcde	3.278a	8.47abcd	0.4774a
KG4-30	10.17ab	17.09gh	4.500b	13.92g	0.6915ef
RCB266	11.11abc	11.27bc	5.250bc	7.67abc	0.5329abc
SER16	11.14abc	21.41i	5.083bc	19.48i	0.8116g
SER83	12.00abc	11.05bc	5.194bc	7.34abc	0.4772a
CZ109-22	12.22abc	11.99bcd	5.222bc	9.38b-e	0.5629a-d
SER125	12.28abc	7.79a	5.361c	5.71a	0.5525a-d
BFS60	12.42abc	11.33bc	4.833bc	7.43abc	0.4636a
CZ104-61	12.44abc	13.57cdef	4.944bc	9.71b-e	0.5561a-d
41-EX-VAM	12.64abc	9.24ab	5.083bc	6.77ab	0.5194ab
MR13905-6	12.64abc	13.15cde	4.611bc	10.17c-f	0.6511c-f
KG25-21	12.83abc	11.87bcd	4.889bc	8.33a-d	0.5454a-d
BFS20	12.92abc	12.87cde	4.833bc	10.71def	0.6576def
SER82	13.14abc	11.57bcd	4.778bc	7.27abc	0.4656a
SER124	14.00bc	16.22fg	5.222bc	12.94fg	0.6246b-e
KG104-72	14.56c	15.09efg	5.194bc	10.77def	0.5371a-d
RCB233	15.03c	14.49defg	5.278bc	12.05efg	0.6343b-f
SER45	19.83d	19.42hi	5.250bc	16.48h	0.7441fg
Mean	12.8	13.42	4.934	10.26	0.5836
F.test _{0.05}	***	***	***	***	***
CV%	9.4	1.6	5.1	3.5	3.4

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test*** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

(14.49 g), CZ104-61 (13.57 g), MR13905-6 (13.15 g), BFS20 (12.87) and pass (12.18g). Lowest weight of pods was obtained from SER125 (7.79g), 41-EX-VAM (9.24g), SER83 (11.05g), RCB266 (11.27g) and BFS60 (11.33g). Other genotypes were moderate on weight of pods per plant (Table 6).

There were also highly significant differences ($P \leq 0.001$) of weight of pods per plant with regard to water stress periods (Table 6). The heaviest pods occurred from genotypes with the unstressed treatments (17.58 g) followed by those stressed at mid

pod filling (14.58 g) and the lightest pods was from genotypes stressed at flowering (10.02 g) (Table 6).

4.3.3.3 Number of seeds per pod

There were highly significant differences ($P \leq 0.001$) on number of seeds per pod among common bean genotypes (Table 6). Highest number of seeds per pod was recorded from SER125 (5.36). Genotype with lowest number of seeds was PASS (3.27) followed by KG 4-50 (4.500). Other genotypes had moderate number of seeds and they were statistically the same (Table 6)

There were no significant differences of number of seeds per pod of bean genotypes between the unstressed and those stressed at mid-pod filling treatments, although, significant differences was observed between those genotypes stressed at flowering and unstressed condition (Table 6). The number of seeds per pod in a non-stressed treatment was 5.12 followed by those genotypes stressed at mid-pod filling (5.09) and the lowest number of seeds was from stress at flowering (4.6).

4.3.3.4 Weights of seeds per plant

There were highly statistical differences ($P \leq 0.001$) of weight of seeds per plant among common bean genotypes (Table 6), highest weight of seeds per plant was recorded from SER16 (19.48 g), followed by SER45 (16.48 g), KG4-30 (13.92 g), SER124 (12.94 g), and RCB233 (12.05 g), (Table 5). Genotype with highest weight of seeds was SER125 (5.7 g), followed by 41-EX-VANY (6.72 g), SER82 (7.27 g), SER83 (7.34 g), BFS60 (7.43 g), and RCB266 (7.67 g); however, SER82, SER83, BF560 and RCB266 were statistically not different. Other genotype had moderate weight of seeds (Table 6).

The response of genotypes on seeds weight per plant due to different water treatments was highly significant ($p < 0.001$) (Table 5). The highest weight of seeds was recorded from SP0 (10.419 g) followed by SPII (9.183 g) while SPI (4.946 g) was the lightest (Table 6).

4.3.3.5 Harvest index

Genotypes were highly significant ($p \leq 0.001$) on harvest index (Table 6). Highest harvest index was obtained from SER16 (0.8116 g) followed by SER45 (0.7441 g), KG4-30 (0.6915 g), BFS20 (0.6576g), MR13905-6 (0.6511 g), RCB233 (0.6343 g) and SER124 (0.6246 g). Genotype with lowest harvest index was BFS60 (0.4636 g) followed by SER82 (0.4656 g), SESR83 (0.4772g), PASS (0.4774g,) 41-EX-VAM (0.5194 g) and RCB266 (0.5329 g). The remained genotype had moderate harvest index and they were statistically similar (Table 6).

The response of genotypes at different water treatments showed significant differences ($p \leq 0.01$). Highest harvest index was from unstressed treatment (0.64) followed by stress at mid-pod filling (0.58) and the lowest was determined from stress at flowering (0.53) (Table 6).

4.3.4 Effects of interaction between water tress treatments and common bean genotype on yield components

4.3.4.1 Effects of interaction on number of pods per plant

However, the interaction effect was not significant on number of pods (Table 7), highest number of pods among genotypes with no water stress was from SER45

(26.58) followed by BFS60 (25.5), 41-EX-VAM (21.83), RCB233 (20.92) and SER124 (18.5) (Table 7). Genotypes with moderate number of pods in this condition was SER16 (17) followed by CZ109-22 (17.08) SER125 (17.00), BFS60 (16.67), SER82 (16.5) and 16.42 number of pods were recorded from both KG104 and SER 83. The highest number among genotypes stressed at flowering was from SER124 (16.88) followed by SER45 (15.58), SER83 (14.75), SER16 (12.83) and KG104-72 (12.81) (Table 5), whereas the highest number of pods of genotypes stressed at mid-pod filling was from RCB233 (21.33) followed by BFS20 (20.83), SER45 (17.33), CZ109-22 (15.17), SER83 (14.83) and KG104-72(14.75) (Table 7). The lowest number of pods of bean genotypes grown under unstressed treatments was from KG4-

30 (13.42) followed by PASS and MR13905-6 with 14.25 number of pods each. On the other hand, lowest number of pods stressed at flowering was from PASS (7.75) followed by CZ109-22 (8.42), BFS60 (8.92), KG4-30 (9.33), RCB266 (9.42) and 41-EX-VAM (9.83), while the lowest number of pods among genotypes stressed at mid-pod filling was from PASS (5.33) followed by 41-EX-VAM (6.25), KG4-30 (7.75) and RCB266 (10.67).

Table 7: Effects of interaction between water treatments and common bean genotypes on yield components

Water treatments x Genotype	Number of pods per plant	Weight of pods per plant(kg)	Number of seeds per pod	Weight of seeds per plant(g)	Harvesting index (%)
SP0 X SER82	16.50g-m	12.61b-n	4.417c-f	8.06a-f	0.5416c-h
SP0 X SER16	17.33i-m	25.34t	5.083d-g	23.40n	0.8324k
SP0 X KG104-72	16.42f-m	15.83k-q	5.167d-g	11.65f-l	0.5980d-j
SP0 X RCB266	14.25c-l	14.50h-p	5.667efg	10.71c-k	0.6672f-k
SP0 X SER125	17.00h-m	9.57a-h	5.167d-g	7.16a-f	0.5615c-h
SP0 X KG25-21	15.92c-m	12.67b-n	5.000c-g	8.87b-g	0.6223e-k
SP0 X PASS	14.25c-l	18.38o-r	3.833bcd	14.91i-l	0.7026g-k
SP0 X SER124	18.50klm	20.00qrs	5.250d-g	16.53lm	0.6846f-k
SP0 X BFS20	16.67g-m	15.01h-q	4.667c-g	11.98f-l	0.6757f-k
SP0 X CZ104-61	15.75d-m	14.06g-o	5.333d-g	12.08f-l	0.6671f-k
SP0 X KG4-30	13.42b-k	17.93no-r	5.167d-g	15.83klm	0.7408h-k
SP0 X CZ109-22	17.08h-m	15.23i-q	5.083d-g	11.93f-l	0.6063d-j
SP0 X MR13905-6	14.25c-l	13.77f-o	4.500c-g	11.45f-l	0.6973g-k
SP0 X RCB233	20.92lmn	17.20m-r	5.583efg	14.43h-l	0.6739f-k
SP0 X SER83	16.42f-m	12.21b-m	6.000g	10.18e-j	0.6191e-k
SP0 X BFS60	25.50no	13.11c-o	4.833c-g	9.61c-i	0.5540c-h
SP0 X 41-EX-VAM	21.83mn	10.16a-j	5.750efg	7.45a-f	0.5510c-h
SP0 X SER45	26.58o	24.08st	5.667efg	21.79n	0.7973ijk
SPI X SER82	11.42a-k	7.57abc	4.667c-g	3.85ab	0.3872a-d
SPI X SER16	12.83a-k	16.76l-q	4.750c-g	15.10jkl	0.7917ijk
SPI X KG104-72	12.81a-k	15.10h-q	4.833c-g	12.37fg-l	0.5824d-i
SPI X RCB266	9.42a-g	8.68a-g	5.250d-g	5.30a-e	0.4222a-e
SPI X SER125	11.42a-k	6.10a	5.333d-g	4.47abc	0.5477c-h
SPI X KG25-21	11.83a-k	9.74a-i	4.833c-g	7.75a-f	0.4930b-g
SPI X PASS	7.75abc	7.33ab	3.500abc	3.33a	0.2477a
SPI X SER124	16.88l-q	11.41a-l	5.167d-g	8.33a-f	0.5514c-h
SPI X BFS20	10.67a-j	10.13a-j	4.333cde	8.54a-f	0.6332e-k
SPI X CZ104-61	10.50a-j	12.78b-n	4.500c-g	7.39a-f	0.4360a-e
SPI X KG4-30	9.33a-g	15.67j-q	2.833ab	11.61f-l	0.6444e-k
SPI X CZ109-22	8.42a-e	9.68a-i	4.917c-g	7.98a-f	0.5407c-h
SPI X MR13905-6	11.00a-k	12.47b-n	4.500c-g	10.00d-j	0.6652f-k
SPI X RCB233	10.75a-j	12.88c-o	4.333cde	9.45c-h	0.5969d-j
SPI X SER83	14.75h-o	8.00a-e	4.917c-g	3.67ab	0.3116ab
SPI X BFS60	8.92a-f	8.47a-f	4.333cde	4.67a-d	0.3524abc
SPI X 41-EX-VAM	9.83a-i	7.56abc	4.833c-g	5.58a-e	0.4826b-g
SPI X SER45	15.58d-m	14.37h-o	4.833c-g	11.33f-l	0.6903f-k
SPII X SER82	11.50a-k	14.52h-p	5.250d-g	9.90c-j	0.4680b-f
SPII X SER16	13.50b-k	22.13rst	5.417efg	19.95mn	0.8107jk
SPII X KG104-72	14.75h-o	14.34h-o	5.583efg	8.29a-f	0.4309a-e
SPII X RCB266	10.67a-j	10.63a-k	4.833c-g	7.00a-f	0.5093b-g
SPII X SER125	13.42b-k	7.69a-d	5.583efg	5.49a-e	0.5482c-h
SPII X KG25-21	12.75a-k	13.21d-o	4.833c-g	8.37a-f	0.5211b-h
SPII X PASS	5.33a	10.84a-k	2.500a	7.17a-f	0.4819b-g
SPII X SER124	12.00a-k	17.24m-r	5.250d-g	13.97g-l	0.6379e-k
SPII X BFS20	11.42a-k	13.49e-o	5.500efg	11.61f-l	0.6639f-k
SPII X CZ104-61	11.08a-k	13.88f-o	5.000c-g	9.67c-i	0.5651c-h
SPII X KG4-30	7.75abc	17.67m-r	5.500efg	14.33h-l	0.6893f-k
SPII X CZ109-22	15.17d-m	11.05a-k	5.667efg	8.24a-f	0.5416c-h
SPII X MR13905-6	12.67a-k	13.20d-o	4.833c-g	9.05b-h	0.5907d-j
SPII X RCB233	21.33mn	13.39e-o	5.917fg	12.28f-l	0.6323e-k
SPII X SER83	14.83cl	12.93c-o	4.667c-g	8.17a-f	0.5009b-g
SPII X BFS60	20.83lmn	12.42b-n	5.333d-g	8.01a-f	0.4845b-g
SPII X 41-EX-VAM	6.25ab	10.01a-i	4.667c-g	7.29a-f	0.5247b-h
SPII X SER45	17.33i-m	19.83p-s	5.250d-g	16.33lm	0.7447h-k
Mean	12.8	13.42	4.934	10.26	0.5836
F.test	ns	ns	ns	ns	ns
C.V%	28.3	20.9	15.1	11.5	19.0

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test, ns= non-significant, *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

4.3.4.2 Effects of interaction on weight of pods per plant

However, the interaction effect was not significant on weight of pods per plant (Table 7). Highest weight of pods among genotypes grown under non-stressed condition was from SER45 (25.34 g) followed by BFS60 (24.08 g), SER124 (20g) and BFS20 (18.38 g) (Table 5). On the other hand, highest weight of pods among genotypes stressed at flowering were from SER124 (16.76 g) followed by SER45 (15.67 g), KG4.30 (14.37 g), SER16 (12.88 g), BF20 (12.475 g) and KG25-29 (11.41 g) (Table 5), while the heaviest pods of genotypes stressed at mid pod filling were RCB233 (21.13 g) followed by 41-EX-VAM (19.83 g), KG4-30 (17.67 g) and SER45 (17.24 g). In the unstressed treatment lowest weight was obtained from KG4-30 (13.42g) followed by MR13905-6, RCB266 and PASS and all had a weight of 14.25 g. The lightest genotypes under stress at flowering was 41-EX-VAM (6.1 g) followed by RCB 233 (7.31 g) and genotypes, BFS60 and CZ109-22 were statistically similar with weight of pods per plant of 7.56 g and 7.57 g respectively (Table 6), while the lightest genotype in terms of weight of pods stressed at mid pod-filling was SER45 (7.69 g) followed KG104-22 (9.2 g) and SER125 (9.42 g)

4.3.4.3 Effects of interaction on number of seeds per pod

The interaction effect was not significant (Table 7) on number of seeds; however, highest number of seeds in the unstressed treatment was from SER83 (6) followed by 41-EX-VAM (5.75), SER45 and RCB266 (with 5.67 number of seeds per pod each) and RCB233 (5.583), although, 41-EX-VAM, SER45, RCB266 and RCB233 were statistically similar (Table 6). On the other hand largest number of seeds per pod among genotypes stressed at flowering was from SER125 (5.33) followed by SER124 (5.167) while the largest number of seeds stressed at mid pod filling was

from CZ109-22 (5.667) followed by SER125 (5.83), and 5.5 number of seeds per pods was from both SER124 and KG4-30 (Table 7). The lowest number of seeds in the unstressed treatment was from SER82 (4.41) followed by MR13905-6 (4.5); however, they were statistically similar with BFS60 (4.833), and also, lowest number of seeds among genotypes stressed at flowering was from KG4-30 (2.83) followed by PASS (3.5) while the lowest number of seeds stressed at mid pod filling was from PASS (2) followed by 41-EX-VAM and SER83 with 4.667 number of pods per seed each.

4.3.4.4 Effects of interaction on weight of seeds per plant

The interaction effect did not significantly influence weight of seeds per plant among the common bean genotypes (Table 7), although, heaviest seeds among genotypes grown in the unstressed treatments was from SER45 (23.4 g) followed by BFS60 (21.79 g), SER16 (16.53 g) and RCB233 (15.83 g) (Table 6). On the other hand, heaviest seeds among genotypes stressed at flowering were from KG4-30 (15.10 g) followed by SER45 (11.61 g) and BFS124 (11.33 g). The heaviest seeds stressed at mid pod filling were from RCB233 (19.95 g) followed by BFS60 (16.23 g), KG4.30 (14.33 g) and BFS20 (13.96 g), while genotype with lowest weight of seeds when grown in unstressed condition was SER82 (7.16 g) followed by KG104-72 (7.45 g), SER125 (8.06 g) and MR13905-6 (8.87 g). Also lowest in weight of seeds under stress at flowering were from RCB266 (3.33 g) followed by SER82 (3.67 g), BFS60 (3.85 g) and 41-EX-VAM (4.47 g), although, genotypes SER82 and BFS60 were significantly the same (Table 6). The lowest weight of seeds under stress at mid pod filling was from 41-EX-VAM followed by SER82 (7.00 g), SER83 (7.17 g),

RCB266 (7.29 g), PASS (8.01 g), CZ104-61(8.18 g) and MR13905-6 (8.37 g), but SER82, SER83, PASS, CZ104-61 and MR13095-6 were statistically similar.

4.3.4.5 Effects of interaction on harvest index

The interaction effect was not significant on harvest index (Table 7); however, highest harvest index among genotypes under the non-water stressed treatment was observed from SER16 (0.83) followed by SER45 (0.80), KG4-30 (0.74), and PASS (0.70.). Under this condition, genotypes which had moderate harvest index were MR13905-6 (0.70) followed by SER124 (0.68), BFS20 (0.68) and RCB233 (0.67). On the other hand, highest harvest index among genotypes stressed at flowering was from SER16 (0.8) followed by SER45 (0.69), MR13905-6 (0.66), BFS (0.63) and KG4-03 (0.64) while the highest under stress at mid pod filling was from SER16 (0.81) followed by SER45 (0.74), KG4-30 (0.68) and BFS20 (0.66). The genotype with lowest harvest index grown in the unstressed treatment was SER82 (0.54) followed by 41-EX-VAM (0.551) and BFS60 (0.554); however, all these three genotypes were statistically similar (Table 7), and genotype with lowest harvest index under stress at flowering was PASS (0.24) followed by RCB233 (0.31), SER83 (0.35) RCB266 (0.42) and CZ104-61(0.13); however, RCB266 and CZ104-6 was statically similar (Table 7). Genotypes, KG104-72 (0.13) and SER82 (0.46) was determined with lowest harvest index when stressed at mid pod filling.

4.4 Results of Analysis of Variance (ANOVA) from the Field Experiment

Results of ANOVA at 0.05 level of significant for the effects of water treatments, and common bean genotypes on growth characteristics, presented on Table 8.

4.4.1 Effects of water stress treatments and common bean genotype on growth characters

The growth characteristics observed were the number of days of the bean genotypes to attain 50% flowering and 85% physiological maturity.

4.4.1.1 Days to 50% flowering

There were highly significant differences ($p \leq 0.001$) of number of days to reach 50% flowering among common bean genotypes (Table 8). The earliest genotype was G104-72 (34.33) DAP followed by SEE82 (36.0) DAP, SER125 (36.36) DAP and RCB266 (36.89) DAP. The intermediate genotype in days to reach 50% flowering was SER16 (37.78) DAP followed by KG25-21 (38.67) DAP and 40.89 DAP was from PASS and SER124. The latest genotypes was 41-EX-VAM (48.56) DAP, SER45 (47.56) DAP, MR13905-6 (43.56) DAP and RCB233 (43.22) DAP.

In this study, there were no significant differences of flowering among bean genotypes across water treatments (Table 8) since water stress treatments started at flowering stage (when 50% of the whole plot attained flowering)

4.4.1.2 Days to 85% physiological maturity

There were highly significant differences ($P \leq 0.001$) of number of days to reach 85% physiological maturity among common bean genotypes (Table 8). The earliest genotypes to reach 85% maturity was SER82 (83) DAP followed by KG104-72 (84.22) DAP, RCB266 (85.44) DAP and SER125 (85.67) DAP. Genotypes which

Table 8: Effects of water stress treatments and common bean genotypes on growth characteristics (Field Experiment)

Water treatments (a)	50% flowering	85% maturity
SP0	40.37a	94c
SPI	41.3a	84.43a
SPII	41.5a	88.15b
Mean	41.06	88.86
F.test _{0.05}	ns	**
CV%	4.0	1.0
Genotype (b)		
KG104-72	34.33a	84.22ab
SER82	36.00ab	83.00a
SER125	36.67abc	85.67bc
RCB266	36.89a-d	85.44abc
SER16	37.78a-e	86.00bc
KG25-21	39.11b-f	88.78ef
PASS	40.89c-f	94.11i
SER124	40.89c-f	86.11bcd
BFS20	41.56def	92.11ghi
BFS60	41.89ef	89.44ef
CZ104-61	42.33ef	92.78hi
KG4-30	42.33ef	87.22cde
SER83	42.44ef	88.56def
RCB233	43.00fg	93.67i
MR13905-6	43.22fg	90.11fg
CZ109-22	43.56fg	88.67ef
SER45	47.56gh	92.78hi
41-EX-VAM	48.56h	90.78fgh
Mean	41.6	88.86
F.test _{0.05}	***	***
CV%	2.0	1.5

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test. *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

followed in early maturity were SER16 (86.0) DAP, SER124 (86.11) DAP and KG4-30 (87.22) DAP. Genotypes with moderate days to reach 85% was SER83 (88.56) DAP followed by CZ109-22 (88.67) DAP and KG25-21 (88.78) DAP. On the other hand longest days for maturity was recorded from PASS (94.11) DAP and RCB233 (93.67) DAP, however these two genotypes were statistically similar. Other genotypes with longest maturity were SER45 and CZ104-61 with 92.78 DAP each and BFS20 with 92.11 DAP (Table 8).

There were statistical differences ($P \leq 0.01$) among genotypes to reach 85% maturity across water treatments effects (Table 8). The earliest to reach 85% maturity was from those genotypes stressed at flowering (84.43) DAP followed by those stressed at mid pod filling (88.15) DAP and the latest was those genotypes with unstressed condition (94.00) DAP (Table 8).

4.4.2 Effects of interaction between water stress treatments and common bean genotypes on growth characteristics (Field experiment)

The interaction effect between water treatments and bean genotypes was not significant (Table 9); however, earliest genotypes to reach 85% maturity in a non-water stressed condition were SER82 and SER125 with (89) DAP each. Genotypes which followed in early maturity in the unstressed treatment were KG104-72 (89.33) DAP followed by KG4-30 (90.00) DAP, RCB266 (91.00) DAP and SER16 (91.67) DAP. On the other hand earliest genotypes to attain 85% maturity when stressed at flowering was SER82 (82.67) DAP followed by KG104-72 (83.33) DAP, SER125 (85) DAP and 185.33 DAP from both RCB266 and SER124, while when stressed at mid pod filling the earliest was SER82 (77.33) DAP followed by both KG104-72 and RCB266 with 80.00 DAP each. On the other hand longest days to reach maturity under unstressed treatment was recorded from PASS (99) DAP followed by BFS20 (98.33) DAP, SER45 (98) DAP, RCB233 (96.67) DAP and BFS60 (96) DAP (Table 6). The latest genotypes to reach 85% maturity under stress at flowering was PASS (94.67) DAP followed by RCB233 (93.33) DAP and 93.00 DAP was recorded from both CZ104-61 and SER45.

Table 9: Effects of interaction between water treatments and common bean genotypes on growth characteristics

Water treatments x Genotypes	50% Flowering	85% maturity
SP0 X SER82	33.67ab	89.00f-p
SP0 X KG104-72	34.33ab	89.33g-q
SP0 X RCB266	33.00a	91.00l-t
SP0 X SER125	36.33a-e	89.00g-p
SP0 X KG25-21	38.67a-g	95.00s-x
SP0 X SER16	40.67a-i	91.67m-u
SP0 X PASS	40.67a-i	99.00x
SP0 X SER124	38.33a-g	95.00s-x
SP0 X BFS20	41.00a-i	98.33wx
SP0 X CZ104-61	38.00a-f	95.67t-x
SP0 X KG4-30	42.33b-i	90.00i-s
SP0 X MR13905-6	41.33a-i	95.67t-x
SP0 X CZ109-22	44.00d-i	94.33q-x
SP0 X RCB233	42.33b-i	96.67u-x
SP0 X BFS60	42.00a-i	96.00t-x
SP0 X SER83	44.33e-i	94.00p-x
SP0 X 41-EX-VAM	49.00i	94.33q-x
SP0 X SER45	46.67f-i	98.00vwx
SPI X SER82	36.33a-e	82.67bcd
SPI X KG104-72	35.00a-d	83.33cde
SPI X RCB266	38.33a-g	85.33d-i
SPI X SER125	37.00a-e	85.00c-i
SPI X KG25-21	39.33a-h	87.33d-m
SPI X SER16	38.00a-f	86.33d-l
SPI X PASS	40.00a-i	94.67r-x
SPI X SER124	42.00a-i	85.33d-i
SPI X BFS20	40.00a-i	90.00i-s
SPI X CZ104-61	44.33e-i	93.00n-v
SPI X KG4-30	42.00a-i	86.00d-l
SPI X MR13905-6	45.33e-i	91.00j-t
SPI X CZ109-22	41.33a-i	87.33d-m
SPI X RCB233	42.33b-i	93.33o-w
SPI X BFS60	44.00d-i	88.00e-n
SPI X SER83	41.33a-i	85.67d-k
SPI X 41-EX-VAM	48.00hi	89.33g-q
SPI X SER45	48.67i	93.00n-v
SPII X SER82	38.00a-f	77.33a
SPII X KG104-72	33.67ab	80.00abc
SPII X RCB266	39.33a-h	80.00abc
SPII X SER125	36.67a-e	83.00cde
SPII X KG25-21	39.33a-h	84.00c-g
SPII X SER16	34.67abc	80.00abc
SPII X PASS	42.00a-i	88.67f-o
SER124	42.33b-i	78.00ab
SPII X BFS20	43.67c-i	88.00e-n
SPII X CZ104-61	44.67e-i	89.67h-r
SPII X KG4-30	42.67b-i	85.67d-j
SPII X MR13905-6	44.00d-i	83.67c-f
SPII X CZ109-22	44.33e-i	84.33c-h
SPII X RCB233	44.33e-i	91.00j-t
SPII X BFS60	41.33a-i	84.33c-h
SPII X SER83	40.00a-i	86.00d-l
SPII X 41-EX-VAM	48.67i	88.67f-o
SPII X SER45	47.33ghi	87.33d-m
Mean	41.6	88.86
F.test0.05	ns	ns
C.V%	11	2.8

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test, ns= non-significant, *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

The latest under stress at mid pod filling was observed from RCB233 (91.0) DAP followed by CZ104-61 (89.67) DAP, and 88.67 DAP was recorded from both PASS and 41-EX-VAM (Table 9).

4.4.3 Effects of water stress and common bean genotypes on yields and yield components (field experiment)

The studied variables were seeds yield, number of seeds per plant, weight of seeds per plant, number of seeds per pod, weight of seeds per plant and 100 seed weight.

4.4.3.1 Yields

There were highly significant differences ($P \leq 0.001$) of yields among common bean genotypes (Table 10). Genotypes with highest yield was SER16 (1419 kg/ha) followed by KG104-72 (1375 kg/ha) and KG4-30 (1374 kg/ha), however KG104-72 and KG4-30 were statistically similar (Table 8). Genotypes with lowest seed yield was 41-EX-VAM (763 kg/ha) followed by PASS (824 kg/ha), BFS20 (935 kg/ha), SER45 (1062 kg/ha) and MR 13905-6 (1123 kg/ha). The remaining genotypes had moderate seed yield and they were statistically similar (Table 10).

On the other hand, there were highly significant differences ($P \leq 0.001$) in response to water treatments. The unstressed treatment produced highest yield (1759 kg/ha) followed by those genotypes stressed at mid pod filling (966 kg/ha) and lowest yield was from those stressed at flowering (835 kg/ha); however, yields under stress at mid pod filling and flowering were statistically the same (Table 10).

Table 10: Effects of water treatments and common bean genotypes on yield and yield components

Water treatments (a)	Yield (kg/ha)	Number of pods per plant	Weight of pods per plant (g)	Number of seeds per pod	weight of seed per plant (g)	100 seed weight (g)
SP0	1759b	17.48c	21.0c	5.12b	14.9c	23.72b
SPI	824a	9.9a	10.23a	4.71a	6.49a	23.43b
SPII	977a	11.44b	16.3b	5.01b	10.99b	20.00a
Mean	1187	12.94	15.75	5.011	10.79	22.38
F.test _{0.05}	**	***	***	ns	***	**
CV%	6.8	1.9	10	1.4	10.5	1.3
Genotype (b)						
41-EX-VAM	763a	12.42abc	11.90a	5.156bc	7.90a	17.49a
PASS	824ab	9.49a	14.40a-d	3.933a	9.29abc	30.21g
BFS20	935abc	12.71abc	16.55c-f	4.689b	10.97b-f	25.00f
SER45	1062bcd	19.16d	19.89f	5.244bc	13.68f	20.31b
MR13905-6	1123cde	12.31abc	14.71a-d	4.711bc	10.03a-e	24.29ef
CZ104-61	1152c-f	12.58abc	14.75a-d	4.978bc	9.82a-e	23.50ef
SER82	1184c-f	13.02bc	14.07abc	4.822bc	9.10ab	20.56bc
SER83	1211def	12.82abc	15.88b-e	5.178bc	11.01b-f	21.33bcd
KG25-21	1232def	13.07bc	14.51a-d	4.889bc	10.65a-e	21.32bcd
SER125	1233def	12.75abc	13.96abc	5.328bc	9.74a-d	23.33ef
SER124	1254def	14.49bc	17.76def	5.200bc	12.09c-f	21.15bcd
RCB233	1258def	14.58c	18.40ef	5.156bc	12.69ef	20.64bc
BFS60	1300def	12.44abc	17.80def	4.867bc	12.35def	23.30ef
RCB266	1322def	11.40abc	12.83ab	5.356c	8.96ab	21.07bcd
CZ109-22	1335def	12.64abc	15.87b-e	5.244bc	10.80b-e	22.44cde
KG4-30	1374ef	11.09ab	17.77def	5.178bc	12.74ef	22.85de
KG104-72	1375ef	11.29abc	15.00a-e	5.200bc	10.18a-e	23.34ef
SER16	1419f	14.67c	17.47c-f	5.078bc	12.30def	20.77bc
Mean	1187	12.94	15.75	5.011	10.79	22.38
F.test _{0.05}	***	***	***	***	***	***
CV%	9.7	6	4.4	4.5	7.6	3

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test. ns = Non significant, ** = Significant at 0.01, *** = Significant at 0.001. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

4.4.3.2 Number of pods per plant

There were highly significant differences ($P \leq 0.001$) of number of pods per plant among common bean genotypes (Table 10). Genotype with highest number of pods was SER45 (19.16) followed by SER16 (14.67) and RCB233 (14.58); however, SER16 and RCB233 were statistically similar (Table 8). Genotypes, that followed in number of pods per plant were SER124 (14.49), KG25-21 (13.07) and SER82 (13.02), although, these three genotypes were statistically the same. Lowest number

of pods per plant was recorded from PASS (9.49) followed by KG4-30, KG104-72 (11.29) and RCB266 (11.40); however, KG4-30 and KG104-72 were statistically not different.

There were also statistical differences ($P < 0.01$) of number of pods per plant across water treatments, the largest number of pods was from unstressed treatment (17.48) and the lowest was from those stressed at mid-pod filling and at flowering which had 11.43 and 10.21 number of pods respectively, although, these two treatments (SPI and SPII) were statistically similar (Table 10).

4.4.3.3 Weight of pods per plants

There were highly significant differences ($P \leq 0.001$) of weight of pods per plant among common bean genotypes (Table 10). Genotype with highest weight of pods per plant was SERF45 (19.89 g) followed by RCB233 (18.40 g), BFS60 (17.80 g), KG4-30 (17.77 g), SER124 (17.76 g) and SER16 (17.47 g); however BFS60, KG4-30 and SER124 were statistically not different. Genotypes with lowest weights of pods was 41-EX-VAM (11.9 g) followed by RCB233 (12.83 g) SER125 (13.96 g) and SER82 (14.07 g), although genotype SER125 and SER82 were statistically the same. Other genotypes had moderate weight of pods per plant (Table 10).

The results across water treatment were significant ($P \leq 0.001$). Highest weight of pods per plant was under unstressed treatment (21 g) followed by those stressed at flowering (15.96 g) and the lightest weight was found to those stressed at flowering (10.3 g) (Table 10).

4.4.3.4 Number of seeds per pod

There were highly significant differences ($P \leq 0.001$) of number of seeds per pod among bean genotypes (Table 10). Genotypes with highest number of seeds per pod was RCB266 (5.356) followed by SER125 (5.328), while genotypes with lowest number of pods was PASS (3.933) followed by BFS20 (4.689), (Table 10). The remaining genotypes had moderate number of seeds per pod and they were statistically similar (Table 10)

The effect of water treatments on number of seeds was not significant (Table 10), but the highest number of seeds per pod was recorded from those stressed at mid pod filling (5.20) followed by those with unstressed treatment (5.12) and the lowest was from those stressed at flowering (4.71) (Table 10).

4.4.3.5 Weight of seeds per plant

Common bean genotypes showed significant differences ($P \leq 0.001$) on seeds weight per plant (Table 10). Genotype with highest weight of seeds per plant was SER45 (13.68 g) followed by KG 4-30 (12.74 g) and RCB233 (12.69 g); however, these two genotypes were statistically similar (Table 10). Genotypes with moderate weight of seeds were BRS60 (12.35G) SER16 (12.30 g) and SER124 (12.69G). Genotype with lowest weight of seeds per plant was 41-EX-VAM (7.90g) followed by RCB266 (8.969), SER82 (9.10g) and PASS (9.29G). Other genotypes had an intermediate weight of seeds per plant (Table 10).

There were statistical differences ($p \leq 0.001$) across water treatments (Table 10). The weight of seeds per plant under unstressed treatment was 14.9 g followed by those stressed at mid pod filling (10.96 g) and lowest weight of seeds per plant was from those stressed at flowering (6.52 g) (Table 10).

4.4.3.6 Weight of 100 Seeds

Common bean genotypes differed significantly ($P \leq 0.001$) on 100 seed weight (Table 10). Genotypes with highest 100 seed weight was PASS (30.21 g) followed by BFS20 (25.09 g). Other genotypes which followed 100 seed weight were MR.13905-6 (24.29 g), CZ104-61 (23.50 g), KG104-72 (23.34g), SER125 (23.33g) and BFS (23.30 g), although, these genotypes were not statistically different (Table 10). Genotypes with lowest 100 seed weight was 41 -EX- VAM (17.49 g) followed by SER 45 (20.31g), SER 82(20.56 g), RCB233 (20.64 g) and ser16 (20.77 g). The remaining genotypes had moderate 100 seed weight (Table 10).

There were significant differences ($P \leq 0.01$) of 100 seed weight with regard to water treatments. The highest 100 seed weight was from unstressed treatment (23.72 g) followed by those stressed at flowering (23.4 g) and the lowest 100 seed weight was from those stressed at mid-pod filling (20.62 g); however, the overall 100 seed weight under stress at flowering and under unstressed treatments was statistically the same (Table 10).

4.4.4 Effects of interaction between water treatments and common bean genotypes on yield and yield components

4.4.4 Seed yield

The influence of interaction on yields of bean genotypes was not significant (Table 11), although, in the unstressed treatment, genotype SER16 (2183 kg/ha) produced highest yield followed by RCB266 (2071 kg/ha), BFS60 (1999 kg/ha), CZ109-61 (1991 kg/ha), KG104-72 (1939 kg/ha) and SER83 (1906 kg/ha) (Table 8). The highest yields under those genotypes stressed at flowering was from BFS60 (1085kg/ha) followed by SER16 (1015 kg/ha), MR13905-6 (961 kg/ha), CZ 104-61(957 kg/ha) and SER82 (916 kg/ha) (Table 11) while highest yields among genotypes stressed at mid-pod filling was from KG4-30 (2024 kg/ha) followed by RCB266 (1163 kg/ha), KG25-21(1153 kg/ha), SER125 (1120 kg/ha) and SER124 (1153 kg/ha), SER 125 (1120 kg/ha) and SER 124 (1090 kg/ha). Genotypes with lowest yield grown under unstressed condition was KG4-30 (1240 kg/ha) followed by BFS20 (1306 kg/ha), MR13905-6 (1347 kg/ha), SER125 (1623 kg/ha) and SER45 (1648 kg/ha), and lowest yield among genotypes stressed at flowering were from 41-EX-VAM (300 kg/ha) and PASS (461 kg/ha), and also lowest yields among genotypes stressed at mid pod filling was from 41-EX-VAM (617 kg/ha) followed by SER45 (809 kg/ha), PASS (812 kg/ha), BFS20 (814 kg/ha) and BFS60 (818 kg/ha).

Table 11: Effects of interaction between water treatments and common bean genotypes on yields and yield components

Water treatments x Genotypes	Yield (kg/ha)	Number of pods per plant	Weight of pods per plant(g)	Number of seeds per pod	Weight of seeds per plant(g)	100 Seed weight(g)
SP0 X SER82	1713k-n	16.87f-m	18.76g-o	4.667a-h	12.04g-q	21.54b-l
SP0 X KG104-72	1939mn	15.40d-m	18.00f-n	5.133c-h	12.72h-r	23.76i-n
SP0 X RCB266	2071mn	15.00c-l	18.07f-n	5.600fgh	12.87i-r	22.44f-m
SP0 X SER125	1623i-m	17.53h-m	17.92f-n	5.067c-h	12.80h-r	24.67l-p
SP0 X KG25-21	1802lmn	16.80f-m	18.84g-o	4.800a-h	15.74n-s	22.63g-m
SP0 X SER16	2183n	18.00i-m	22.47m-p	5.000b-h	16.56p-s	21.14b-l
SP0 X PASS	1200d-j	13.20a-k	20.26j-o	3.867ab	13.67k-r	34.95q
SP0 X SER124	1830lmn	18.00i-m	23.60nop	5.200c-h	15.97o-s	22.33f-m
SP0 X BFS20	1306f-k	16.93f-m	20.38j-o	4.467a-f	13.54k-r	26.85nop
SP0 X CZ104-61	1807lmn	15.67e-m	21.57m-p	5.400d-h	15.39m-s	24.56l-p
SP0 X KG4-30	1240e-k	14.33b-l	20.07i-o	5.267c-h	14.35l-s	23.85i-n
SP0 X MR13905-6	1991mn	18.20j-m	21.05l-p	5.200c-h	14.94m-s	24.38k-p
SP0 X CZ109-22	1347g-l	14.20b-l	19.49h-o	4.733a-h	13.80k-r	24.24j-o
SP0 X RCB233	1892mn	21.73mn	24.78op	5.533fgh	17.11qrs	22.19f-m
SP0 X BFS60	1906mn	19.13klm	21.47m-p	5.800gh	15.15m-s	23.17i-n
SP0 X SER83	1999mn	16.87f-m	25.20op	5.000b-h	17.69rs	24.98l-p
SP0 X 41-EX-VAM	1373h-l	20.53lm	20.62k-p	5.867h	14.43l-s	18.69a-f
SP0 X SER45	1648j-m	26.27n	26.73p	5.6fgh	19.43s	20.66b-k
SPI X SER82	1041c-h	9.13a-e	10.73a-d	4.933b-h	6.93a-g	25.67m-p
SPI X KG104-72	733a-e	9.47a-e	9.26abc	5.400d-h	5.97a-e	21.67c-l
SPI X RCB266	956b-h	9.33a-e	9.58abc	5.267c-h	5.97a-e	23.67i-n
SPI X SER125	741a-e	10.40a-f	12.25a-f	5.000b-h	7.60a-i	23.00i-m
SPI X KG25-21	1015c-h	12.87a-k	10.73a-d	4.867a-h	6.87a-g	23.00i-m
SPI X SER16	461ab	7.60ab	8.13ab	3.733a	4.80ab	27.67op
SPI X PASS	841b-g	11.93a-j	13.54a-i	5.133c-h	8.93a-k	22.33f-m
SPI X SER124	684a-d	9.93a-c	10.14a-d	4.267a-e	5.87a-e	25.00l-p
SPI X BFS20	759a-e	10.87a-h	8.74abc	4.533a-f	5.28a-d	24.00i-o
SPI X CZ104-61	859b-h	8.73a-d	13.30a-h	4.600a-g	9.57a-l	24.33k-p
SPI X KG4-30	957b-h	8.87a-c	9.19abc	4.867a-h	5.61a-e	22.67h-m
SPI X MR13905-6	961b-h	10.53a-f	10.01a-d	4.667a-h	6.19a-f	28.00p
SPI X CZ109-22	830b-g	10.67a-g	9.78a-d	4.133abc	6.54a-f	22.00c-m
SPI X RCB233	841b-g	7.60ab	11.33a-c	4.867a-h	7.53a-h	22.00d-m
SPI X BFS60	1085c-h	8.27abc	7.80a	4.267a-e	5.07abc	24.67l-p
SPI X SER83	300a	7.13a	7.38a	5.000b-h	4.37a	18.00abc
SPI X 41-EX-VAM	728a-e	13.87a-k	13.07a-h	4.667a-h	8.47a-k	21.67c-l
SPI X SER45	1144c-i	9.33a-e	16.28d-m	5.533fgh	10.89e-o	20.60b-k
SPII X SER82	1163d-j	9.73a-e	11.18a-e	5.067c-h	8.04a-j	19.10a-h
SPII X KG104-72	1120c-h	11.40a-i	14.37b-k	5.650fgh	10.44d-n	21.65c-l
SPII X RCB266	1153d-i	12.00a-j	12.43a-g	4.867a-h	8.62a-k	18.32a-e
SPII X SER125	1060c-h	13.13a-k	19.22h-o	5.367de-h	13.46k-r	18.16a-d
SPII X KG25-21	812b-f	7.67ab	14.82c-l	4.200a-d	9.39a-l	28.01p
SPII X SER16	1090c-h	13.53a-k	16.13d-m	5.267c-h	11.36f-p	18.78a-g
SPII X PASS	814b-f	11.27a-i	19.12h-o	5.333c-h	13.51k-r	23.14i-n
SPII X SER124	890b-h	11.20a-h	13.94a-j	5.000b-h	8.80a-k	21.94d-m
SPII X BFS20	2024mn	10.20a-f	19.95i-o	5.667fgh	14.30l-s	20.37b-j
SPII X CZ104-61	1057c-h	10.87a-h	17.36e-n	5.667fgh	11.85g-q	20.26b-i
SPII X KG4-30	1060c-h	12.20a-j	14.63b-l	4.733a-h	10.09b-m	20.64b-k
SPII X MR13905-6	1052c-h	11.33a-i	20.65k-p	5.800gh	14.41l-s	17.74ab
SPII X CZ109-22	888b-h	11.73a-j	14.85c-l	4.867a-h	10.35c-m	18.83a-h
SPII X RCB233	818b-f	12.20a-j	20.41j-o	5.333c-h	14.30l-s	20.27b-i
SPII X BFS60	617abc	9.60a-c	7.68a	4.600a-g	4.89ab	15.77a
SPII X SER83	809b-f	17.33g-m	19.87i-o	5.467e-h	13.13j-r	18.60a-f
SPII X BFS60	818b-f	12.20a-j	20.41j-o	5.333c-h	14.30l-s	20.27b-i
SPII X 41-EX-VAM	617abc	9.60a-c	7.68a	4.600a-g	4.89ab	15.77a
SPII X SER45	809b-f	17.33g-m	19.87i-o	5.467e-h	13.13j-r	18.60a-f
Mean	1187	12.94	15.75	5.011	10.79	22.38
F.test	ns	ns	ns	ns	ns	ns
C.V%	20.7	23.7	20.8	11.4	24.2	20.7

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test, ns= non-significant. SP0 = Without water stress, SPI=Stress at flowering and SPII=Stress at mid-pod filling

4.4.4.2 Number of pods per plant

However, the interaction effect was not significant on number of pods per plant (Table 11), highest number of pods in the non-stressed treatment was from SER45 (26.27) followed by RCB233 (21.73) 41-EX-VAM (20.53), CZ109-22 (18.2) and SER124 (18.00) (Table 11). The highest number of pods per plant stressed at flowering was SER45 (13.87) followed by SER16 (12.87), SER124 (11.93), SER82 (11.07), CZ104-61 (10.87), RCB233 (10.67) and MR13905-6 (10.53) (Table 7), while the highest number of pods stressed at mid pod filling were from SER45 (17.33) followed by SER124 (13.53) SER16 (13.13), BFS60 (12.20), MR13905-6 (12.2) and KG25-12 (12.00); however, BFS60 MR13905-6 and KG25-12 were statistically the same. Genotypes with lowest number of pods under unstressed treatment was PASS (13.2) followed by MR13905-6 (14.20), and KG4-30 (14.33); however, statistically they were similar (Table 11). The lowest number of pods among those stressed at flowering was 41-EX-VAM (7.13) followed by PASS and SER 83 with (7.60) each, while the lowest number of pods stressed at mid pod filling was PASS (7.67) followed by KG104-72 (9.33), 41-EX-VAM (9.60) and RCB266 (9.73); however KG104-72, 41-EX-VAM and RCB266 were statistically the same, (Table 11)

4.4.4.3 Weight of pods

However the interaction effects was not significant (Table 11), highest weight of pods in the non-stressed condition was from SER45 (26.73 g) followed by BFS60 (25.20 g), RCB233 (24.78 g), SER124 (23.6 g) and SER16 (24.47 g) (Table 9). Genotypes with highest weight of pods stressed at flowering was SER124 (13.54 g) followed by KG4-30 (13.30 g) SER45 (13.07g) and KG25-21 (12.25 g) (Table 11),

although, SER45 and KG4-30 were statistically similar, while highest weight of pods among genotypes stressed at mid pod filling was from RCB233 (20.65 g) followed by BFS60 (20.41 g), KG4-30 (19.95 g), SER45 (19.87 g), SER16 (19.22 g) and BFS 20 (19.12 g); however BFS60 and KG4-30 were statistically similar and also SER16 and BFS20 were statistically the same. The lowest weight of pods of genotypes grown in unstressed treatment was from SER125 (17.73 g) followed by KG104-72 (18.00 g), RCB266 (18.07 g), SER82 (18.76 g), KG25-21(18.84 g) and MR13096-5(19.40 g). The lightest pods of bean genotypes stressed at flowering was 41-EX-VAM (7.38 g) followed by BFS60 (7.80 g); however, 41-EX-VAM and BFS60 were statistically the same (Table 7). Other genotypes with lowest weight of pods and statistically similar were CZ104-61 (8.74 g), SER82 (8.98 g), CZ109-22 (9.19 g), RCB266 (9.26 g) and SER125 (9.58 g). Genotype with lowest weight of pods under stress at mid pod filling was 41-EX-VAM (7.68 g) followed by RCB266 (11.81 g), KG21-25 (12.43 g) and CZ104-61 (13.94 g).

4.4.4.4 Number of seeds per pod

The interaction effect of water treatments and genotypes on number of seeds per pod was not statistically significant (Table 11); however, highest number of seeds under the non-stressed condition was from 41-EX-VAM (5.86) followed by SER83 (5.80) (Table 11). Other genotypes with highest number of seeds under this treatment were SER45 and RCB266 with 5.6 numbers of seeds per pod each. Also highest number of seeds of bean genotypes stressed at flowering was from RCB266 (5.49) followed by SER125 (5.27), SER124 (5.13), but SER125 and SER124 were statistically the same (Table 11). Highest number of seeds for those genotypes stressed at mid pod filling was RCB233 (5.8) followed by KG4-30 and CZ109-22 with 5.67 number of

seeds each. Other genotypes with highest number seeds were SER125 (5.65), KG4-30 (5.53), SER16 (5.37); however, KG4-30, KG104-72, CZ109-22 and SER125 were statistically the same (Table 11). On the other hand lowest number of seeds from the unstressed treatments was PASS (3.87) followed by BFS20 (4.47), SER82 (4.67), MR13095-6 (4.73) and KG25-21(4.8). Genotype with lowest number of seeds stressed at flowering was PASS (3.73) followed by RCB233 (4.13) and 4.27 of number of seeds was from both BFS20, BFS60, while the lowest number of seeds stressed at mid pod filling was from PASS (4.20) followed by 41-EX-VAM (4.67). and 4.67 number of seeds was from both KG25-21 and SER83.

4.4.4.5 Weight of seeds per plant

Interaction effects was not significant (Table 11), although, heaviest genotype under the non-stressed treatment was SER45 (19.43 g) followed by BFS60 (17.69 g), RCB233 (17.11 g), SER16 (16.56 g), SER124 (15.97 g) and CZ109-22 (14.94 g) (Table 11), although, CZ104-61, SER 83 and CZ109-22 were statistically the same. Highest weight of seeds stressed at flowering was from KG4-30 (9.59 g) followed SER124 (8.94 g) SER45 (8.47 g) KG25-21 (7.60 g), SER83 (7.53 g) (Table 9); however, K25-21 and SER83 were statistically the same. On the other hand, highest weight of seeds stressed at mid pod filling was from RCB233 (14.41 g) followed by KG4-30 and BFS60 with 14.30 g seeds weight per plant each; although, RCB233, KG4-30 and BFS60 were statistically the same (Table 9). Lowest weight of seeds was from SER82 (12.04 g) KG104-72 (12.72 g), SER125 (12.8 g) and RCB266 (12.87 g). On the other hand lowest weight of seeds stressed at flowering was from 41-EX-VAM (4.37 g) followed by PASS (4.80 g) BFS60 (5.07g) and SER82 (5.18

g), while the lowest weight of seeds stressed at mid pod filling was from 41-EX-VAM (4.89g) followed by RCB266 (8.04 g) KG25-21 (8.62g) and CZ104-61 (8.80g); however, KG25-21 and CZ104-61 were statistically the same (Table 11).

4.4.4.6 Weight of 100 seeds

There were no significant differences as a result of interactions effect (Table 11); however, heaviest genotypes on 100 seeds grown in unstressed environments was PASS (34.95 g) followed by BFS20 (26.85 g), BFS60 (24.98 g), SER125 (24.67 g), CZ104-61 (24.56 g), CZ109-22 (24.38 g) and MR3905-6 (24.24 g) (Table 9); however, SER125, CZ104-61, and BFS60 were statistically the same. Highest 100 seed weight of genotypes stressed at flowering was from MR3905-6 (28 g) followed by PASS (27.69 g), KG104-72 (25.67 g), BFS20 (25 g), BFS60 (24.67 g), KG4-30 (24.33 g), BFS20 (25 g), BFS60 (24.67 g) KG4-30 (24.37 g) and CZ104-61 (24 g) (Table 11); however, BFS20 and BFS60 were statistically the same. On the other hand, highest 100 seed weight stressed at mid-pod filling was PASS (28.01 g) followed by BFS20 (23.14g), CZ104-61 (21.94 g), SER125 (21.65 g), MR3905-6 (20.64 g), KG104-72 (20.61 g), KG4-30 (20.37 g), BFS60 (20.27 g) and CZ109-22 (20.26 g); however, BFS60 and SER109-22 were statistically similar (Table 11). The lowest genotypes in 100 seed weight in the non-stressed treatment was 41-EX-VAM (18.69 g) followed by SER45 (20.66 g), SER16 (21.14 g) and SER82 (21.54 g). Also lowest 100 seed weight stressed at flowering was from 41-EX-VAM (18.00 g) followed by RCB266 and SER45 with 21.67 g of 100 seed weight each. Other genotypes with lowest 100 seed weight under this treatment were RCB233 and SER124 with 22.00 g each. Further, a weight of 22.33 g of 100 seed weight among

genotypes stressed at flowering was recorded to both SER82 and SER124 while the lowest 100 seed weight among genotypes stressed at mid pod filling was 41-EX-VAM (15.77 g) followed by RCB233 (17.74 g), SER82 (17.79 g), SER16 (18.16 g), KG25-21 (18.32 g), SER45 (18.60 g), SER124 (18.78 g), SER83 (18.82 g), and RCB266 (19.10 g) (Table 11).

4.5 Identification of Drought Tolerant Bean Genotypes Using Selection Indices

The highest drought tolerant genotypes observed under yield index (YI) was BFS60 (1.33) followed by KG104-72 (1.27), SER16 (1.24), MR13905-6 (1.18), CZ 109-22 (1.17) and SER125 (1.17) while STI selected SER16 (0.72) as most tolerant in drought condition, followed by BFS60 (0.70), KG104-72 (0.65), CZ 109-22 (0.62) and KG4-30 (0.56). On the other hand, SSPI selected RCB266 (39.01), SER16 (34.05), 41-EX-VAM (31.28), SER83 (26.65), RCB233 (30.96) and KG25-21 (30.93) as tolerant genotypes (Table 12).

Table 12: The means of yield under stress and non-stress conditions and drought tolerance selection indices of bean genotype

GENOTYPES	Yp	Ys	YI	STI	SSPI
SER82	1713	916	1.111	0.507	23.236
KG104-72	1939	1041	1.263	0.653	26.181
RCB266	2071	733	0.889	0.491	39.009
SER125	1623	956	1.160	0.502	19.446
KG25-21	1802	741	0.899	0.432	30.933
SER16	2183	1015	1.231	0.716	34.052
PASS	1200	461	0.559	0.179	21.545
SER124	1830	841	1.020	0.498	28.834
BFS20	1306	684	0.987	0.344	18.134
CZ104-61	1807	759	0.921	0.443	30.554
KG4-30	1240	859	1.042	0.562	11.108
CZ109-22	1991	957	1.161	0.616	30.146
MR13905-6	1347	961	1.166	0.419	11.254
RCB233	1892	830	1.007	0.508	30.962
SER83	1906	841	1.020	0.518	31.050
BFS60	1999	1085	1.316	0.701	26.647
41-EX-VAM	1373	300	0.364	0.133	31.283
SER45	1648	728	0.883	0.388	26.822

Yp=Yield under non-water stress, Ys=Yield under water stress, YI=Yield index, STI= Stress tolerance index, SSPI=Stress susceptibility percent index

4.6 Estimation of Drought Tolerant Bean Genotypes

According to ranking the means of ranks of yields under non-stressed treatment. under stress condition, and the selection indices (yield index, stress tolerance index and stress susceptibility percent) (Table 13). The results showed genotype SER16 was ranked the highest followed by BFS60, KG104-72, CZ109-22, SER83, RCB233 and RCB266 (Table 13).

Table 13: The ranks, ranks means ($\bar{R}$) of the bean genotypes

Genotypes	Yp	Ys	YI	STI	SSPI	$\bar{R}$
SER82	11	7	7	5	13	8.6
KG104-72	5	2	2	3	12	4.8
RCB266	2	14	14	11	1	8.4
SER125	13	6	6	9	15	9.8
KG25-21	10	13	13	13	6	11
SER16	1	3	3	1	2	2
PASS	18	17	17	17	14	16.6
SER124	8	10	10	10	9	9.4
BFS20	16	16	16	16	16	16
CZ104-61	9	12	12	12	7	10.4
KG4-30	17	8	8	5	18	11.2
CZ109-22	4	5	5	4	8	5.2
MR13905-6	15	4	4	14	17	10.8
RCB233	7	11	11	7	5	8.2
SER83	6	9	9	6	4	6.8
BFS60	3	1	1	2	11	3.6
41-EX-VAM	14	18	18	18	3	14.2
SER45	12	15	15	15	10	13.4

Yp=Yield under non-stress, Ys=Yield under stress, YI=Yield index,
 STI= Stress tolerance index, SSPI=Stress susceptibility percent index,
 $\bar{R}$ = Mean of ranking.

4.7 Identification of Suitable Drought Tolerance Selection Indices

Results showed, seed yield under non-water stress was significant ($P < 0.5$) (Table 10) and positively correlated with YI ($r = 0.5008^*$), STI ($r = 0.7196^{***}$), and SSPI (0.7624^{***}). Yields under water stress treatments was highly significant and positively correlated with YI ($r = 0.9880^{***}$) and STI ($r = 0.9238^{***}$), but negatively correlated with SSPI ($r = -0.1264$) (Table 14).

Table 14: Correlation coefficient between Yp, Ys, and drought tolerance selection indices

Sn	Variables	1	2	3	4	5
1	Yield under non-stress(Yp)	-				
2	Yield under stress (Ys)	0.5456*	-			
3	Yield index (YI)	0.5008*	0.9880**	-		
4	Stress tolerance index (STI)	0.7196***	0.9238**	0.9031***	-	
5	Stress susceptibility percent index (SSPI)	0.7624***	0.1264ns	0.1702ns	0.1384ns	-

ns = Non-significant

* = Significant at 0.05

** = Significant at 0.01

*** = Significant at 0.001

CHAPTER FIVE

5.0 DISCUSSION

5.1 Response of Bean Genotypes to Different Water Stress Periods on Growth Characteristics

Differences were observed among 18 bean genotypes, water stress treatments and interactions in both field and screen house experiments with respect to variables measured, including the derived variables calculated from drought tolerance selection indices.

Days to attain 50% flowering among the common bean genotypes differed significantly ($P \leq 0.05$) as summarized in Table 4 for the screen house and Table 9 for the field experiments. These results indicate that, there is genetic variability among common bean on number of days to reach 50% flowering and these results are in agreement with the findings of Yoshinda (1981), which revealed the genetic variation among genotypes of common bean on days to attain 50% flowering. Similarly, Das (2005), reported considerable variability of traits including number of days to 50% flowering of snap beans.

Among the 18 common bean genotypes, there were differences in days to 85% maturity and also they responded differently when exposed to water stress treatments (Table 4 and 9). The variation among genotype is influenced by the genetic constituents of an individual. The stress treatments influenced the time taken to attain maturity in such a way that, beans matured earlier in a stressed area, than in non-stressed area, this situation could be enhanced by a harsh condition (water deficit)

faced plants, as a result plants accelerate senescence and hence the life circle of the plant is shortened. This act enables the reserved food in leaves to be partitioned to harvestable parts in order to maintain its generation. This type of adjustment mechanism to water stress condition was reported by Sabaghpour *et al.* (2003) who found that early phenology, such as early maturity was the most important mechanism for genotypes to escape terminal drought stress as associated with high initial growth vigour. Guar *et al.* (2008) associated the early maturing of the chickpea in the dry areas of India to their drought mechanism. The genotype with early maturity would be less vulnerable to terminal drought and hence suited as drought tolerant genotype. Similar result was found by Beaver and Rosas (1998) in their study for drought tolerance of common beans, where selection for earlier flowering in red beans permitted the identification of the bean genotypes with a shorter life cycle without affecting its yield potential and with greater rate of partitioning assimilates.

On the other hand, shoot dry weight was largely reduced when stress was imposed at flowering and it was moderately reduced when stress was introduced at mid pod filling (Table 4). Genotypes such as KG104-72, SER82, RCB266 and SER125 lost shoot dry weight lesser as compared to other genotypes, this signifies that genotypes respond differently in respect to shoot dry weight when subjected to water stress and those which are sensitive to water stress lost more. These findings confirm the work undertaken by Asfaw *et al.* (2012) and Ghanba *et al.* (2013) that, common bean genotypes sensitive to water stress reduce their shoot growth in a more significant manner.

Further, significant influence of water stress treatments to root elongation was noted, the overall root length was shorter in a non-stressed treatment than in stressed plots (SPI and SPII) (Table 4). This implies that withholding irrigation at flowering and mid-pod filling, increases food and nutrients assimilation towards the roots and reduces them towards the shoot to favour the growth of roots for the purpose of increasing efficiency of roots to absorb water and nutrients. The results showed that, root length shifted from 41.41 cm in a non-stressed treatment to 41.87 cm in a stress at flowering (Table 4). These findings are in agreement with Sponchiado *et al.* (1988) who pointed out that, drought avoidance through rapid root growth can be an important drought tolerant mechanism in common bean, although, its importance can be limited by the soil properties which limits the growth of roots. The same author reported that roots of drought tolerant genotypes reached a depth of 1.3 m while those which are susceptible tend to reach a depth of 0.8 m only. A similar study by Kashiwagi *et al.* (2006) reported that root length, especially at a depth of 15.3, cm contributed positively to seed yield under moderate terminal drought and deeper root system was observed to improve yields under severe terminal drought condition. In this study there is no direct recommendation of suitable genotypes basing on root length since yields can be affected by the yield component characteristics as happened to genotype PASS which had highest root length but low yields.

Roots dry weight differences were noted among common bean genotypes and across water stress treatments. Roots dry weight was significantly affected by water stress treatments (Table 4). Root dry weight was highly reduced in stress at flowering by 57% and in stress at mid pod filling by 34%. The reduction in roots dry weight

across water stress treatment was caused by reduction of assimilates translocated to the roots in a stress condition. Drought causes shrinkage of roots that consequently affect their growth as well as nutrient transport to the root surface due to reduced contact between roots and soil (Munoz-Perea *et al.*, 2006: In North and Norble, 1997).

Common bean genotypes differed significantly in number of leaves per plant (Table 4) and water stress treatments reduced number of leaves per plant significantly by 45% in stress at flowering and by 23% in stress at mid pod filling. According to Boutrac and Sanders (2001), low irrigation level reduces number of leaves per plant. The reduction of number of leaves per plant is largely accelerated by the reduced growth of common bean genotypes under SPI and SPII (stress at flowering and mid pod filling) treatments. The growth of a plant is associated with increase in number of leaves, plant height and number of nodes in which their increase leads to the increment of number leaves of per plant.

5.2 Response of Yields and Yield Components to Water Stress Treatments

Subjecting genotypes to water stress during the reproductive stage reduced grain yields in this study. Water regimes affected significantly seed yields among genotypes, at different levels. SER16 yielded the highest (2183 kg/ha) under unstressed condition (Table 10). Other genotypes that yielded better were RCB266, BFS 60, kg104-72 with average of 2071 kg/ha, 1999 kg/ha and 1939 kg/ha respectively. The overall difference of yields per hectare across water treatments was 44.5% from non-stressed treatment to stress at mid pod filling and 53.2% from unstressed treatment to stress at flowering. These findings are in agreement with

what other researchers have found. Emam, (1985); Emam and Seghatoleslami (2005) stated that common bean grain yield is significantly reduced when water stress occurs during the reproductive phase. The reduction in grain yield is attributed to lower percentage of pod production when the water stress occurs during flowering (Emam, 1985) and from embryos abortion when the water stress occurs during pod filling stage (Robins and Domingo, 1956). Barrios *et al.* (2005) reported that seed yield reduction of up to 60 % observed in common beans under drought stress was attributed to losses of 63.3 % in pods per plant, 28.9 % in seed per pod and 22.3 % in seed weight per plant. The number of pods per plant in the screen house and field experiments were related in most of the genotypes. In the screen house, the number of pods per plant differed significantly by 35.9% from unstressed treatments to the stress at flowering and by 27% to stress at mid pod filling. The mean difference between the highest and the lowest number of pods per plant across genotypes for the field and screen house experiment were 50.5%. SER45 performed the best followed by SER16 and RCB233 (Table 6 and 10), while genotype PASS had the lowest number of pods. In this study, the number of pods per plant was significantly influenced by water stress treatments. The introduction of water stress lowered the number of pods per plant and seed number per pod. This finding is in agreement with that obtained by Castaneda- Saucedo *et al.* (2009). The researchers stated that high moisture stress during the reproductive stage exposed the plant to floral abortion and resulted in low seed yield. Other authors (Barrios *et al.*, 2005; Singh 1995; Sponchiado *et al.* 1989) reported that water stress imposed during flowering and pod setting caused flower and pod abortion. Generally, the reproductive stage is the most sensitive to drought stress (Nielsen and Nelson, 1998). This phase includes flower

formation (Pedroza and Muñoz, 1993), full flowering (Pimentel *et al.*, 1999), pod formation (Castañeda *et al.*, 2006), or grain filling (Nielsen and Nelson, 1998). Water deficits cause falling or abortion of reproductive structures in soybeans (Kokubun *et al.*, 2001), reduced pollen formation and pollination in common bean (Boutra and Sanders, 2001). The need to maintain the high pod numbers under water stress conditions in common bean is vital, since it constitutes an important yield component that determines final yield. Confalone *et al.* (1991) reported that the number of pods per plant constitute the main yield component which is mostly affected by water deficit during flowering stage and can reduce seed yield up to 70 % depending on the duration and severity of the water stress. Lopez *et al.* (1996) reported that total number of flowers in some susceptible varieties may be reduced up to 47 % under drought conditions thereby influencing the number of pods per plant; though pod setting may also vary among different common bean varieties in response to drought.

In observation of weight of pods per plant, the heaviest pods per plant in overall were measured from unstressed treatment. The mean difference of pods weight per plant between unstressed treatment and stressed at mid pod filling was 24% and when stressed at flowering, the difference was 52% (Table 7) for the field experiment. The average difference in weight of pods per plant among genotypes was 40%. The result indicate that water stress exerted at flowering and mid pod filling growth stage effected plants by reducing weight of pods, as drought affects formation of pods and development of reproductive parts of the plant. Due to this reason, beans may form empty pods and hence are measured lighter compared to

those beans grown under unstressed treatment which were not affected early abortion of seed embryos. The response of weight of pods per plant in the field experiment also corresponded to those from screen house (Table 6 and 10)

In determination of seed weight per plant, the result showed trends of seed weight per plant among genotypes in both screen house and field experiment was almost similar (Table 6 and 10). In the field experiment, the highest quantity of seed weight per plant was measured from unstressed treatment followed by stress at mid pod filling and the least was recorded from stress at flowering. Seed weight per plant under unstressed treatment differed by 32.9% from those stressed at mid pod filling and 56% from those stressed at flowering.

Number of seeds per pod varied from 4 to 5 for the field screen house experiment (Table 6 and 10); however, PASS was observed to contain an average of less than 4 seeds at all experimental sites (Table 6 and 10). Water treatments affected number of seeds per pod especially for beans stressed at flowering. This observation corresponds with the findings of Nuñez *et al.* (2005) who also identified number of pods per plant as the principal cause of yield losses of bean subjected to drought stress, followed by the number of seeds per pod and seed weight. The trend of seed number per pod in the screen house was largely related to those in the field experiment (Table 6 and 10).

In this study, 100 seed weight obtained under unstressed treatment was statistically the same with those plots stressed at flowering and was significantly different from those plots stressed at mid pod filling (Table 6 and 10). 100 seed weight at mid pod filling was the lowest and highly affected by moisture deficit. This observation

signifies that, 100 seed weight stressed at flowering was less because when irrigation was resumed after 20 days it was the period of pod filling for most of genotypes, this phenomenon enabled these genotypes to maximize translocation of assimilates to the seeds and finally the seeds size and dry matter weight. However for those stressed at mid pod filling, stress was experienced when the seed size and weight were at critical stage of development. This shortage of soil moisture, lead to under development of seeds and finally, 100 seed weight decrease. Teran and Singh (2002) reported that drought stress, on the average reduced 100 seed weight of common bean by 13 %. Singh (1995) observed a decrease in grain yield and mean weight of a hundred seeds along with accelerated maturity among these characteristics.

5.3 Identification of Drought Tolerant Genotypes Using Selection Indices

Since results obtained from ranks of indices from selection indices were not consistent (Table 13), therefore the final estimation of drought tolerant genotypes could be done by ranking the means ($\bar{R}$) of ranked yield indices (Table 13), Genotypes with lowest ranked means were considered as drought tolerant genotypes and these results are in agreement with those found by Shirani-radi and Abbasian (2011). Genotypes with higher yields under all conditions can be used as parental materials for breeding purposes and will be suited in areas with short rains as well to the areas with long rains

5.4 Identification of Suitable Selection Indices

The significant and positive correlation between Y_p and Y_I , STI and $SSPI$ implies that, these indices (Table 14) could be used in selecting for high yielding genotypes

under non water stress condition. The significant and positive correlation between Y_s and Y_I and STI signifies that the indices are suitable for selecting bean genotypes with potential yield under stress condition. This findings are similar with the work of Dehghani *et al.* (2009) who reported that STI was significantly and positively correlated with yield under stress condition. Both Y_p and Y_s were significant and positively correlated with Y_I and STI which depict that they are good predictor of genotypes with high potential yields under non-water stress and water-stressed environments. The mentioned parameters under level of high to moderate stress were correlated with yield under both conditions (Akcura *et al.*, 2011). Also, they were able to differentiate genotypes belonging to genotypes with high-yield performance in both conditions, from the others. Farshadfar *et al.* (2001) believed that most appropriate index for selecting stress tolerant cultivars is an index which has partly high correlation with seed yield under stress and non-stress conditions. Mitra, (2001) recommended that, suitable index must have a significant and positive correlation with grain yield under all conditions. On the other hand, positive correlation between yields of genotypes under unstressed with $SSPI$ implies that, the index may be useful in identifying genotypes that yield higher under unstressed condition. The negative correlation between Y_s and $SSPI$ implies that $SSPI$ can not be used in selecting genotypes with high yield under stressed condition.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In the view of the results of this experiment it is concluded that;

- (i) Common bean genotypes differed significantly in their growth characteristics yields and yields components, when evaluated in different water stress treatments and across genotypes. Some common bean yielded better while others yielded moderately and few yielded poorly.
- (ii) Highest yields among genotypes stressed at flowering were; BFS60, KG104-72, SER16, MR13905-6, CZ109-22, and SER125.
- (iii) Highest yields among genotypes stressed at mid-pod filling were; KG4-30, RCB266, KG25-21, KG104-72 and SER125.
- (iv) Genotypes that yielded relatively better under both stresses (stress at flowering and mid pod filling) were SER16, KG104-72 and SER125.
- (v) Genotypes that yielded better under all conditions (non stress, stress at flowering and mid pod filling) were SER16, KG104-72, KG4-30, and CZ109-22.
- (vi) The rankings of means of ranks of yields under non-water stress, yield under stress and the used selection indices in this study showed the most tolerant genotypes were; SER16, BFS60, KG104- 72 and CZ109-22.

- (vii) YI and STI are suitable selection indices to identify genotypes with higher yield potential under non-water stressed and water-stressed condition.
- (viii) SSPI is suitable for predicting genotypes that produce higher yields under unstressed condition.

6.2 Recommendations

Since the study was based on the observations of morphological response of bean genotypes treated with different water stress periods, therefore there is need to investigate the presence of any physiological mechanisms involved in providing tolerance under limited moisture. This knowledge will help to improve selection criteria for drought tolerance of common bean.

Genotypes SER16, BFS60 and KG104-72 were observed to be superior in yield under water stress conditions; therefore, it is recommended that, those genotypes could be used as a source of breeding materials for drought resistance in areas which are affected by drought at flowering.

In areas where droughts occur during mid-pod filling, it is recommend that genotypes KG4-30, RCB266, KG104-72 and SER125 could be used as a source of breeding materials for drought resistance.

In order to verify the findings, it is recommended that, the study has to be repeated by other researchers to confirm the findings.

In screening genotypes with high yields under non-water stress and water stress conditions, it is recommended that YI and STI could be used.

Since the selection was based on morphological characterization, it is recommended that, marker assisted selection could be deployed to confirm the findings.

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APPENDICES

Appendix 1: Summarized mean monthly weather data (Field Experiment)

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

Source: Uyole Meteorological station (2015)

Appendix 2: Summarized mean monthly weather data (Screen House Experiment)

Month	Temperature ($^{\circ}\text{C}$)		Relative humidity (RH%)
	Maximum temperature	Minimum temperature	
May	24.85	7.31	79.1
June	24.56	9.14	82.4
July	20.5	8.6	78.1
August	24.71	8.52	63.3
September	19.11	13.4	64.7
October	27.55	12.17	65.6
November	24.02	15.03	76.5

Source: Uyole Meteorological station (2015)

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