EVALUATION OF DROUGHT TOLERANCE MECHANISMS IN MESOAMERICAN DRY BEAN GENOTYPES

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRONOMY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2013

DECLARATION

I hereby declare that this is my own original work and that it has not been presented for the award of a degree in any other University or Institute of higher learning.

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I dedicate this thesis to: my beloved husband, Hezron; our children, Faith and Angie; my parents Josphat and Colleta, and my entire family for their great love, understanding and support.

ACKNOWLEDGEMENTS

I thank the Almighty God for His grace that kept me going and for giving me strength to do my work each and every day.

I greatly acknowledge RUFORUM for funding the research as well as paying fees for me. I wish we have more collaboration in future.

I am also thankful to my supervisors Dr. G.N. Chemining'wa, Prof. P.M. Kimani, Prof. M.W. Mburu and Prof. J.H. Nderitu for their timely guidance, support, encouragement and critique during the entire research period. I heartily thank them all for their valuable advise which has moulded my intellectual ability and maturity and on which I stand to benefit for the rest of my life.

In addition, I would like to thank the University of Nairobi and more so the Department of Plant Science and Crop protection for allowing me to pursue my post graduate studies.

I would also like to express my gratitude to Mr. John Wambugu of the University of Nairobi Bean Research Program for his help and sacrifice during the whole period of conducting the research.

It is also my pleasure to express my gratitude to my family and parents for their daily prayers, support and understanding during the entire period of learning.

Finally, I am grateful to everyone who contributed towards the success of this work directly or indirectly. May the Almighty God bless you all and give you the will to keep up the good work.

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ABSTRACT

Drought is a major abiotic constraint to common bean (*Phaseolus vulgaris* L.) production globally. It results into yield losses of over 60% depending on severity, time and duration of occurrence. In the face of climate change and variability, droughts have become frequent and more severe in Kenya leading to reduced bean production. It is therefore important to curb further decline in dry bean production and enhance food security by developing drought tolerant varieties of dry bean. Of the two major dry bean gene pools, the small seeded Mesoamerican beans are considered to be more drought tolerant than the large seeded Andean beans. However, little has been done to develop drought tolerant bean varieties and to understand the mechanisms of drought tolerance in Kenya and East Africa in general. The objective of this study was to identify physiological and phenological traits associated with enhanced drought tolerance in Mesoamerican dry bean genotypes. Eighty-five small and medium seeded bean lines were evaluated for drought tolerance on-farm in Mwea in Kirinyaga County and on-station at Kabete Field Station of the University of Nairobi between April 2011 and March 2012. Participatory varietal selection was conducted in Mwea and Kabete Field Station to identify the most drought tolerant lines based on farmers' selection criteria. Selectors were well qualified dry bean farmers, traders and consumers. The on-station field trial at Kabete Field Station was used to study physiological mechanisms of adaptation to drought stress including stomatal control and assimilate partitioning. Both trials were conducted during the dry periods of the year to avoid unexpected moisture supply. The 85 Mesoamerican dry bean genotypes which included three market classes (navy beans, small reds and mixed colours), local and international checks with contrasting drought responses were tested under drought stress and non drought stress conditions. Irrigation was withheld at pre-flowering to induce moisture stress. Non destructive sampling of plants for canopy temperature, leaf chlorophyll and stomatal conductance measurements was conducted at flowering and mid-pod filling stages. At mid pod filling, destructive sampling of plants on a 0.5 m row of each genotype was conducted to determine genotypic differences in partitioning of dry matter to the stems, leaves and pods. Data on phenology including duration to flowering and physiological maturity, seed yield and yield components were also recorded. Shoot biomass was measured at physiological maturity. Soil moisture at soil depths of 0 to 80 cm was monitored every week from the time of moisture stress induction to physiological maturity in both treatments in order to indicate the level of moisture stress and need for irrigation on the non-water stress plots. Harvest index, pod harvest index, pod partitioning index and stem biomass reduction measurements were calculated for both drought stressed and non-water stress treatments. Stomatal conductance was measured at flowering and mid pod filling growth stages. The results indicated that under drought stress some genotypes such as DSR11-02, DSR11-21, DMC11-10, DMC11-11, DNB11-03, DNB11-07 as well as checks like SEA 15, KAT B1 and KATB9 exhibited a tendency to escape drought effects through accelerated reproductive development. Drought stress reduced grain yield by over 30% and harvest index by 15% for most of the dry bean genotypes with the mixed colours recording the highest reduction. Under drought stress, grain yield ranged between 400 $kgha^{-1}$ and 800 $kgha^{-1}$, while harvest index varied between 34 and 55%. Significant differences in dry matter partitioning among genotypes were observed with high yielding drought tolerant genotypes such as DSR11-08, DMC11-10, DNB11-10 and SEA15 having higher harvest indices than the susceptible genotypes like DMC11-14, DMC11-20, DNB11-13 and GLP585. Stomatal conductance was low under drought stress conditions and ranged between 36 $mmm^{-2}s^{-1}$ and 206 $mmm^{-2}s^{-1}$. There was a strong correlation between grain yield under drought stress and plant attributes such as pod harvest index (r=0.40***), pod partitioning index (r=0.89***) and stem biomass reduction (r=0.32***). Significant genotypic variation in drought tolerance existed among genotypes in the three market classes under drought stress and non drought stress conditions with navy beans showing more drought tolerance and mixed colours least drought tolerance. Performance of most test genotypes was comparable to international drought lines but better than all local checks in most aspects with an average yield advantage of about 25%. It was concluded that the best drought tolerant materials were high yielding under both drought stress and non drought stress conditions across different locations. They also displayed improved partitioning of dry matter and efficient remobilization towards the developing grain under drought stress which led to high yield. These genotypes also had a good stomatal control especially under drought stress. There is need for studies on root related traits enhancing drought tolerance in Mesoamerican dry bean genotypes.

CHAPTER ONE: INTRODUCTION

1.1. Dry bean production and distribution

Common bean (*Phaseolus vulgaris L.*) is the most important grain legume globally (Broughton et al., 2003) with a total production of over 12 million metric tonnes (Beebe et al., 2009). In tropical Latin America and Africa, seven million metric tonnes are produced (CIAT, 2008). About 3,741,000 hectares is annually sown to bean in Africa in different geographical areas (Beebe et al., 2009). However, much of the production is obtained from altitudes of between 1000 m and 1800 m above sea level with over 750 mm annual average rainfall (Wortmann et al., 1998; Buruchara, 2007). There are two major types of common bean: the large seeded Andean type and the small and medium seeded or Mesoamerican type. These two diverse types differ in their biochemical and morphological characteristics such as seed size, colour, protein content, growth habit and agro-ecological adaptation (Blair et al., 2006).

Due to drought, population pressure, high input costs, and poverty, most dry bean farmers have been forced to engage in low input farming systems which yield about 500 kg/ha compared to the potential average of 1500 $kgha^{-1}$ obtained with adequate inputs (FAOSTAT, 2008). Dry bean production in Africa is mainly done by women for subsistence, but about 40% of the total produce obtained is sold at an estimated market value of 452 million USD (Wortmann et al., 1999). Over the last 30 years, bean has been traded in regional and international markets of the world including Nairobi, Kinshasa and Johannesburg in Africa (FAOSTAT, 2007). The onset of globalization has resulted in a rapidly expanding international market for beans that is estimated to be 2.4 million metric tonnes (CIAT, 2008).

Common bean cultivation is widely distributed in Africa with approximately 80% of African bean production occurring in about 10 countries (Wortmann et al., 1998). In terms of production area in Africa, Kenya is the leading producer of common bean followed by Uganda and then Tanzania. Bean yields are higher in Uganda than in Kenya because the farmer has more favourable weather conditions for beans (FAO, 2008). In Eastern Africa, common bean is grown over two seasons in a year, with sowing seasons running from March to April and September to October (Wortmann et al., 1999).

Bean cultivation in Africa is concentrated in the highlands and mid elevation areas of east, central and southern Africa with altitudes of over 1000 meters above sea level, sufficient amounts of precipitation (> 400 mm of rain) during the cropping season and soil pH of above 5.5 (Karanja, 2006). In Kenya, cultivation of small seeded beans is done together with large seeded beans in the regions of Rift Valley, Western, Eastern and Central highlands. These areas account for about 75% of total annual cultivation. However, small seeded types are predominant in the Western part of the country (Karanja, 2006). Production in the former Eastern and Coast provinces is constrained by insufficient rainfall and high temperatures. Rift Valley and Western regions grow beans over two seasons in a year. Common bean is highly sensitive to temperature changes, moisture, soil fertility and drainage (Wahid et al., 2007). However, cultivation has extended to many low potential areas due to population pressure.

Common bean is considered as the poor man's meat. The East and Central African regions has the highest per capita consumption of beans which is estimated to be 50 kg/person per year though in parts of western Kenya, consumption may be over 66 kg/person per year (Wortmann et al., 1999). More frequent consumption of beans reduces the risk of attack by diseases like cancer, diabetes or coronary heart diseases because of its low fat content and no cholesterol. Beans also suppress appetite as a result of its slow digestion thus containing hunger and maintaining low blood sugar level (Leterme, 2002).

Common bean is important in the diets of low income populations as they supply proteins (60%), carbohydrates, vitamins, minerals, energy, folic acid and dietary fibre (Nyombaire et al., 2007). Protein obtained from bean is high in lysine, which is not sufficient in maize, cassava or rice, thus making it a better dietary complement to these staples (Timothy et al., 2000). Bean together with cereals, roots and tubers form the bulk of foods consumed in most developing countries (CIAT, 2008).

1.2. Problem statement and justification

Bean production trends in Kenya have not kept pace with the annual estimated population growth rate of 2%. This is because of several abiotic, biotic and socio-economic setbacks such as droughts, diseases and lack of resources (Xavery et al., 2005). Drought is a major abiotic constraint to bean production and has caused a tremendous decline in dry bean yields. It can result in high bean crop losses of up to 60% and loss of productive land under dry bean production in previously high potential areas (Rao et al., 2007; Singh, 2007). Drought effects of highly erratic and variable rainfall regimes have drastically reduced bean productivity in east and central Africa where crop production is mainly rainfed (Miller et al., 2002; Rao, 2001). The countries affected in this region include Kenya, Uganda, Ethiopia, Tanzania, Burundi and Rwanda (Simmonds et al., 1999; Beebe et al., 2008). In a period of four years, at least one of these countries experiences crop losses due to drought (Xavery et al., 2005; Kambewa, 1997). Climate change and variability is expected to exacerbate both terminal and intermittent droughts within cropping seasons leading to crop failures (Jarvis, 2009; IPCC, 2007). This is likely to cause malnutrition and food insecurity for an estimated population of eight million people in the near future (CIAT, 2007; CIAT, 2008). In addition, food availability and malnourishment have become more rampant among women and children especially in developing countries (CIAT, 2007; CIAT, 2008). Due to the current trends in population growth and high bean consumption rates, demand for this crop in Latin America and Sub Saharan Africa is likely to be higher (Timothy et al., 2000) though production of beans reduced from 0.64 tonnes/ha in 1990 to 0.45 tonnes/ha in 2007 (FAOSTAT, 2007).

Mesoamerican bean type is known to be high yielding under drought stress compared to the large seeded Andean beans (Maciel et al., 2001; Acosta Gallegos, 1999; Munoz- Perea et al., 2006). However, little work has been done to develop small and medium seeded bean varieties in the east and central African region compared to the large seeded Andean types, which are popular in the region (Karanja, 2006). In contrast, considerable work has been done on developing improved small seeded types in Latin America (Beebe et al., 2008).

Consequently, there are few drought tolerant small and medium seeded bean varieties in Kenya and eastern Africa in general. Despite being high yielding and drought tolerant, they are less preferred by farmers. In addition, farmers in East and Central Africa (ECA) have had limited access to these improved types bred in Latin America. Therefore, farmers' participation in selection of high yielding, drought tolerant Mesoamerican dry bean varieties is of ultimate importance as it would expose them to many improved varieties of small seeded beans. Also, familiarizing farmers with available drought tolerant high yielding dry bean varieties especially the Mesoamerican types is crucial in increasing the range of alternatives at their disposal under the current climate variability and change as well as improving farm productivity and profitability.

Understanding the mechanisms of adaptation to drought stress specific to different Mesoamerican dry bean genotypes is necessary to enhance identification and selection of drought tolerant varieties. This will contribute to development of many drought tolerant bean varieties, thus increasing productivity of beans growing under moisture stress (Cotty et al., 2001). This knowledge will be highly important in African countries where bean yields have declined drastically in recent years and the area under production has continued to decline due to effects of drought and associated climate change (Jarvis, 2009).

Studies done in Latin America revealed that drought tolerance mechanisms arise from a synergy of deep root architecture, stomatal control and improved mobilization of assimilates to the developing grain under drought stress (CIAT, 2008; Terán and Singh, 2002; Rosales-Serna *et al*., 2004). Such studies have not been reported in east and central African countries. It is thus important to investigate the mechanisms of adaptation to drought stress in small and medium seeded beans with a view of developing selection criteria for drought tolerance. Moreover, strategies that aim at encouraging adoption of small seeded bean types to enhance dry bean productivity and curb widespread malnutrition and food insecurity experienced in Kenya and other Sub-Saharan countries need to be made. These considerations informed the major objectives of this study.

1.3. Objectives

The overall objective of this study was to enhance productivity of Mesoamerican dry bean genotypes under drought stress conditions.

The specific objectives were:

1. To conduct farmer participatory selection of drought tolerant small seeded Mesoamerican genotypes under field conditions

2. To assess the agronomic performance of Mesoamerican dry bean genotypes under drought stress and non-drought stress conditions

3. To evaluate genotypic variation in dry matter partitioning in the shoot among Mesoamerican dry bean genotypes grown under drought stress and non-drought stress conditions in the field

4. To identify physiological traits associated with drought tolerance among Mesoamerican dry bean lines

1.4. Hypotheses

1. Farmers' selection criteria for drought tolerant dry bean genotypes do not differ with scientific criteria
2. There is no difference in agronomic performance of Mesoamerican dry bean genotypes in drought stress and non-drought stress conditions
3. There are no differences in dry matter partitioning among Mesoamerican dry bean genotypes available to bean programs in Eastern Africa
4. There are no physiological traits that are related to drought tolerance in small seeded bean genotypes

CHAPTER TWO: LITERATURE REVIEW

2.1. Mesoamerican gene pool

Common bean (*Phaseolus vulgaris* L.) has two major gene pools known as Andean and Mesoamerican (Blair et al., 2006). The Mesoamerican gene pool which consists of small and medium seeded beans was first domesticated in Northern Mexico and Colombia (Freyre et al., 1996) and has four major races namely Durango, Jalisco, Mesoamerica and Guatemala (Beebe et al., 2000, 2001) which are believed to have resulted from multiple domestications (Beebe et al., 2000; Singh, 2001). These four races differ in their range of ecological and geographical adaptation as well as morphological and agronomic characteristics (Singh, 2001). Race Durango from Highland Mexico and race Mesoamerica from Central America are known to be high yielding under stress (Acosta Gallegos et al., 1999; CIAT, 2008) as they originated from areas that are known to experience severe drought within seasons of growth (Acosta Gallegos et al., 1999). Genes for drought tolerance and adaptability of many genotypes have been obtained from these two races and have been incorporated into many genotypes through intensive breeding. As a result, crosses made from these two races have resulted in high yielding Mesoamerican bean types under drought stress (Schneider et al., 1997; Beebe et al., 2008).

Most Mesoamerican beans display an indeterminate growth habit with or without guides (Buruchara, 2007). This translates into higher yield as more pods containing two to four seeds are borne along the length of the stem which is about 18 to 24 inches (Buruchara, 2007). Some small seeded dry bean varieties are vine-like while others are erect and bushy. The bush type is mainly grown in Africa (Buruchara, 2007).

Mesoamerican beans are sold in a variety of forms. Mixes of beans are most commonly sold as whole seeds in unprocessed form. Navy beans are found in canned form, black beans are made into refried beans, among other uses while red beans are used for baked beans. Small seeded beans which are not fit for human consumption are used as livestock feed (FAOSTAT, 2007).

2.2. Constraints to dry bean production

2.2.1. Diseases and pests

Pests and diseases are the major biotic constraints contributing to low yields of beans. Major bean diseases in eastern Africa are angular leaf spot (*Phaeiosariopsis griseola*) (Pastor-

Corrales, 1998), anthracnose (*Colletotrichum lindemuthianum*), root rot, common bacterial blight (CBB), rust, and bean common mosaic virus (Allen et al., 1998). Important pests include the bean stem maggot (BSM) (*Ophiomyia* spp.) (Otsyula et al., 1998), aphids (*Aphis fabae*) and bruchids (*Zabrotes subfasciatus)* that are highly destructive post harvest pests (Nchimbi and Misangu, 2002). These diseases and pests have been reported to cause yield losses of over 40% and 30% respectively (Cardona, 2004). Major disease and pest control interventions adopted include use of pesticides and physical methods. Weeds are also important in bean production and can cause significant losses of up to 60% as beans are poor competitors with weeds (Allen et al., 1998). Weed management is done by hand weeding which sometimes is not timely. In developing countries, most of the bean production occurs under low input agriculture on small-scale farms where management of abiotic stresses is very poor. However, high input commercial oriented farmers have more resources to combat diseases, insect pests and weeds through the use of pesticides, fertilizers and herbicides. In efforts to reduce bean losses due to diseases and pests, a lot of work on developing disease resistant varieties has been done through classical and marker assisted selection breeding (Kelly et al., 2003; Beebe et al., 2000).

2.2.2. Edaphic factors

Declining soil fertility is a major problem in dry bean production in eastern Africa (Kimani et al., 2007). Major edaphic constraints include low soil nitrogen, low soil phosphorus, soil acidity and toxic levels of aluminium and manganese (Lunze et al., 2007; Kimani et al., 2007). With fertile, well-drained and good soil conditions, higher yields of beans can be obtained (Wortmann et al., 1998).

Wortmann et al. (1998) reported N deficiency in 93 of 95 bean growing areas from eastern Africa. The vast majority of bean producers therefore, cannot afford to correct soil fertility problems through intensive fertilization, use of soil amendments or prolonged fallows. The bean plant meets its nitrogen requirements from the soil nutrient pool and symbiotic nitrogen fixation. This is why an elaborate root system with several root whorls is absolutely necessary in beans and enhances yield performance in poor soils (Bouhmouch et al., 2005).

2.2.3. Poor marketing strategies

Marketing of common beans is a major constraint for farmers particularly because production is based on small scattered plots. There is a relatively high degree of competition that has raised producer prices. Nevertheless, traders are better placed in fixing prices since they are few and have good knowledge of the market compared to the numerous farmers who sell immediately after harvest to reduce post harvest losses caused by pest damage. Therefore, traders benefit from low prices by purchasing beans from farmers immediately after harvest. Prices are determined by quality, variety, season, and their total marketing costs. This causes producers to suffer heavy losses thus making them give less preference to dry bean farming (Kimani et al., 2000).

2.2.4. Drought

Drought has been defined as a prolonged period without considerable precipitation that may result in reduction in soil water content causing a deficit in plant water (Tardieu, 1996). The major abiotic constraint to dry bean production is drought which limits adaptation of many pulse crops (Rao et al., 2007; Miller et al., 2002). Drought effects on common bean cultivars including those of Mesoamerican gene pool differ depending on the frequency, duration and the intensity of stress and the stage of growth of the affected crop (Nunez-Barrios et al., 2005). Drought stress results in significant reduction in seed yield in about 60 % of the total global bean producing areas (Graham and Ranalli, 1997; Rosales-Serna et al., 2004). Due to rising competition for dry bean production areas, expansion of bean acreages to more marginal areas with increased abiotic stress have been realized (Porch et al., 2008), though the average global yield remains lower than 900 kg/ha (Rao et al.,2009).

Drought has been worsened by climate change and variability which is predicted to continue over a long period (Jarvis, 2009). Climate variability has resulted in intermittent and terminal droughts. These two distinct kinds of droughts are associated with inadequate rainfall. Intermittent drought is due to climate patterns of sporadic rainfall that causes intervals of drought and can occur at any time within the growing season of a crop (Schneider et al., 1997). Terminal drought occurs when the plants accessibility to water reduces during later stages of reproductive growth or when the crops are grown at the beginning of a dry season (Frahm et al., 2004). Also, increase in local temperatures as a result of climate variability has constrained crop yields in seasonally dry and tropical regions (Jarvis, 2009). As a result, variable and extreme weather conditions such as droughts will make local crop production impossible and subject about 49 million people to a risk of hunger by 2020 (Jarvis, 2009). In addition, global weather forecasts indicate even more variability and water shortages in the future (IPCC, 2007). Hence, the importance and urgency of developing high yielding drought resilient cultivars that use water more efficiently thus reducing dependence on expensive irrigation water to improve bean productivity. High yielding drought resilient varieties increase and sustain yield in drought affected areas while maintaining high returns for producers (Griffiths et al., 2002).

2.3. Effects of drought on dry beans

Insufficient and/or unpredictable rainfall significantly lowers yield potential of many dry bean cultivars as most dry bean production in the world takes place under rainfed conditions (Rao et al., 2009). The range of reduction in dry bean seed yield due to drought varies with intensity of drought stress imposed and genotypes used (Frahm et al., 2004; Shenkurt and Brick, 2003). Dry bean seed yield reduction under stress can be attributed to the adverse effects of the stress on individual yield components including the number of pods per plant, number of seeds in every pod, seed weight and harvest index (Nunez-Barrios et al., 2005; Teran and Singh, 2002). However, the relative importance of these components as determinants of seed yield varies across experiments (Shenkurt and Brick, 2003; Boutraa and Sanders, 2001).

Drought stress reduces total plant biomass and seed yield of beans by about 20-90% (Padilla-Ramirez et al., 2005). It has also been reported to lower the harvest index, number of filled pods per plant, number of seeds per pod, seed weight, days to flowering and days to physiological maturity (Abebe and Brick, 2003; Munoz-Perea et al., 2006; Ramirez et al., 2005). Drought stress during the reproductive phase of dry bean result in excessive abortion of flowers, young pods and seeds (Padilla-Ramirez et al., 2005). It extends the cooking time of dry bean by increasing hard seed shell defects (Hosfield et al., 2000) and lowers seed protein content of beans on dry weight basis (Frahm et al., 2004). The canning quality of beans such as navy beans is reduced by drought due to poor maturation of the seed, extended cooking time and reduced seed weight (Hosfield et al., 2000).

Drought adversely affects water use efficiency and plant or seed uptake of most macro and micro nutrients (Munoz-Perea et al., 2007). For instance, moisture stress reduces phosphorus uptake (Guida dos Santos et al., 2004), nitrogen uptake and nitrogen fixation (Ramos et al., 1999; Serraj and Sinclair, 1998). These result from the limitation of root growth, development and expansion that consequently affect transportation of nutrients to the root surface due to reduced contact between root and soil (North and Nobel, 1997).

2.4. Adaptation mechanisms of dry bean to drought stress

Considerable efforts have been focused on breeding for biotic stresses in Mesoamerican bean genotypes by various scientists and research organizations in both developed and developing countries. In the recent past, efforts have also been directed at developing varieties tolerant to abiotic stresses such as drought (Beebe et al., 2000). However, the mechanisms essential for drought tolerance have not adequately been addressed. In fact, detailed studies looking at mechanisms of adaptation to drought among dry bean varieties such as deeper roots, stomatal control and partitioning of dry matter in Mesoamerican beans have not been reported in eastern Africa. Such studies have only been carried out in Latin America. This study will contribute to fill this research gap.

The mechanisms of adaptation to drought vary among dry bean genotypes resulting in seed yield differences. The differences in seed yield can be attributed to physiological and biochemical responses such as tissue water retention, osmotic adjustment, integrity of membrane system, protease activity and stomatal control (Costa Franca et al., 2000; Hieng et al., 2004; Lizana et al., 2006). There is an increasing need to improve drought tolerance in common bean cultivars through adaptive mechanisms such as root architecture, growth habit, maturity acceleration, early flowering, shoot biomass accumulation and efficient assimilate redistribution towards seeds which improves the harvest index of beans (Terán and Singh, 2002; Rosales-Serna et al., 2004).

2.4.1. Accelerated phenological development

Grain yield in beans is a component of the number of plants per unit area, number of pods per plant, number of seeds per pod and seed weight (Teran and singh, 2002). The number of plants per unit area is determined by the number of plants that emerge and/or survive till maturity (German et al., 2006). Also, yield components are crucial for producing economic yield, and vary in time scale. However, drought at the beginning of the growing season is very detrimental as it affects most yield components such as number of pods per plant and seeds per pod which highly depend on the number of branches produced by the plant and the number of well-developed pods and seeds (Grifiths et al., 2002; German et al., 2006). In addition, drought affects pod formation, seed setting and seed filling by interfering with assimilate production, translocation and partitioning (Munoz-Perea et al., 2006). However, the most variable trait to affect grain yield in beans is the number of pods per plant and is responsible for the significant reduction of yield during drought at or after flowering. Drought at flowering causes abortion of flowers and pods as a result of assimilate shortage resulting in yield reduction (German et al., 2006).

Early phenology leading to rapid ground cover and efficient dry matter production in legumes allows efficient water use after flowering thus encouraging greater partitioning of dry matter into seeds (Siddique et al., 2001). Dry bean cultivars that adjust their phenology exhibit higher seed yields under drought conditions (Rao et al., 2007). However, some genotypes usually fail at the final stages of grain production. This is referred to as the “lazy pod syndrome” (Beebe et al., 2008). Such genotypes are low yielders especially under drought stress. Drought resistant dry bean varieties also have better yields in favorable conditions and within a short growth period (Beebe et al., 2008).

2.4.2. Deep root system

Root characteristics are vital in determining crop responses to drought and differences in yield under low moisture stress (Lynch, 2007). Deep root architecture is highly important in dry beans as it enables the plant to reach and mine water from the lower soil profile levels (Frahm et al., 2003). Shallow roots are not ideal under drought stress (Rubio et al., 2003). However, deep rooting alone does not confer drought resistance. Data on root density at different levels of the soil profile suggest that ‘deep rooting genotypes are not always the best yielding materials under water stress’ (Lynch and Brown, 2008). This is also confirmed by data on stomatal conductance and canopy temperature depression which shows that these genotypes are accessing water which does not translate into higher yield (Lynch, 2007).

2.4.3. Assimilate partitioning

Remobilization of assimilates from the shoot to pods and finally from pod wall to the developing grain is an important mechanism of drought resistance in common bean (Rao et al., 2007). There exists variations in accumulation of biomass and partitioning among dry bean genotypes which are reflected in canopy biomass dry weight at mid pod filling, pod partitioning index and pod harvest index (Rao et al., 2007). This variability causes differences in yield.

Accumulation of shoot biomass is key to attaining high seed yield in grain legumes (Shenkurt and Brick, 2003). Significant differences for shoot biomass accumulation exist among dry bean cultivars grown under moderate to severe drought stress conditions (Rosales-serna et al., 2002; Ramirez-Vallejo and Kelly, 1998). A strong positive correlation has also been reported between total plant biomass and seed yield under drought stress and non stress conditions (Shenkurt and Brick, 2003). In addition to dry matter accumulation, the ability of genotypes to partition stored vegetative biomass to reproductive organs to a large extent determines sink establishment and economic yield under stress (Chaves et al., 2002).

2.4.4. Stomatal control

Stomatal control is one of the main mechanisms for adaptation to water stress in common bean (Miyashita et al., 2004). Stomata often close in response to drought before a major decline in water potential which is in the range of -0.5 Mpa and -1.5 Mpa (Miyashita et al., 2004; Socías et al., 1997). Drought stress reduces the osmotic potential for most dry bean genotypes due to higher solute accumulation. However, it is not clear if the decrease results from osmotic adjustment or if it results from a concentration of the cell sap due to tissue dehydration, as previously reported for common bean (Amede and Schubert, 2003). In common bean, drought stress at its initial phase limits photosynthesis mainly due to stomatal closure (Miyashita et al., 2005; Amede and Schubert, 2003). However, as the stress continues for an extended period, non-stomatal inhibition of photosynthesis may become more important (Lawlor and Cornic, 2002; Medrano et al., 2002). Increasing evidence suggests that down-regulation of different photosynthetic processes under drought stress depends more on CO_2 availability in the mesophyll (i.e. stomatal closure) rather than leaf water potential or leaf relative water content (Medrano et al., 2002). Therefore, drought resistance seems to result from a synergy of mechanisms including a deep root system, root distribution in the soil profile, stomatal control and improved photosynthates remobilization under stress (Beebe et al., 2008).

CHAPTER THREE

FARMER PARTICIPATORY DRY BEAN VARIETAL SELECTION FOR DROUGHT TOLERANCE

3.1. Abstract

Common bean (*Phaseolus vulgaris L.*) is the most important grain legume in Kenya. It is cultivated in high potential, semi-arid and marginal agro-ecologies. However, its productivity especially in semi arid areas is severely constrained by frequent droughts associated with climate change and variability. Consequently, the country has low average bean yield of about 500 kgha^{-1}, and is dependent on imports to meet domestic consumption. The objective of this study was to introduce farmers to new drought tolerant and high yielding Mesoamerican dry bean genotypes by involving them in selection of the best materials from three market classes. On-farm trials were conducted in Mwea from April 2011 to February 2012 while on-station trials were conducted at Kabete Field Station of the University of Nairobi between June 2011 and March 2012. Eighty five advanced lines of three market classes (navy, small reds and mixed colours) were grown in irrigated (non drought stress) and rainfed (drought stress) plots at each location. The 85 lines included local varieties (GLP585, GLPX92, KATB1 and KATB9) and international drought checks (SEA15, SER16, MEX142, SEN53 and NCB226). The trials were laid out in a split plot design with three replicates. Water stress levels were assigned to the main plots and genotypes to the subplots. Water stress treatment was imposed at flowering. Twenty seven (10 women and 17 men) and 36 (21 women and 15 men) experienced bean farmers evaluated the genotypes at physiological maturity in June 2011 and February 2012 respectively in Mwea. At Kabete, 36 experienced farmers (23 women and 13 men) evaluated the genotypes in March, 2012. The ribbon method of participatory variety selection was followed in all the evaluations. The evaluation criteria included agronomic characteristics such as pod load, drought tolerance, susceptibility to pests and diseases, and seed characteristics such as seed colour, market value and colour of stew. Farmers rated genotypes as excellent (5), very good (4), good (3), poor (2) and very poor (1). Pod load was ranked as the most important selection criterion by both men and women selectors. Women and men selectors differed in their rating of some aspects like grain colour and growth habit as women concentrated on grain colour while men used criteria such as growth habit to rate varieties. Among the mixed coloured genotypes, DMC11-03, DMC11-10, DMC11-12, DMC11-23 and SEN53 were preferred by over 57% of the farmers. Navy beans including DNB11-03, DNB11-07 and DNB11-16 were preferred by over 50% of the farmers while small reds such as DSR11-02, DSR11-08, DSR11-21, DSR11-23, SEA15 and TIO CANELA were highly preferred by over 70% of the farmers during the two seasons in Mwea. In Kabete, among the genotypes selected from the mixed colours were DMC11-03, DMC11-12, and NCB226 and were preferred by about 41% of the farmers. Preferred navy beans included DNB11-03, DNB11-07, and DNB11-15 and were selected by about 36% of the farmers. Small reds that were highly preferred by over 50% of the farmers were DSR11-02, DSR11-14, DSR11-21, GLP585, RCB592 and SER155. Genotypes within the small reds market class were most preferred while navy beans were the least preferred. Results showed that genotypes selected in Kabete and Mwea sites differed though the selection criteria used by farmers was comparable. Most of the preferred and selected genotypes in the two locations were new indicating an increasing range of alternatives at the farmers' disposal with the changing climate. It was concluded that farmers could identify the best drought tolerant materials and discard the most susceptible genotypes using their own evaluation criteria.

Key words: Mesoamerican, genotype, criteria, market class, navy bean, rank

3.2. Introduction

Common bean is a vital grain legume cultivated in Kenya (Karanja, 2006). About 67 g/capita/day of protein is consumed in Kenya out of which 10% (7 g/capita/day) is contributed by beans (FAO, 2002; 2003). In the semi-arid areas of Kenya, beans are usually grown in marginal environments where conditions are highly unfavourable due to frequent droughts. Besides, production is mainly done by small scale farmers whose resource base is poor, who can hardly afford external inputs and are faced with other challenges such as lack of good quality seed (Letourneau, 1994: Ampofo and Massomo, 1998). Small seeded dry bean remain a better choice as less seed (45 kg) is required per hectare compared to 100 kg per hectare for large seeds (Buruchara, 2007). Due to socio-economic constraints, farmers can rarely alleviate the effects of drought. As a result, on-farm yield of beans has remained less than 500 kgha^{-1} compared to more than 1500 kgha^{-1} obtained under favourable experimental conditions (Muasya, 2001).

Though farmers are dynamic and quickly adapt to their changing environment, their scope of knowledge is localized and requires professional validation (Nkunika, 2002: Trutmann et al., 1996). For example, farmers in Kenya are not familiar with the wide range and potential of small and medium seeded varieties available in research stations and seed companies the region. Therefore, introduction and familiarization of farmers with a wide range of well adapted bean varieties plays a key role in enhancing their knowledge (Letourneau, 1994). It also enables them to make informed decisions on the choice of suitable varieties (Songa and Ampofo, 1999).

For successful adoption, new improved bean varieties should satisfy the grower, trader, seed producer and consumer (Graham and Ranalli, 1997). Their involvement in selection of bean genotypes can enhance identification of genotypes which better meet their preferences. Participatory plant breeding offers a crucial platform as it allows farmers, research scientists and extension agents to conduct research together thus spearhead the adoption process. Farmers' fields provide variable environments thus allowing a considerable interaction between the genotypes and the environment. The level of interaction in these fields differs from that experienced in research stations (Ceccarelli and Grando, 2007). In addition, farmers base their selections on criteria which may differ with the researchers' criteria.

Conventional breeding methods used by most Kenyan bean breeding research programs have released many varieties suitable for various agro-ecologies. However, slow adoption of these varieties has led to continued deficits in bean supply. In addition, wrong choice of well adapted varieties to various regions has resulted in poor bean yields in many environments (Songa and Ampofo, 1999). Moreover, less preference of some of the varieties within certain market classes because of grain colour or growth habit has led to well adapted varieties of beans being rejected (Kimani et al., 2005).

According to Ceccarelli and Grando (2007), conventional plant breeding has been successful among farmers in high potential areas who can afford farm inputs to meet expected output but has achieved less in marginal environments where most farmers are resource poor and the environment is highly diverse. Despite these challenges, formal bean breeding programmes have been successful in mitigating against these challenges by developing varieties suitable for diverse environments including drought prone areas. It is, therefore, important to develop sustainable research strategies aimed at finding possible solutions to devastating drought effects by allowing farmers to actively participate in identification of suitable bean varieties that are able to thrive under prevailing environmental conditions in their locations. Therefore, the objective of this study was to introduce farmers to new dry bean genotypes considered to be drought tolerant and high yielding by breeders, their different market classes and involve them in selection of the best materials using their own evaluation criteria.

3.3. Materials and Methods

3.3.1. Trial sites

3.3.1.1. Mwea

The study was carried out at Kimbimbi location, Nyangati village in Mwea, Kirinyaga South District in Central Kenya at an elevation of 1214 m above sea level. This site is geographically located on 0^{o}36’21.66” S and 37^{o}22’01.24”E (Google, 2010). It is a warm lowland area with minimum and maximum temperatures of 17^{0}C and 26^{0}C, respectively, and average annual rainfall of 950 mm p.a. The rainfall pattern is bimodal with the long rains coming in April to May and the short rains in October to December every year. Relative humidity varies from 52 to 67% (Manene, 2010). Farming is basically small to medium scale and is mainly done by sprinkler and flood irrigation. Major crops grown in this area are paddy rice, tomatoes and snap beans under irrigation and common beans, maize, cowpeas and green grams which are mainly rainfed (Manene, 2010). The study was conducted in March to June 2011 and November 2011 to February 2012 towards the end of the rains. Supplementary irrigation was used to sustain the crop during the vegetative growth stage.

3.3.1.2. Kabete Field Station

Kabete Field Station of the University of Nairobi is located on latitude 1°15’ S and longitude 36°41’ E (Google, 2010), at an altitude of 1,820 meters above sea level. It receives an average annual rainfall amount of 980 mm which is received during long rains (March to May) and short rains (October to December) seasons every year. The site has minimum and maximum mean temperatures of 13.7 and 24.3°C respectively. The soils are characterized as very deep, well-drained, dark reddish, deep friable clay type resistant to erosion (Michieka, 1977). Among the crops grown in this area are maize, vegetables and beans which are mainly rainfed. Field trials were set up between June and September 2011 and November 2011 to March 2012 towards the end of the rains. Supplementary irrigation was used during the vegetative growth stage.

3.3.2. Experimental design, treatments and crop husbandry

On-farm field experiments were set up in Mwea in March to June 2011 and November 2011 to February 2012. On-station field experiments were set up in Kabete in November 2011 to March 2012. The planting material consisted of 64 dry bean lines from three market classes namely mixed colours (24 lines), navy beans (17 lines) and small reds (23 lines) which were sourced from the University of Nairobi bean research program. Four local varieties namely KATB1, GLPX92 (mixed colours), KATB9 and GLP585 (small reds) were used as checks. The following international drought tolerant lines were also used as checks: SEN53, SEN56, SXB404 (mixed colours), MEX142 (navy bean), and SEA15, SER16, Tio canela (small reds). These made a total of 85 dry bean lines (Table 3.1).

The experimental design was a split plot with three replicates. Each replicate consisted of non drought stress and drought stress treatments adjacent to one another and separated by a 2 m path. Drought stress treatments were assigned to the main plots while the 85 varieties were assigned to the subplots. Non drought stress plots were irrigated once a week until physiological maturity while the drought stress treatment did not receive additional water from flowering to physiological maturity. Irrigation was done to field capacity (35-50 mm of rainfall). Each plot had two 3 m rows of each genotype. The spacing between rows was 50 cm and spacing between plants was 10 cm giving 30 seeds per row and 60 plants per plot. Dry conditions persisted to maturity throughout the experimental period. Soil moisture was monitored from the time of drought stress induction to physiological maturity by taking soil samples from soil depths of 0-5 cm, 5-10 cm, 10-20 cm 20-40 cm, 40-60 cm and 60-80 cm.

Table 3.1: List of bean genotypes evaluated in both on-farm and on-station field experiments

Market class	**Number of test lines**	**Number of local checks**	**Number of International checks**	**Total**
Mixed colours	24 (DMC11-01 to DMC11-24)	2	5	31
Navy beans	17 (DNB11-01 to DNB11-19)	0	1	18
Small reds	23 (DSR11-01 to DSR11-24)	2	11	36
Total				85

Land was ploughed and harrowed using a tractor. Fertilizers were not applied on the crop. The plots were kept weed free by hand weeding three weeks after emergence and just before flowering. Pests such as bean stem maggot, aphids and whiteflies were controlled by spraying with Tata alpha® (Cypermethrin 100 g/l) at the rate of 1 l/ha which was repeated four times in the entire crop cycle. Incidence of rust, angular leaf spot, common bacterial blight and bean common mosaic virus was very low to warrant control measures.

3.3.3. Data collection

Evaluation and selection of genotypes in Mwea was done at physiological maturity by 27 farmers in the first season (10 women and 17 men) and 36 farmers (21 women and 15 men) in the second season. In Kabete, 36 farmers consisting of 23 women and 13 men evaluated the genotypes at physiological maturity. The ribbon method of participatory variety selection was used (Christinck, 2000b). Yellow and red coloured ribbons were used by male farmers to denote preferred and rejected genotypes respectively. Women used white ribbons for preferred genotypes and black ribbons for rejected genotypes. Each farmer received a total of 20 ribbons half of which were for the preferred genotypes. Prior to selection, black polythene bags were tied to the label pegs in each plot (Plate 1a). For each genotype, a sample of seeds in a transparent polythene bag was placed at the edge of the corresponding plot. Before selection, farmers were informed about the purpose of the experiment and shown how to do the selections using the ribbons with the colours of their choice (Plate 1b). During the selection, farmers examined the genotypes (Plate 1c) and placed the respective ribbons in the black polythene bags (Plate 1d) which were tied on the label pegs in order to allow independent decisions about the genotypes. The ribbons in the black polythene bags were subsequently tied on the pegs according to colour (Plate 1e) in order to identify highly preferred and rejected genotypes (Plate 1f and 1g). The total number of positive and negative ribbons by men and women were counted for each genotype by participating farmers and recorded by the researchers. After selection, a discussion was held with farmers to determine their evaluation criteria for selecting genotypes, the rating of the genotypes according to performance and the criteria for selecting or rejecting genotypes (Plate 1h). For the selected varieties, male and female farmers were separately asked to rank the genotypes based on a scale of 1 to 5, where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. Farmers were also asked to give reasons for preference or no preference. The participatory variety selection procedure can be summarized in photographic form as follows:


Plate 1a) Field layout before PVS


Plate 1b) Choice of ribbons


Plate 1c) Familiarization with the trial


Plate 1d) Selection of genotypes


Plate 1e) Tying ribbons

Plate 1f) Preferred line

Plate 1g) Rejected genotype


Plate 1h) Group discussions


Plate 1i) Way forward

Plate 1(a-i) shows the procedure followed during participatory variety selection exercise at Kabete

Source: PVS pictures that were taken during the on-station exercise in Kabete.

3.3.4. Data analysis

Data analysis on farmer selections was done using Microsoft excel to calculate the averages or total number of selections. Average grain yield was obtained using Genstat edition 13 (Mead et al., 2003).

3.4. Results

The positive and negative criteria suggested by the farmers for evaluating dry bean genotypes are shown in Table 3.1. Seventeen plant characteristics and seven seed traits were used by both male and female farmers to identify the best genotypes. These plant characteristics were ranked in the order of importance with the top seven plant characteristics being high pod load, early maturity, drought tolerance, low pest and disease attack, uniform maturity, many seeds in each pod and good plant stand. Seed traits included attractive seed coat colour, high market value, good taste and good keeping quality (Table 3.2). Criteria for rejecting varieties were 12 plant characteristics: low yielding lines, poor drought tolerance, susceptibility to pests and diseases, light pods, late maturity, climbing growth habit, poor plant stand, low pod load but more foliage, poor uniformity at maturity, weak stems, shattering in the field and small pods; and seven seed characteristics which included dull seed colour, types that spoil easily after cooking, prolonged cooking and poor taste (Table 3.2). Characteristics like cooking time, market value and poor taste were predictions made by farmers based on visual judgements without active measurements. All the farmers (100% men and 100% women) considered yield as indicated by pod load, drought resistance, pest and disease tolerance, plant stand and market value as the most important criteria in selecting the best bean genotypes (Table 3.3). However, some of the criteria used in selection differed between men and women. These included cooking quality which farmers determined by smoothness or roughness of the seed coat (the smoother the seed coat the faster the cooking and vice versa), suitability for local stew based on colour, growth habit, lodging and shattering (Table 3.3). Growth habit was considered important by 100% of the men and only 50% of the women. Suitability of the beans for local stew was an important consideration by 100% of the women and only 40% of the men. Seed colour was highly regarded by 100% women but only 80% of the men. No differences were noted among men and women with regard to plant height (80% each) and stand uniformity (50% each) (Table 3.3).

Table 3.2: Ranking of the most important selection criteria in order of decreasing importance suggested by both male and female farmers for evaluating dry bean varieties

<table>
<tr><th>Positive criteria</th><th>Negative criteria</th></tr>
<tr><td>Plant characteristics
1. High pod load
2. Early maturity
3. Drought tolerance
4. Disease and pest resistance
5. Uniform maturity of plants
6. Many seeds in each pod
7. Good plant stand
8. Hard pod wall
9. Upright growth habit
10. Suitable for intercropping
11. Strong stems
12. Many branches
13. Good adaptation
14. Non shattering in the field
15. Tolerant to low soil fertility
16. Stay green even at harvest (foliage used as fodder)
17. Low foliage at harvest</td><td>Plant characteristics
1. Low yielding varieties
2. Poor tolerance to drought (dried plants)
3. Susceptibility to diseases and pests
4. Light pods (allows moisture to enter causing seed germination in the pod and also easy pest damage)
5. Late maturity
6. Climbing growth habit
7. Poor plant stand
8. Low pod load but more foliage
9. Poor uniformity at maturity
10. Weak stems (sprawling)
11. Shattering in the field
12. Small pods</td></tr>
<tr><td>Most preferred seed characteristics
1. Attractive seed coat colour (by appearance)
2. High market value (by market class/seed type)
3. Good taste (determined by grain colour)
4. Good keeping quality when cooked (seed type)
5. Fast cooking ability (light seed coat)
6. Resistant to storage pests (bruchids) (hard seed coat)
7. Hard seed coat</td><td>Non preferred seed characteristics
1. Dull-coloured seeds
2. Types that spoil easily after cooking
3. Prolonged cooking
4. Poor taste
5. Poor colour to soup
6. Low market value
7. Storage pest damage in the field</td></tr>
</table>

Table 3.3: Ranking of the top 13 selection criteria used by male and female farmers in selecting drought tolerant Mesoamerican dry bean genotypes in Kabete and Mwea

Rank	Selection criterion	Kabete		Mwea	
		Males (%)	Females (%)	Males (%)	Females (%)
1	Yield/pod load	100	100	100	100
2	Drought resistance	100	100	100	100
3	Pest and disease resistance	100	100	100	100
4	Plant stand	100	100	100	100
5	Market value	100	100	100	100
6	Seed colour	80	100	80	100
7	Cooking quality	80	100	80	100
8	Growth habit	100	50	100	50
9	Plant height	80	80	80	80
10	Suitability for local stew	40	100	40	100
11	Lodging	60	80	60	80
12	Shattering	70	50	70	50
13	Stand uniformity	50	50	50	50

Selection of genotypes in the three market classes by men and women differed with small reds being preferred by most selectors in both locations. Some genotypes were selected in one season or one location; other genotypes were selected in both seasons and locations while others were not selected at all. Among the mixed colours, the most preferred genotypes in Mwea included DMC11- 03, DMC11-10, DMC11-11, DMC11-12 and DMC11-23. These were selected by 32%, 32%, 27%, 37%, and 29% of the farmers respectively. All the local checks including GLPX92 and KATB1 were rejected by farmers (Table 3.4). Within the navy beans, DNB11-03, DNB11-07 and DNB11-15 were selected by 29%, 24% and 17% of the farmers respectively. The check MEX142 was not preferred by farmers (Table 3.5). Small reds were more preferred by both gender with genotypes such as DSR11-02, DSR11-08, DSR11-21 and DSR11-23 selected by 44%, 38%, 37% and 32% of the farmers respectively. Local checks GLP585 and KATB9 were among the least preferred lines. However, farmer preference for international drought lines used as checks including Tio canela, RCB592, and SER16 was comparable to the test genotypes (Table 3.6). In all the classes, new genotypes were more preferred than the respective checks due to high yield and drought tolerance.

In Kabete, small reds were most preferred to the other market classes which led to selection of many genotypes from this class. In the mixed colours, DMC11-03, DMC11-12, and NCB226 were preferred by 11%, 75%, and 22% of the farmers respectively (Table 3.7).

Navy beans that were highly preferred were DNB11-03, DNB11-07 and DNB11-15 and were selected by 36%, 31% and 25% of the farmers respectively (Table 3.8). Among the small reds, genotypes including DSR11-02, SR11-21, GLP585, RCB592 and were selected by 47%, 44%, 58% and 47% of the farmers respectively (Table 3.9).

Table 3.4: Selection of genotypes in the mixed colours under drought stress treatment by male and female farmers during the first and second seasons in Mwea

Market class	First season				Second season						
	Frequency				Frequency						
Mixed colours	Men	Women	Total positive ribbons	Rating of the genotype	Men	Women	Total positive ribbons	Rating of the genotype	Total preferred	% preference	Grain yield (kg/ha
DMC 11-12	11	11	22	5	1	0	1	1	23	37	424.0
DMC 11-03	3	8	11	2	8	1	9	2	20	32	640.0
DMC 11-10	11	9	20	4	0	0	0	1	20	32	744.5
SEN53*	10	9	19	4	1	0	1	1	20	32	634.0
DMC 11-23	11	6	17	4	1	0	1	1	18	29	507.0
DMC 11-11	13	3	16	4	0	1	1	1	17	27	774.0
DMC 11-02	6	5	11	2	0	0	0	1	11	17	768.5
DMC 11-15	7	3	10	3	0	0	0	1	10	16	496.0
DMC 11-17	0	1	1	1	2	2	4	1	5	8	288.5
DMC 11-21	2	1	3	1	1	0	1	1	4	6	613.0
SEN56*	2	0	2	1	2	0	2	1	4	6	142.5
DMC 11-22	3	0	3	1	0	0	0	1	3	5	557.0
DMC 11-01	2	0	2	1	0	0	0	1	2	3	626.0
DMC 11-06	0	0	0	1	0	1	1	1	1	2	411.0
DMC 11-09	0	0	0	1	1	0	1	1	1	2	434.5
DMC 11-14	0	0	0	1	1	0	1	1	1	2	277.0
DMC 11-18	0	0	0	1	1	0	1	1	1	2	291.0
KATB1*	0	0	0	1	0	1	1	1	1	2	537.5
DMC 11-04	0	0	0	1	0	0	0	1	0	0	300.5
DMC 11-05	0	0	0	1	0	0	0	1	0	0	394.5

DMC 11-07	0	0	0	1	0	0	0	1	0	0	469.5
DMC 11-08	0	0	0	1	0	0	0	1	0	0	432.0
DMC 11-13	0	0	0	1	0	0	0	1	0	0	359.0
DMC 11-16	0	0	0	1	0	0	0	1	0	0	259.0
DMC 11-19	0	0	0	1	0	0	0	1	0	0	288.0
DMC 11-20	0	0	0	1	0	0	0	1	0	0	227.0
DMC 11-24	0	0	0	1	0	0	0	1	0	0	749.0
GLPX92*	0	0	0	1	0	0	0	1	0	0	1118.5
NCB226*	0	0	0	1	0	0	0	1	0	0	358.0
NCB280*	0	0	0	1	0	0	0	1	0	0	726.0
SXB404*	0	0	0	1	0	0	0	1	0	0	125.0
Mean	**3**	**2**	**4**	**2**	**1**	**0**	**1**	**1**	**5**	**8**	**483.0**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=108.2

Table 3.5: Selection of genotypes in the navy beans under drought stress treatment by male and female farmers during the first and second seasons in Mwea

Market class	First season				Second season						
	Frequency				Frequency						
Navys	Men	Women	Total positive ribbons	Rating of the genotype	Men	Women	Total positive ribbons	Rating of the genotype	Total preferred	% preference	Grain yield (kg/ha
DNB 11-01	3	6	9	2	9	0	9	2	18	29	467.5
DNB 11-03	3	2	5	2	9	1	10	2	15	24	699.0
DNB 11-04	6	5	11	3	0	0	0	1	11	17	353.0
DNB 11-05	1	3	4	1	2	2	4	1	8	13	374.5
DNB 11-06	3	4	7	2	0	0	0	1	7	11	410.5
DNB 11-07	4	1	5	2	0	1	1	1	6	10	617.5
DNB 11-08	0	1	1	1	3	2	5	2	6	10	327.0
DNB 11-09	0	4	4	1	0	0	0	1	4	6	557.5
DNB 11-10	0	1	1	1	0	0	0	1	1	2	501.0
DNB 11-12	0	1	1	1	0	0	0	1	1	2	372.5
DNB 11-13	0	0	0	1	0	0	0	1	0	0	362.0
DNB 11-14	0	0	0	1	0	0	0	1	0	0	418.0
DNB 11-15	0	0	0	1	0	0	0	1	0	0	400.0
DNB 11-16	0	0	0	1	0	0	0	1	0	0	409.5
DNB 11-17	0	0	0	1	0	0	0	1	0	0	622.0
DNB 11-18	0	0	0	1	0	0	0	1	0	0	380.0
DNB 11-19	0	0	0	1	0	0	0	1	0	0	512.5
MEX142*	0	0	0	1	0	0	0	1	0	0	488.0
Mean	**1**	**2**	**3**	**1**	**1**	**0**	**2**	**1**	**4**	**7**	**459.6**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=108.2

Table 3.6: Selection of genotypes in the small reds under drought stress treatment by male and female farmers during the first and second seasons in Mwea

Market class	First season				Second season						
	Frequency				Frequency						
Small reds	Men	Women	Total positive ribbons	Rating of the genotype	Men	Women	Total positive ribbons	Rating of the genotype	Total preferred	% preference	Grain yield (kg/ha
DSR 11-02	6	7	13	3	12	3	15	3	28	44	555.5
TIO CANELA*	0	9	9	2	5	11	16	4	25	40	389.0
DSR 11-08	7	5	12	3	2	10	12	3	24	38	552.0
DSR 11-21	5	5	10	2	7	6	13	3	23	37	466.0
DSR 11-23	0	8	8	2	2	10	12	3	20	32	511.0
SEA15*	1	8	9	2	7	4	11	3	20	32	727.0
DSR 11-04	3	4	7	2	2	6	8	2	15	24	472.5
DSR 11-01	2	4	6	2	0	8	8	2	14	22	289.0
DSR 11-09	4	3	7	2	3	3	6	2	13	21	558.0
SER16*	0	0	0	1	5	3	8	2	8	13	392.0
RAB620*	1	0	1	1	0	3	3	1	4	6	512.5
DSR 11-20	2	1	3	1	0	0	0	1	3	5	330.5
DSR 11-06	1	1	2	1	0	0	0	1	2	3	590.0
DSR 11-19	0	2	2	1	0	0	0	1	2	3	390.0
KATB9*	1	1	2	1	0	0	0	1	2	3	328.0
DSR 11-11	0	0	0	1	1	0	1	1	1	2	390.5
DSR 11-12	0	0	0	1	1	0	1	1	1	2	511.0
DSR 11-13	0	0	0	1	1	0	1	1	1	2	398.5
DSR 11-03	0	0	0	1	0	0	0	1	0	0	477.0
DSR 11-05	0	0	0	1	0	0	0	1	0	0	405.0

DSR 11-07	0	0	0	1	0	0	0	1	0	0	332.5
DSR 11-10	0	0	0	1	0	0	0	1	0	0	462.5
DSR 11-14	0	0	0	1	0	0	0	1	0	0	573.0
DSR 11-15	0	0	0	1	0	0	0	1	0	0	448.0
DSR 11-16	0	0	0	1	0	0	0	1	0	0	438.5
DSR 11-18	0	0	0	1	0	0	0	1	0	0	460.5
DSR 11-22	0	0	0	1	0	0	0	1	0	0	340.5
DSR 11-24	0	0	0	1	0	0	0	1	0	0	538.5
GLP585*	0	0	0	1	0	0	0	1	0	0	457.0
RAB651*	0	0	0	1	0	0	0	1	0	0	777.5
RCB231*	0	0	0	1	0	0	0	1	0	0	492.5
RCB270*	0	0	0	1	0	0	0	1	0	0	414.5
RCB592*	0	0	0	1	0	0	0	1	0	0	693.0
SER155*	0	0	0	1	0	0	0	1	0	0	209.5
SER76*	0	0	0	1	0	0	0	1	0	0	557.5
SER95*	0	0	0	1	0	0	0	1	0	0	366.0
Mean	**1**	**2**	**3**	**1**	**1**	**2**	**3**	**1**	**6**	**9**	**466.8**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=108.2

Table 3.7: Selection of genotypes in the mixed colours under drought stress treatment by male and female farmers during the PVS in Kabete

Market class	Frequency					
Mixed colours	**Men**	**Women**	**Total positive ribbons**	**Rating of the genotype**	**% preference**	**Grain yield (kg/ha)**
DMC 11-12	11	16	27	5	75	709.9
NCB226*	2	6	8	2	22	540.8
DMC 11-03	1	3	4	1	11	541
DMC 11-10	1	1	2	1	6	882.4
GLPX92*	0	2	2	1	6	527.9
SEN53*	0	2	2	1	6	971.6
DMC 11-06	0	1	1	1	3	479.5
DMC 11-07	0	1	1	1	3	548.6
DMC 11-14	0	1	1	1	3	508.7
DMC 11-15	0	1	1	1	3	513.3
DMC 11-17	0	1	1	1	3	612.6
SXB404*	0	1	1	1	3	245.5
DMC 11-01	0	0	0	1	0	835.3
DMC 11-02	0	0	0	1	0	628.5
DMC 11-04	0	0	0	1	0	710.2
DMC 11-05	0	0	0	1	0	584.8
DMC 11-08	0	0	0	1	0	360.9
DMC 11-09	0	0	0	1	0	458.9
DMC 11-11	0	0	0	1	0	661
DMC 11-13	0	0	0	1	0	588.4
DMC 11-16	0	0	0	1	0	736.1
DMC 11-18	0	0	0	1	0	570
DMC 11-19	0	0	0	1	0	534
DMC 11-20	0	0	0	1	0	447.3
DMC 11-21	0	0	0	1	0	753
DMC 11-22	0	0	0	1	0	689.4
DMC 11-23	0	0	0	1	0	584.3
DMC 11-24	0	0	0	1	0	715.1
KATB1*	0	0	0	1	0	876.3
NCB280*	0	0	0	1	0	594.9
SEN56*	0	0	0	1	0	880
Mean	**0**	**1**	**2**	**1**	**5**	**622.3**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=168

Table 3.8: Selection of genotypes in the navy beans under drought stress treatment by male and female farmers during the PVS in Kabete

Market class	Frequency					
Navys	**Men**	**Women**	**Total positive ribbons**	**Rating of the genotype**	**% preference**	**Grain yield (kg/ha)**
DNB 11-03	10	3	13	3	36	1009.3
DNB 11-07	11	0	11	3	31	917.2
DNB 11-15	8	1	9	2	25	1019.1
DNB 11-06	2	5	7	2	19	802.8
MEX142*	0	4	4	1	11	861.7
DNB 11-04	0	1	1	1	3	953.5
DNB 11-13	1	0	1	1	3	419.6
DNB 11-01	0	0	0	1	0	919.2
DNB 11-05	0	0	0	1	0	810.6
DNB 11-08	0	0	0	1	0	596.4
DNB 11-09	0	0	0	1	0	708.1
DNB 11-10	0	0	0	1	0	945.1
DNB 11-12	0	0	0	1	0	711.8
DNB 11-14	0	0	0	1	0	723.1
DNB 11-16	0	0	0	1	0	859.1
DNB 11-17	0	0	0	1	0	682.6
DNB 11-18	0	0	0	1	0	531.6
DNB 11-19	0	0	0	1	0	459.4
Mean	**2**	**1**	**3**	**1**	**7**	**773.9**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=168

Table 3.9: Selection of genotypes in the small reds under drought stress treatment by male and female farmers during the PVS in Kabete

Market class	Frequency					
Small reds	Men	Women	Total positive ribbons	Rating of the genotype	% preference	Grain yield (kg/ha)
GLP585*	7	14	21	5	58	800.5
DSR 11-02	9	8	17	4	47	562.4
RCB592*	8	9	17	4	47	1012.4
DSR 11-14	9	7	16	4	44	556.7
SER155*	9	4	13	3	36	566.8
DSR 11-21	4	7	11	3	31	686.8
DSR 11-11	3	5	8	2	22	613.7
DSR 11-01	3	4	7	2	19	665.3
DSR 11-18	0	6	6	2	17	697.4
DSR 11-22	1	5	6	2	17	604.6
KATB9*	0	6	6	2	17	527.7
DSR 11-16	1	3	4	1	11	565.8
RAB620*	0	3	3	1	8	0
RCB270*	0	3	3	1	8	539.6
DSR 11-03	0	2	2	1	6	733.7
DSR 11-09	1	1	2	1	6	757.8
DSR 11-10	0	2	2	1	6	638.4
SER16*	1	1	2	1	6	602.9
DSR 11-15	1	0	1	1	3	725.9
RCB231*	1	0	1	1	3	730.2
DSR 11-04	0	0	0	1	0	652.3
DSR 11-05	0	0	0	1	0	549.1
DSR 11-06	0	0	0	1	0	473.1
DSR 11-07	0	0	0	1	0	714.2
DSR 11-08	0	0	0	1	0	589.7
DSR 11-12	0	0	0	1	0	702
DSR 11-13	0	0	0	1	0	674.3
DSR 11-19	0	0	0	1	0	590.3
DSR 11-20	0	0	0	1	0	581.6
DSR 11-23	0	0	0	1	0	537.9
DSR 11-24	0	0	0	1	0	755
RAB651*	0	0	0	1	0	462.8
SEA15*	0	0	0	1	0	737.9
SER76*	0	0	0	1	0	876.8
SER95*	0	0	0	1	0	590.2
TIO CANELA*	0	0	0	1	0	518.9
Mean	**2**	**3**	**4**	**2**	**11**	**627.6**

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor. The symbol * on genotypes denotes checks. LSD_G=168

Some of the least farmer preferred varieties with a rating of 2 and below in both seasons in Kabete and Mwea were KATB1, DMC11-06 and DMC11-14. Low yield, poor drought tolerance and evergreen characteristic (DMC11-14) were some of the reasons for rejection of all the least preferred varieties (Table 3.10).

Table 3.10: Some of the least farmer preferred varieties in Mwea and Kabete, frequency of dislike and the reasons for rejection as numbered in Table 3.2 above.

Genotype	Frequency	Reasons for rejection	Rating by farmers
KATB1	30	1,2,10,11,17,19	2
DMC 11-06	21	1,2,6,7,9,10,13,17,18	1
DMC 11-14	25	1,2,3,5,6,10,18,	1
RAB620	33	1,2,	2
SEN56	34	1,2,11,13,16,17,18	2
SER95	36	1,2,5,15	2
DMC 11-16	35	1,2,5,6,7,9,10,12,13,17,18	1
SXB404	28	1,2,9,	1
DMC 11-20	25	1,2,3,5,6,7,10,	1
KATB9	23	1,2,11,19	2
DNB 11-08	22	1,2,5,13,14,17,18,	1

The numbers used for reasons for rejection are as numbered in Table 3.2 for the negative selection criteria.

Rating of genotypes was based on a scale of 1-5 where 5 was excellent, 4-very good, 3-good, 2-fair, and 1-poor.

3.5. Discussion

Farmers were able to identify and select the best high yielding drought tolerant genotypes and discard poorly adapted genotypes using their own evaluation criteria. Grain yield which was attributed to pod load was found to be the most important criterion for identifying the best varieties followed by drought tolerance which shows adaptability of bean lines to different environments. Similar findings were reported by Witcombe, (2005). It was also noted that most of the preferred varieties such as DSR11-02, DMC11-12 and DNB11-07 were new and yet to be released. This shows that there is a high chance of adoption of new varieties by farmers if they are allowed to participate in scientific research (Morris and Bellon, 2004). Also the range of choices of well adapted varieties to various environments will be widened to farmers who will be able to identify these varieties based on their knowledge and information gathered about the varieties through their participation in selection (Sthapit and Rao, 2007). Most of the existing so called drought tolerant commercial varieties like KATB1 and KATB9 were either less preferred or rejected by farmers due to their poor performance under drought stress and low grain yield. This may explain why these varieties which were developed for drought tolerance have not been widely adopted.

Men and women farmers differed in some aspects of the selection criteria such as seed colour, cooking quality and growth habit. For instance, men preferred navy bean (white) such as DNB11-03 and DNB11-07 to many other genotypes because of high pod load while women did not like it because of the white seed colour which determines the colour of the stew. This shows different gender perceptions supported by social roles as women as opposed to men are the cooks in their homes. This underscores the importance of participation by both gender in selection of varieties (Ceccarelli and Grando, 2007).

Some genotypes like DMC11-10, DMC11-11, DMC11-12, DMC11-23 and SEN53 were highly preferred and rated as excellent or very good by farmers in the first season but very poor in the second season. This could be attributed to the differences in drought intensity where the second season had a more severe drought which led to poor performance of all genotypes including the best genotypes. This must have contributed to the differences in rating of these genotypes by farmers in the two seasons.

Some of the criteria are related, for instance, pest and disease resistance, drought tolerance and yield. This is because biotic and abiotic factors affect yield by reducing the quantity and quality of the harvestable product (Rao et al., 2007). Hard pods, strong stems and early maturity are related because, varieties with strong stems remain upright even at maturity and should they lodge due to the weight of pods, the hard pod cover prevents damage to the pods by water if the variety is late maturing. However, early maturing varieties with hard pods protect the pods from damage should a change in weather occur before harvesting (Buruchara, 2007). Also, some of the criteria have scientific basis such as low pod yield and more foliage which relate to harvest index (Beebe et al., 2009). In addition, farmers preference for fast cooking varieties indicate consumer changing lifestyles with preference for fast cooking foods which save on the very expensive fuel (Habtu et al., 2006).
Therefore, based on these observations, it is important for the superior genotypes like DMC11-10, DMC11-12, DNB11-07, DNB11-03, DSR11-02 and DSR11-21 to be fast-tracked for release into the market through hastening the seed certification process. These genotypes should be evaluated in different agro-ecological zones in order to identify the best

performing genotypes in these areas. This will enhance Mesoamerican dry bean production. Finally, an elaborate seed supply system should be established and promotion of new varieties be carried out to speed up the process of adoption.

CHAPTER FOUR

AGRONOMIC PERFORMANCE OF MESOAMERICAN DRY BEAN GENOTYPES UNDER DROUGHT STRESS AND NON STRESS CONDITIONS

4.1. Abstract

Drought is a major abiotic constraint to dry bean production in eastern Africa and other parts of the World. It adversely affects the phenological development and yielding ability of most dry bean genotypes. Losses of over 60% have been experienced due to drought. The National Agricultural Research System in Kenya has developed varieties that are said to be drought tolerant. There is very little information on their actual ability to resist drought effect. In fact, most of these varieties escape drought by early maturity which means that high yield losses can occur if drought occurs at the critical stages of crop growth. It is important to understand the performance of these varieties under moisture stress at critical stages and compare with the new high yielding advanced drought tolerant lines. The objective of this study was to assess the phenological and yield characteristics of Mesoamerican dry bean genotypes under drought stress and non drought stress conditions. On-farm trials were conducted in Mwea between April, 2011 and February, 2012 while on-station field trials were conducted at Kabete between June, 2011 and March, 2012. These trials targeted the dry periods of the year. Eighty five Mesoamerican dry bean genotypes of three market classes including local and international checks with contrasted drought responses were tested under drought stress and non drought stress conditions. Both experiments were initially grown under irrigation which was done to 80% field capacity. Irrigation was withheld from pre-flowering to physiological maturity for the drought stress plots to induce drought stress. Drought stress significantly reduced time to flowering, time to physiological maturity, grain yield, number of pods per plant, number of seeds per pod and harvest index. Under drought stress, some genotypes such as DSR11-02, DMC11-10, DNB11-03, among others exhibited a tendency to escape drought effects through accelerated reproductive development. Days to physiological maturity reduced by about 8% on average for some genotypes. Drought stress significantly reduced grain yield by about 30% with most genotypes yielding between 400-800 kg/ha. Harvest indices of most dry bean genotypes were also significantly reduced by up to 15% with some genotypes recording harvest indices lower than 34%. New advanced lines were higher yielding than most local checks with a yield advantage of about 18%. Of the three market classes, navy bean market class significantly out yielded mixed colours and small

reds. It was concluded that drought stress affects the agronomic performance of beans especially by reducing grain yield.

Key words: yield, on-farm, Kabete, harvest index, navy bean

4.2. Introduction

Maintaining bean yields under adverse ‘stress’ environmental conditions is a major challenge facing modern agriculture. Drought is a major problem affecting bean production because about 73% of World beans are grown in regions subjected to water shortage (Beebe et al., 2008). Despite the identification of several selection criteria for resistance to drought and the great effort made in bean breeding, the average global yields of beans have remained relatively low (<900 kg/ ha) (Thung and Rao, 1999; Singh, 2001). Furthermore, resistance to drought has continuously reduced in modern bean varieties (Singh, 2001), mainly because the emphasis of breeding has focused on introducing resistance to biotic (insect pests and diseases) rather than abiotic stresses such as drought. In common bean, drought affects phenological development by reducing plant size, days to physiological maturity and grain yield (Teran and Singh, 2002). Drought stress significantly lowers yield (Padilla-Ramirez et al., 2005) by reducing the harvest index, the number of pods and seeds per pod, seed weight and days to physiological maturity since the more severe the drought the faster the senescence (Abebe and Brick, 2003; Munoz-Perea et al., 2006; Ramirez et al., 2005). Seed yield is the most important economic trait, hence the main selection criteria for drought resistance include plant growth and grain production (Singh, 2001). Drought stress also results in excessive flower, pod and seed abortion in dry beans especially if it occurs during pre-flowering and reproductive periods of growth (Munoz-Perea et al., 2006). Drought research in east Africa has not received much attention due to many challenges. Low heritabilities and genetic variability in drought tolerance have been found to exist in many crops including beans (Beebe et al., 2008). These factors have made it very difficult to phenotype stress reactions by plants. In beans, genetic engineering for abiotic stress has not been successful (Beebe et al., 2008) although efforts have been made to develop drought resistant varieties. However, their drought tolerance has not been well established. The objective of this research is to evaluate developed drought resilient advanced lines and local landraces for agronomic performance under drought stress and identify the best performing lines.

4.3. Materials and Methods

4.3.1. Experimental site

This field study was conducted for two seasons; on-farm at Mwea between March 2011 and February 2012 and on-station at Kabete Field Station between June 2011 and March 2012 during the dry periods of the year. Detailed descriptions of the two sites are given in sections 3.3.1.1 and 3.3.1.2 respectively.

4.3.2. Experimental design, treatments and crop husbandry

The test lines were 85 lines of Mesoamerican dry beans comprising 17 lines of drought tolerant navy beans (DNB), 24 lines of drought tolerant mixed colours (DMC), 23 lines of drought tolerant small reds (DSR), 4 local varieties and 17 international drought lines (Table 1 in chapter 3). The experimental design used was a split plot with three replicates. Main plots were either non drought stressed (NS) or drought stressed (DS) while subplots consisted of the 85 genotypes. Both NS and DS experiments were initially irrigated two times per week up to field capacity. Stress treatments were imposed at pre-flowering to physiological maturity for the DS treatment. Drought stress treatments were not irrigated from pre-flowering period to physiological maturity. A plot consisted of two 3 m rows with 30 plants each making a total of 60 plants. Spacing was 50 cm between rows and10 cm within rows with one seed per hole. Two hand weedings were done at three weeks after emergence and another at six weeks after emergence when the plants were about to flower. Insect pests were controlled by spraying once every two weeks using a broad spectrum insecticide Tata Alpha® (Cypermethrin 100 g/l) applied at 0.5 l/ha and Tata mida® (Imidacloprid 200 g/l) applied at 0.5 l/ha. Bean diseases such as rust, common bacterial blight, anthracnose, angular leaf spot and floury leaf spot did not affect the crop hence disease control measures were not applied in the trials.

4.3.3. Data collection

Data on days to flowering, days to physiological maturity, grain yield and yield components such as number of pods per plant, number of seeds per pod and 100 seed weight were recorded. Days to flowering were recorded as actual number of days from planting to when approximately 50% plants in a plot had at least one opened flower. Days to physiological maturity were recorded as the actual number of days from planting to when approximately 50% of plants in a plot had at least one dry pod. Yield was determined by counting and harvesting all the plants in a plot and taking the grain weight when the beans were totally dry. Pods per plant and seeds per pod were determined by sampling five plants from each plot and counting the number of pods per plant or seeds per pod which was expressed as an average and recorded per plant or pod respectively. One hundred seed weight was determined by obtaining a sample of seeds from each harvested seed, counting 100 seeds and weighing to determine the weight (CIAT, 1987; Rao et al., 2009). Harvest index was calculated as a percentage of the ratio of seed yield and dry biomass yield (CIAT, 1987). Drought intensity index (DII) for each growing season was calculated as DII = 1 – Xds/Xns, where Xds and Xns were mean yields of all genotypes under drought stress (ds) and no stress (ns) treatments respectively. Drought susceptibility index (DSI) for seed yield of each genotype was calculated as (1 – Yds/Yns)/DII, where Yds and Yns were mean yields of a given genotype in DS and NS environments respectively (Fisher and Maurer, 1978). Also, soil moisture content of both stress and non stress plots was monitored every week from the time of stress induction to physiological maturity in order to assess moisture requirements by the non drought stress treatment using the gravimetric method. This involved sampling soil from depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-40 cm, 40-60 cm and 60-80 cm. About 100 g of soil from each depth was weighed to determine its fresh weight and then oven dried at a temperature of 105ºC for 24 hours after which the samples were weighed to determine the dry weight (Black, 1965). Soil moisture content was calculated as follows:

$$\text{\% soil moisture content} = \left[\frac{\text{Fresh weight (g)} - \text{Dry weight (g)}}{\text{Fresh weight (g)}}\right] \times 100$$

4.4. Data analysis

Data on different parameters were analyzed using Genstat version 13 with locations, seasons, irrigation treatments and genotypes as factors and the measurements as variables. Comparison of means was done using Fischer’s protected least significance difference (LSD) test. Correlations between measurements were done using Sigma plot version 10 software (Mead et al., 2003).

4.5. Results

4.5.1. Drought intensity and drought susceptibility indices

During the first season, both sites experienced a normal season characterized by a rainfall amount of about 650 mm in Kabete and 450 mm in Mwea, normal average temperature of 19°C and relatively low soil moisture. Less severe drought stress was experienced. Drought intensity indices (DII) in Kabete and Mwea were 0.36 and 0.49 respectively while average drought susceptibility indices (DSI) were 0.2 and 0.3 in Kabete and Mwea respectively (Appendix 11). The second season was a very dry season with a rainfall amount of 250 mm in Kabete and no rainfall in Mwea. The average temperatures in both locations were above 22°C. Drought stress was more severe in both locations. Drought stress began from the late vegetative phase of the crop to maturity. Drought intensity indices were 0.68 and 0.85 in Kabete and Mwea sites respectively. Average drought susceptibility indices in Kabete and Mwea during this season were 0.3 and 0.5 respectively (Appendix 11). In the two sites, trials were set up during the dry periods of the year when little rainfall was expected. This is as shown by the rainfall distribution in Kabete over the two seasons (Appendix 1) and temperature ranges that were experienced during the entire trial period (Appendix 2).

4.5.2. Time to flowering

Time to 50% flowering varied significantly among genotypes in the three market classes due to seasons ($p<0.05$), site ($p<0.05$) and genotypes ($p<0.001$) and there were interactions among site, season, irrigation regime and genotypes. Genotype by treatment interaction did not significantly affect the time to flowering (Table 4.1, 4.2, 4.3). Time to flowering of most genotypes was 30% shorter at Mwea (average 37 days) compared to Kabete (average 48 days) in both seasons. On average, beans flowered in 46 days. There was significant variation in time to flowering among genotypes in the two sites, seasons and water treatments, with mixed colours flowering earlier (44 days on average) and navy beans later (48 days on average). Among the mixed colours, local checks KATB1 and GLPX92 were the earliest flowering varieties compared to all the other genotypes in the same market class. These were followed by DMC11-10, -DMC11-02, DMC11-17, DMC11-21 and international checks NCB280, SEN56, SEN53 and NCB226, whose flowering period ranged between 41 and 45 days. Late flowering lines included DMC11-06, DMC11-20, DMC11-12, DMC11-22, SXB404 (check) and DMC11-01, which took 46 to 48 days to flower (Table 4.1). Navy beans took the longest time to flower among the three market classes with flowering time ranging between 43 and 48 days. Genotypes such as DNB11-13 and DNB11-19 were the earliest in flowering with 43 days each. These were followed by DNB11-12, DNB11-04, DNB11-15, DNB11-16 and the check MEX142 which recorded between 46 and 48 days to flowering (Table 4.2). In the small reds market class, local check KATB9 was the earliest flowering variety within 38 days. Medium flowering lines in this market class ranged between 41 and 45 days and included DSR11-09, DSR11-06, DSR11-12, DSR11-04, DSR11-14 and checks like SER16, SEA15, RCB592 and GLP585. Late flowering lines took 46 to 50 days and included DSR11-03, DSR11-07, DSR11-23, DSR11-10, DSR11-13 and DSR11-21 and checks such as Tio canela, SER95, RCB270 and RAB651 (Table 4.3). In all the three market classes, local checks were the earliest in flowering compared to the genotypes and international drought checks.

Table 4.1: Days to flowering of mixed colours grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Days to 50% flowering										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	mean NS	Overall mean
KATB1*	46.0	46.0	32.0	31.0	43.0	43.0	35.0	31.0	39.0	37.8	38.4
GLPX92*	52.0	52.0	33.0	32.5	43.0	43.0	32.0	31.0	40.0	39.6	39.8
DMC 11-10	52.0	52.0	35.5	35.5	43.0	43.0	38.0	32.0	42.1	40.6	41.4
DMC 11-02	52.0	55.0	32.5	36.0	43.0	43.0	37.0	37.0	41.1	42.8	42.0
NCB280*	47.5	53.0	43.0	43.0	45.5	42.0	32.0	31.0	42.0	42.3	42.2
DMC 11-17	52.0	55.0	33.0	32.0	47.0	43.0	36.5	39.5	42.1	42.4	42.3
SEN56*	47.5	47.5	33.0	32.0	38.5	37.5	52.0	52.0	42.8	42.3	42.6
DMC 11-21	52.0	57.5	36.5	36.5	43.0	43.0	37.0	36.5	42.1	43.4	42.8
SEN53*	55.0	57.5	36.5	33.5	43.0	43.0	41.0	38.0	43.9	43.0	43.5
DMC 11-05	58.0	60.5	33.0	33.0	47.0	43.0	41.0	32.5	44.8	42.3	43.6
NCB226*	47.5	53.0	43.0	43.0	45.0	45.0	41.0	32.0	44.1	43.3	43.7
DMC 11-04	55.0	58.0	36.0	39.5	45.5	45.5	41.0	41.0	44.4	46.0	45.2
DMC 11-06	58.0	58.0	39.0	37.0	49.5	47.0	41.0	38.0	46.9	45.0	46.0
DMC 11-16	60.5	58.0	39.0	36.0	48.0	48.0	41.0	39.5	47.1	45.4	46.3
DMC 11-20	58.0	58.0	40.0	39.5	47.0	45.5	41.0	41.0	46.5	46.0	46.3
DMC 11-13	58.0	60.5	36.0	36.5	51.0	47.0	41.0	41.0	46.5	46.3	46.4
DMC 11-19	58.0	60.5	35.5	40.0	48.0	48.0	41.0	41.0	45.6	47.4	46.5
DMC 11-03	60.5	63.0	40.5	40.0	51.0	47.0	36.0	36.5	47.0	46.6	46.8
DMC 11-14	58.0	58.0	37.0	40.5	51.0	51.0	42.0	42.0	47.0	47.9	47.5
DMC 11-07	63.0	63.0	36.5	36.0	51.0	51.0	41.0	41.0	47.9	47.8	47.9

SXB404*	63.0	63.0	36.5	41.0	51.0	51.0	36.5	41.0	46.8	49.0	47.9
DMC 11-23	63.0	63.0	39.5	35.5	51.0	51.0	41.0	41.0	48.6	47.6	48.1
DMC 11-11	63.0	63.0	37.0	39.5	51.0	49.5	41.0	41.0	48.0	48.3	48.2
DMC 11-12	63.0	63.0	36.0	39.0	51.0	51.0	41.0	41.0	47.8	48.5	48.2
DMC 11-22	63.0	63.0	39.5	37.0	49.5	51.0	41.0	41.0	48.3	48.0	48.2
DMC 11-09	63.0	63.0	36.5	39.0	51.0	51.0	41.0	41.0	47.9	48.5	48.2
DMC 11-15	63.0	63.0	40.0	36.0	51.0	51.0	41.0	41.0	48.8	47.8	48.3
DMC 11-18	63.0	63.0	36.5	39.0	51.0	51.0	42.0	41.0	48.1	48.5	48.3
DMC 11-24	63.0	63.0	36.5	39.0	51.0	51.0	42.0	41.0	48.1	48.5	48.3
DMC 11-01	63.0	63.0	40.0	39.0	51.0	51.0	41.0	42.0	48.8	48.8	48.8
DMC 11-08	63.0	63.0	39.5	39.5	51.0	51.0	41.0	43.0	48.6	49.1	48.9
Mean of genotypes	**56.8**	**58.0**	**37.1**	**37.2**	**47.5**	**46.8**	**39.9**	**39.1**	**45.3**	**45.3**	**45.3**
Mean of checks	**51.2**	**53.1**	**36.7**	**36.6**	**44.1**	**43.5**	**38.5**	**36.6**	**42.6**	**42.4**	**42.5**
Overall mean	**54.0**	**55.6**	**36.9**	**36.9**	**45.8**	**45.2**	**39.2**	**37.9**	**44.0**	**43.9**	**43.9**
CV (%)		**7**									

LSD(P≤0.05)S	2.89*	**LSD(P≤0.05)SxT**	1.78*	**LSD(P≤0.05)SxLxT**	2.37NS
LSD(P≤0.05)L	2.74*	**LSD(P≤0.05)LxT**	2.67*	**LSD(P≤0.05)SxLxG**	4.68**
LSD(P≤0.05)T	0.25NS	**LSD(P≤0.05)SxG**	3.20**	**LSD(P≤0.05)SxTxG**	4.5NS
LSD(P≤0.05)G	2.25**	**LSD(P≤0.05)LxG**	3.43**	**LSD(P≤0.05)LxTxG**	4.66NS
LSD(P≤0.05)SxL	2.44*	**LSD(P≤0.05)TxG**	3.17NS	**LSD(P≤0.05)SxLxTxG**	6.47NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.2: Days to flowering of navy beans grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Days to 50% flowering										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Navys	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	mean NS	Overall mean
DNB 11-13	58.0	58.0	32.5	33.5	47.0	43.0	38.0	35.0	43.9	42.4	43.2
DNB 11-19	58.0	58.0	33.5	33.0	47.0	47.0	38.0	35.5	44.1	43.4	43.8
DNB 11-12	58.0	58.0	33.0	36.0	51.0	51.0	41.0	42.0	45.8	46.8	46.3
DNB 11-18	60.5	58.0	40.5	36.5	49.5	47.0	41.0	41.0	47.9	45.6	46.8
DNB 11-06	58.0	58.0	40.5	39.5	47.0	49.5	41.0	41.0	46.6	47.0	46.8
DNB 11-04	63.0	60.5	39.5	33.0	51.0	51.0	41.0	41.0	48.6	46.4	47.5
DNB 11-15	63.0	63.0	33.5	36.0	51.0	51.0	42.0	41.0	47.4	47.8	47.6
DNB 11-08	60.5	63.0	36.0	39.5	51.0	49.5	41.0	41.0	47.1	48.3	47.7
DNB 11-09	63.0	63.0	36.0	39.5	49.5	51.0	41.0	41.0	47.4	48.6	48.0
DNB 11-01	63.0	63.0	40.0	33.0	51.0	51.0	41.0	42.0	48.8	47.3	48.1
DNB 11-10	63.0	63.0	37.0	36.5	51.0	51.0	41.0	42.0	48.0	48.1	48.1
DNB 11-16	63.0	63.0	40.0	33.0	51.0	51.0	41.0	43.0	48.8	47.5	48.2
MEX142*	63.0	63.0	40.0	36.0	51.0	51.0	41.0	41.0	48.8	47.8	48.3
DNB 11-17	63.0	63.0	37.0	39.0	51.0	51.0	42.0	41.0	48.3	48.5	48.4
DNB 11-03	63.0	63.0	36.0	39.5	51.0	51.0	42.0	42.0	48.0	48.9	48.5
DNB 11-14	63.0	63.0	39.0	39.0	51.0	51.0	41.0	41.0	48.5	48.5	48.5
DNB 11-07	63.0	63.0	37.5	39.0	51.0	51.0	42.0	42.0	48.4	48.8	48.6
DNB 11-05	63.0	63.0	39.0	40.0	51.0	51.0	41.0	42.0	48.5	49.0	48.8
Mean of genotypes	**61.5**	**61.4**	**37.1**	**36.8**	**50.1**	**49.9**	**40.9**	**40.8**	**47.4**	**47.2**	**47.3**
Mean of checks	**63.0**	**63.0**	**40.0**	**36.0**	**51.0**	**51.0**	**41.0**	**41.0**	**48.8**	**47.8**	**48.3**
Overall mean	**62.3**	**62.2**	**38.6**	**36.4**	**50.6**	**50.5**	**41.0**	**40.9**	**48.1**	**47.5**	**47.8**

CV (%)	**7**				
		LSD(P≤0.05)SxT	1.78*		
LSD(P≤0.05)S	2.89*	**LSD(P≤0.05)SxLxT**	2.37NS		
		LSD(P≤0.05)LxT	2.67*		
LSD(P≤0.05)L	2.74*	**LSD(P≤0.05)SxLxG**	4.68**		
LSD(P≤0.05)T	0.25NS	**LSD(P≤0.05)SxG**	3.20**	**LSD(P≤0.05)SxTxG**	4.5NS
LSD(P≤0.05)G	2.25**	**LSD(P≤0.05)LxG**	3.43**	**LSD(P≤0.05)LxTxG**	4.66NS
LSD(P≤0.05)SxL	2.44*	**LSD(P≤0.05)TxG**	3.17NS	**LSD(P≤0.05)SxLxTxG**	6.47NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.3: Days to flowering of small reds grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Days to 50% flowering										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
KATB9*	46.0	46.0	32.0	32.0	43.0	43.0	37.0	32.0	39.5	38.3	38.9
DSR 11-09	52.0	52.0	33.0	33.0	43.0	47.0	39.5	36.5	41.9	42.1	42.0
DSR 11-06	55.0	58.0	33.0	33.5	43.0	43.0	39.5	41.0	42.6	43.9	43.3
SER16*	58.0	58.0	36.0	33.5	43.0	43.0	38.0	38.0	43.8	43.1	43.5
DSR 11-08	55.0	58.0	33.0	32.5	47.0	47.0	39.5	38.0	43.6	43.9	43.8
DSR 11-12	58.0	55.0	33.5	32.0	45.5	45.5	41.0	41.0	44.5	43.4	44.0
DSR 11-22	55.0	58.0	32.5	33.5	47.0	47.0	41.0	39.5	43.9	44.5	44.2
SEA15*	58.0	58.0	41.0	41.0	42.0	41.5	37.5	35.5	44.6	44.0	44.3
RCB592*	47.5	47.5	43.0	43.0	45.0	49.5	38.0	41.0	43.4	45.3	44.4
DSR 11-04	58.0	60.5	36.5	33.5	43.0	47.0	41.0	41.0	44.6	45.5	45.1
DSR 11-18	58.0	58.0	36.0	36.0	43.0	49.5	39.5	41.0	44.1	46.1	45.1
DSR 11-02	58.0	58.0	33.0	36.0	47.0	47.0	41.0	41.0	44.8	45.5	45.2
GLP585*	58.0	58.0	34.5	36.5	45.5	48.0	39.5	41.0	44.4	45.9	45.2
DSR 11-16	58.0	58.0	39.5	35.5	45.5	45.5	41.0	41.0	46.0	45.0	45.5
DSR 11-14	58.0	60.5	36.5	33.0	47.0	51.0	41.0	39.5	45.6	46.0	45.8
DSR 11-03	58.0	58.0	33.5	40.0	47.0	49.5	41.0	41.0	44.9	47.1	46.0
DSR 11-07	58.0	60.5	33.0	36.0	49.5	49.5	41.0	41.0	45.4	46.8	46.1
DSR 11-11	60.5	58.0	37.0	34.0	51.0	51.0	41.0	36.5	47.4	44.9	46.2
DSR 11-23	58.0	58.0	36.0	40.0	47.0	49.5	41.0	41.0	45.5	47.1	46.3
SER155*	47.5	50.5	38.0	38.0	42.0	40.5	58.0	58.0	46.4	46.8	46.6
DSR 11-15	58.0	60.5	39.5	33.0	51.0	51.0	41.0	41.0	47.4	46.4	46.9

DSR 11-24	58.0	60.5	40.0	44.0	43.0	48.0	41.0	41.0	45.5	48.4	47.0
RCB231*	50.5	54.5	43.0	43.0	53.0	49.5	41.0	41.0	46.9	47.0	47.0
DSR 11-20	60.5	63.0	36.0	36.5	51.0	51.0	41.0	41.0	47.1	47.9	47.5
TIO CANELA*	63.0	60.5	39.0	36.0	51.0	51.0	41.0	41.0	48.5	47.1	47.8
DSR 11-10	63.0	60.5	39.5	39.0	49.5	49.5	41.0	41.0	48.3	47.5	47.9
DSR 11-19	63.0	63.0	37.0	36.0	51.0	51.0	41.0	41.0	48.0	47.8	47.9
DSR 11-05	60.5	63.0	40.0	36.0	51.0	51.0	41.0	41.0	48.1	47.8	48.0
SER95*	51.5	50.5	41.0	38.0	46.0	40.5	58.0	58.0	49.1	46.8	48.0
DSR 11-01	63.0	60.5	40.0	39.0	51.0	51.0	41.0	41.0	48.8	47.9	48.4
DSR 11-13	63.0	63.0	39.5	36.5	51.0	51.0	42.0	41.0	48.9	47.9	48.4
RCB270*	55.5	53.0	48.0	51.0	49.5	52.0	41.0	38.0	48.5	48.5	48.5
DSR 11-21	63.0	63.0	40.0	39.5	51.0	51.0	41.0	42.0	48.8	48.9	48.9
RAB651*	54.5	57.0	51.0	51.0	52.0	52.0	41.0	41.0	49.6	50.3	50.0
SER76*	54.5	57.0	41.0	41.0	46.0	46.0	63.0	58.0	51.1	50.5	50.8
Mean of genotypes	**58.8**	**59.5**	**36.4**	**36.0**	**47.6**	**48.8**	**40.8**	**40.4**	**45.9**	**46.2**	46.1
Mean of checks	**53.7**	**54.2**	**40.6**	**40.3**	**46.5**	**46.4**	**44.4**	**43.5**	**46.3**	**46.1**	46.2
Overall mean	**58.1**	**58.8**	**37.4**	**37.2**	**48.0**	**48.0**	**41.0**	**40.4**	**45.4**	**46.6**	46.0

CV (%)	7				
LSD(P≤0.05)S	2.89*	**LSD(P≤0.05)SxT**	1.78*	**LSD(P≤0.05)SxLxT**	2.37NS
LSD(P≤0.05)L	2.74*	**LSD(P≤0.05)LxT**	2.67*	**LSD(P≤0.05)SxLxG**	4.68**
LSD(P≤0.05)T	0.25NS	**LSD(P≤0.05)SxG**	3.20**	**LSD(P≤0.05)SxTxG**	4.5NS
LSD(P≤0.05)G	2.25**	**LSD(P≤0.05)LxG**	3.43**	**LSD(P≤0.05)LxTxG**	4.66NS
LSD(P≤0.05)SxL	2.44*	**LSD(P≤0.05)TxG**	3.17NS	**LSD(P≤0.05)SxLxTxG**	6.47NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

4.5.3. Days to physiological maturity

The mean number of days to physiological maturity under drought stress was 97 and 76 days in the first season and 85 and 73 days in the second season in Kabete and Mwea respectively. Under irrigated treatment, the mean number of days to physiological maturity was 102 and 82 days in the first season and 92 and 80 days in the second season in Kabete and Mwea respectively. Days to physiological maturity of genotypes in the two seasons and locations ranged between 68 and 106 days under the two water treatments. Days to physiological maturity of genotypes in all the three market classes varied significantly in the season ($p<0.05$), site ($p<0.001$) and irrigation treatment. Also, significant interactions among season, site, water treatment and the genotypes were observed (Table 4.4, 4.5, 4.6). Stress levels significantly affected the physiological maturity of most genotypes with genotypes under drought stress recording a 5 % shorter period to maturity compared to the same genotypes under no stress. Days to physiological maturity of most genotypes and checks varied between sites with Mwea recording a 14% shorter growth period compared to Kabete. Significant differences in days to physiological maturity were observed among genotypes in the three market classes with mixed coloured genotypes maturing earlier than small reds and navy beans. In the mixed colours, local checks such as KATB1 and GLPX92 were the earliest maturing (80 and 81 days respectively). These were followed by international drought checks such as SXB404, NCB226, NCB280 and SEN53 which took between 82 and 84 days to attain physiological maturity. Most test lines including DMC11-24, DMC11-10, DMC11-17, DMC11-20 and DMC11-05 were medium maturing and ranged between 85 and 88 days (Table 4.4). Navy beans such as DNB11-13, DNB11-18 and DNB11-19 matured early in all the seasons (84 days on average) and locations compared to the other genotypes in the same market class and the check MEX142. Late maturing lines included DNB11-10, DNB11-16, DNB11-04, DNB11-03 and DNB11-15 which took 86 to 88 days to physiological maturity (Table 4.5). Among the small reds, DSR11-05 (79 days) was the earliest maturing line followed by the check KATB9 (82 days). Most genotypes in this class had a medium maturity period of 83 to 85 days and included DSR11-10, DSR11-06, DSR11-12, DSR11-09 and DSR11-18, and checks like SER16, SEA15, RCB231, RCB592 and RAB651. Late maturing varieties included DSR11-22, DSR11-16, DSR11-21 and DSR11-19 and checks like Tio canela, RCB270, SER95 and SER76. They took 86 to 89 days to attain physiological maturity (Table 4.6). Water stress significantly reduced ($p\leq0.05$) the days to physiological maturity of all genotypes in the three market classes and their respective checks.

Table 4.4: Days to physiological maturity of mixed colours grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

Line/market class	Days to physiological maturity										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
KATB1*	91.5	100.0	71.0	71.0	77.0	83.5	70.0	80.0	77.4	83.6	80.5
GLPX92*	91.5	100.0	74.0	77.5	78.5	83.5	70.0	80.0	78.5	85.3	81.9
SXB404*	100.0	100.0	70.0	76.0	83.5	85.0	70.0	76.0	80.9	84.3	82.6
NCB226*	91.5	98.5	77.0	80.0	86.0	88.0	68.0	74.0	80.6	85.1	82.9
NCB280*	88.5	98.5	77.0	77.0	86.0	93.0	68.0	76.0	79.9	86.1	83.0
SEN53*	91.5	100.0	74.0	84.0	85.0	83.5	73.0	81.0	80.9	87.1	84.0
DMC 11-02	94.0	103.0	74.0	84.0	80.0	85.0	73.0	79.0	80.3	87.8	84.1
SEN56*	84.5	91.5	71.0	71.0	79.0	82.0	94.0	100.0	82.1	86.1	84.1
DMC 11-24	94.0	106.0	71.0	77.5	87.0	87.0	70.0	86.0	80.5	89.1	84.8
DMC 11-10	94.0	100.0	80.5	84.0	80.0	85.0	73.0	82.5	81.9	87.9	84.9
DMC 11-21	94.0	103.0	77.0	84.0	85.0	87.0	73.0	76.5	82.3	87.6	85.0
DMC 11-14	97.0	106.0	77.0	84.0	87.0	87.0	68.0	78.5	82.3	88.9	85.6
DMC 11-09	97.0	103.0	74.0	77.5	87.0	100.0	71.0	79.0	82.3	89.9	86.1
DMC 11-17	100.0	103.0	74.0	80.5	87.0	97.0	68.0	80.0	82.3	90.1	86.2
DMC 11-23	100.0	103.0	77.5	80.5	87.0	95.0	73.0	76.0	84.4	88.6	86.5
DMC 11-22	97.0	103.0	77.0	84.0	87.0	97.0	71.0	76.5	83.0	90.1	86.6
DMC 11-07	97.0	106.0	71.0	84.0	87.0	97.0	68.0	82.5	80.8	92.4	86.6
DMC 11-06	97.0	97.0	77.5	84.0	87.0	103.0	71.0	77.5	83.1	90.4	86.8
DMC 11-15	94.0	106.0	74.0	80.5	87.0	93.5	73.0	86.0	82.0	91.5	86.8
DMC 11-12	97.0	106.0	74.0	80.5	87.0	99.5	68.0	82.5	81.5	92.1	86.8

DMC 11-01	100.0	103.0	71.0	84.0	87.0	97.0	73.0	80.0	82.8	91.0	86.9
DMC 11-11	100.0	106.0	77.0	77.5	87.0	97.0	73.0	77.5	84.3	89.5	86.9
DMC 11-18	100.0	100.0	77.0	84.0	87.0	97.5	70.0	80.0	83.5	90.4	87.0
DMC 11-16	97.0	106.0	77.0	84.0	87.0	97.0	68.0	81.0	82.3	92.0	87.2
DMC 11-03	100.0	106.0	77.0	84.0	87.0	93.0	73.0	80.0	84.3	90.8	87.6
DMC 11-20	100.0	106.0	74.0	84.0	87.0	97.0	74.0	78.5	83.8	91.4	87.6
DMC 11-08	97.0	106.0	77.0	84.0	87.0	95.5	73.0	82.5	83.5	92.0	87.8
DMC 11-13	97.0	106.0	77.5	84.0	85.0	97.0	73.0	83.5	83.1	92.6	87.9
DMC 11-19	100.0	106.0	74.0	84.0	87.0	95.5	74.0	82.5	83.8	92.0	87.9
DMC 11-04	97.0	106.0	77.0	84.0	87.0	102.5	70.0	82.5	82.8	93.8	88.3
DMC 11-05	97.0	106.0	77.0	84.0	87.0	103.0	70.0	86.0	82.8	94.8	88.8
Mean of genotypes	**97.4**	**104.3**	**75.6**	**82.6**	**86.3**	**95.2**	**71.3**	**80.7**	**82.6**	**90.7**	**86.7**
Mean of checks	**91.3**	**98.4**	**73.4**	**76.6**	**82.1**	**85.5**	**73.3**	**81.0**	**80.0**	**85.4**	**82.7**
Overall mean	**94.4**	**101.4**	**74.5**	**79.6**	**84.2**	**90.4**	**72.3**	**80.9**	**81.3**	**88.1**	**84.7**
%CV		**8.6**									

LSD(P≤0.05)S	7.41*	**LSD(P≤0.05)SxT**	2.53NS	**LSD(P≤0.05)SxLxT**	2.7NS
LSD(P≤0.05)L	0.94**	**LSD(P≤0.05)LxT**	1.63*	**LSD(P≤0.05)SxLxG**	10.18**
LSD(P≤0.05)T	1.65*	**LSD(P≤0.05)SxG**	7.24**	**LSD(P≤0.05)SxTxG**	10.23*
LSD(P≤0.05)G	5.08**	**LSD(P≤0.05)LxG**	7.16**	**LSD(P≤0.05)LxTxG**	10.18NS
LSD(P≤0.05)SxL	4.77*	**LSD(P≤0.05)TxG**	7.24NS	**LSD(P≤0.05)SxLxTxG**	14.43*

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.5: Days to physiological maturity of navy beans grown under drought stress (DS) and non stress drought (NS) conditions over two seasons in Kabete and Mwea

	Days to physiological maturity										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Navys	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-13	94.0	100.0	74.0	77.5	85.0	87.0	70.0	79.0	80.8	85.9	83.4
DNB 11-19	94.0	94.0	74.0	80.5	87.0	93.0	74.0	73.5	82.3	85.3	83.8
DNB 11-18	97.0	100.0	77.5	80.5	87.0	97.5	70.0	76.5	82.9	88.6	85.8
DNB 11-10	102.0	106.0	77.0	84.0	87.0	93.0	70.0	74.0	84.0	89.3	86.7
DNB 11-09	102.0	106.0	77.0	84.0	87.0	93.0	70.0	76.5	84.0	89.9	87.0
DNB 11-14	100.0	106.0	77.0	84.0	87.0	97.0	71.0	75.0	83.8	90.5	87.2
DNB 11-16	102.0	106.0	77.0	84.0	87.0	95.0	70.0	76.0	84.0	90.3	87.2
DNB 11-04	100.0	106.0	77.0	84.0	87.0	95.0	71.0	77.5	83.8	90.6	87.2
DNB 11-03	100.0	106.0	77.0	84.0	87.0	95.0	70.0	78.5	83.5	90.9	87.2
DNB 11-01	102.0	106.0	77.0	84.0	87.0	95.0	72.0	76.5	84.5	90.4	87.5
DNB 11-15	102.0	106.0	77.0	84.0	87.0	95.0	72.0	81.0	84.5	91.5	88.0
MEX142*	102.0	106.0	80.5	84.0	87.0	97.5	72.0	75.0	85.4	90.6	88.0
DNB 11-06	102.0	106.0	80.5	84.0	87.0	95.5	68.0	82.5	84.4	92.0	88.2
DNB 11-07	102.0	106.0	80.5	84.0	87.0	95.0	70.0	81.0	84.9	91.5	88.2
DNB 11-05	102.0	106.0	80.5	84.0	87.0	97.5	73.0	76.5	85.6	91.0	88.3
DNB 11-17	102.0	106.0	80.5	84.0	87.0	97.5	73.0	77.5	85.6	91.3	88.5
DNB 11-12	100.0	106.0	80.5	84.0	87.0	97.0	72.0	81.0	84.9	92.0	88.5
DNB 11-08	102.0	106.0	80.5	84.0	87.0	97.5	70.0	83.5	84.9	92.8	88.9
Mean of genotypes	**100.3**	**104.6**	**77.9**	**83.2**	**86.9**	**95.0**	**70.9**	**78.0**	**84.0**	**90.2**	**87.1**
Mean of checks	**102.0**	**106.0**	**80.5**	**84.0**	**87.0**	**97.5**	**72.0**	**75.0**	**85.4**	**90.6**	**88.0**

Overall mean	**101.2**	**105.3**	**79.2**	**83.6**	**87.0**	**96.3**	**71.5**	**76.5**	**84.7**	**90.4**	**87.6**
%CV		**8.6**									
LSD(P≤0.05)S	7.41*		**LSD(P≤0.05)SxT**			2.53NS		**LSD(P≤0.05)SxLxT**			2.7NS
LSD(P≤0.05)L	0.94**		**LSD(P≤0.05)LxT**			1.63*		**LSD(P≤0.05)SxLxG**			10.18**
LSD(P≤0.05)T	1.65*		**LSD(P≤0.05)SxG**			7.24**		**LSD(P≤0.05)SxTxG**			10.23*
LSD(P≤0.05)G	5.08**		**LSD(P≤0.05)LxG**			7.16**		**LSD(P≤0.05)LxTxG**			10.18NS
LSD(P≤0.05)SxL	4.77*		**LSD(P≤0.05)TxG**			7.24NS		**LSD(P≤0.05)SxLxTxG**			14.43*

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.6: Days to physiological maturity of small reds grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Days to physiological maturity										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-05	97.0	53.0	74.0	84.0	87.0	95.5	72.0	76.5	82.5	77.3	79.9
KATB9*	94.0	97.0	74.0	80.5	77.0	83.5	73.0	81.0	79.5	85.5	82.5
DSR 11-10	97.0	103.0	74.0	74.0	81.5	87.0	70.0	76.0	80.6	85.0	82.8
DSR 11-06	94.0	100.0	74.0	80.5	83.0	85.0	72.0	76.5	80.8	85.5	83.2
SER16*	94.0	94.0	77.5	77.5	81.5	83.5	74.0	83.5	81.8	84.6	83.2
DSR 11-12	94.0	94.0	77.5	77.0	85.0	87.5	73.0	77.5	82.4	84.0	83.2
SEA15*	97.0	104.0	79.0	80.5	77.5	86.5	71.5	73.5	81.3	86.1	83.7
DSR 11-24	94.0	97.0	77.0	84.0	83.5	85.0	73.0	76.0	81.9	85.5	83.7
DSR 11-04	94.0	103.0	77.5	80.5	85.0	87.0	71.0	74.0	81.9	86.1	84.0
SER155*	88.5	91.5	68.0	79.0	77.0	81.5	94.0	94.0	81.9	86.5	84.2
DSR 11-08	94.0	103.0	74.0	80.5	85.0	87.0	73.0	80.0	81.5	87.6	84.6
DSR 11-23	97.0	100.0	77.5	80.5	83.5	85.0	73.0	81.0	82.8	86.6	84.7
RCB231*	93.5	94.5	83.0	80.0	86.0	87.5	68.0	86.0	82.6	87.0	84.8
RCB592*	93.5	90.0	87.0	83.0	84.0	89.5	68.0	86.0	83.1	87.1	85.1
DSR 11-11	97.0	100.0	74.0	80.5	87.0	87.0	73.0	82.5	82.8	87.5	85.2
DSR 11-09	94.0	97.0	77.5	84.0	87.0	97.0	70.0	76.0	82.1	88.5	85.3
DSR 11-03	94.0	100.0	77.5	84.0	87.0	93.0	71.0	76.0	82.4	88.3	85.4
DSR 11-07	97.0	103.0	77.0	77.5	87.0	87.0	71.0	83.5	83.0	87.8	85.4
RAB651*	93.5	93.5	87.0	80.0	87.0	89.5	74.0	79.0	85.4	85.5	85.5
DSR 11-18	94.0	103.0	77.5	84.0	85.0	87.0	73.0	81.0	82.4	88.8	85.6

DSR 11-02	97.0	103.0	77.5	84.0	85.0	87.0	74.0	78.5	83.4	88.1	85.8
DSR 11-22	94.0	94.0	74.0	84.0	87.0	97.0	74.0	83.5	82.3	89.6	86.0
GLP585*	100.0	103.0	77.0	80.5	85.0	87.0	74.0	84.0	84.0	88.6	86.3
DSR 11-16	94.0	100.0	77.0	84.0	87.0	93.0	73.0	82.5	82.8	89.9	86.4
RCB270*	90.5	96.5	87.0	83.0	87.0	89.5	72.0	86.0	84.1	88.8	86.5
DSR 11-14	97.0	103.0	74.0	84.0	87.0	93.5	72.0	82.5	82.5	90.8	86.7
DSR 11-01	102.0	103.0	74.0	84.0	87.0	97.0	70.0	76.5	83.3	90.1	86.7
DSR 11-15	100.0	106.0	77.0	84.0	87.0	97.0	74.0	74.0	84.5	90.3	87.4
TIO CANELA*	102.0	105.0	77.0	80.5	87.0	97.5	73.0	81.0	84.8	91.0	87.9
DSR 11-13	102.0	106.0	77.0	84.0	87.0	97.0	73.0	77.5	84.8	91.1	88.0
SER95*	90.5	98.5	74.0	81.0	79.5	86.5	100.0	94.0	86.0	90.0	88.0
DSR 11-21	102.0	106.0	80.5	84.0	87.0	97.0	72.0	76.5	85.4	90.9	88.2
DSR 11-19	102.0	106.0	74.0	84.0	87.0	97.5	74.0	81.0	84.3	92.1	88.2
SER76*	93.5	101.5	68.0	79.0	80.5	86.5	100.0	100.0	85.5	91.8	88.7
DSR 11-20	102.0	106.0	80.5	84.0	87.0	97.5	71.0	86.0	85.1	93.4	89.3
Mean of genotypes	**96.9**	**99.5**	**76.3**	**82.2**	**85.8**	**91.5**	**72.3**	**78.9**	**82.8**	**88.0**	**85.4**
Mean of checks	**94.2**	**97.4**	**78.2**	**80.4**	**82.4**	**87.4**	**78.5**	**85.7**	**83.3**	**87.7**	**85.5**
Overall mean	**95.6**	**98.5**	**77.3**	**81.3**	**84.1**	**89.5**	**75.4**	**82.3**	**83.1**	**87.9**	**85.5**
%CV		**8.6**									
LSD(P≤0.05)S		7.41*		**LSD(P≤0.05)SxT**			2.53NS		**LSD(P≤0.05)SxLxT**		2.7NS
LSD(P≤0.05)L		0.94**		**LSD(P≤0.05)LxT**			1.63*		**LSD(P≤0.05)SxLxG**		10.18**
LSD(P≤0.05)T		1.65*		**LSD(P≤0.05)SxG**			7.24**		**LSD(P≤0.05)SxTxG**		10.23*
LSD(P≤0.05)G		5.08**		**LSD(P≤0.05)LxG**			7.16**		**LSD(P≤0.05)LxTxG**		10.18NS
LSD(P≤0.05)SxL		4.77*		**LSD(P≤0.05)TxG**			7.24NS		**LSD(P≤0.05)SxLxTxG**		14.43*

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

4.5.4. Effect of water stress on grain yield

There were significant grain yield differences due to locations ($p<0.001$), stress levels ($p<0.001$) and genotypes ($p<0.001$). Season x location x drought stress level interaction had a significant effect on the yield performance of beans (Table 4.7, 4.8, 4.9). Yield reduction under drought stress was more than 20% on average. Significant genotypic differences were observed in grain yield within each of the three market classes under drought stress and non stress conditions. In Kabete, grain yield of most genotypes was about 15% higher than in Mwea. Among the three market classes, navy beans performed better under both drought stress and non stress conditions than small reds and mixed colours (Table 4.10). Within the mixed colours, genotypes DMC11-10 and DMC11-24 were the top two high yielding lines under different environments, stress levels and seasons with average grain yield of over 1000 kg/ha. Other lines in the same market class with relatively high yield of over 800 kg/ha included DMC11-01, NCB280 (check), NCB226 (check), DMC11-22, SEN53 (check) and DMC11-13. Low yielding lines in this group were SEN56 (check), DMC11-14, DMC11-08 and KATB1 (check), which produced less than 600 kg/ha (Table 4.7). Local checks GLPX92 and KATB1 performed poorly in terms of grain yield compared to international checks and the test genotypes. However, most test genotypes were high yielding which was comparable to some international drought lines such as SEN53, NCB226 and NCB228. Genotypes that had higher yield across the two locations and seasons in the navy bean market class were DNB11-07 (1066.7 kg/ha), DNB11-15 (1020.6 kg/ha), DNB11-10 (987.5 kg/ha), DNB11-14 (968.4 kg/ha), DNB11-03 (965.2) and DNB11-01(902.7 kg/ha). The lowest yield was obtained from DNB11-13 (598.2 kg/ha). Most genotypes in this market class performed better than the check MEX142 with a yield advantage of about 20% (Table 4.8). Most small reds were medium yielding with a yield ranging between 600 kg/ha and 900 kg/ha. The best yielding lines included DSR11-12, DSR11-03, SEA15 (check), RCB592 (check), DSR11-02, SER76 (check), DSR11-15, DSR11-19 and DSR11-21 and produced above 800 kg/ha of grain. Local checks like GLP585 and KATB9 were among the lowest yielding varieties with less than 700 kg/ha (Table 4.9). Performance of most small reds was comparable to international drought lines used as checks and better than the local varieties. Genotypes including DMC11-10, DNB11-07 and DNB11-06 performed better under both drought stress and non stress conditions compared to KATB1, GLP585, GLPX92 and DMC11-08 which were low yielding even under no stress (Figure 4.1).

Table 4.7: Yield in kg/ha of mixed colours grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Grain yield (kg/ha)										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-10	1141.2	1930.3	885.0	1003.6	927.1	944.7	634.0	783.2	896.8	1165.4	1031.1
DMC 11-24	1323.6	1457.1	728.8	836.9	871.4	805.8	955.5	1047.9	969.8	1036.9	1003.4
DMC 11-01	1056.1	1551.6	625.7	1020.2	619.7	877.7	576.1	780.9	719.4	1057.6	888.5
NCB280*	976.5	1035.5	805.2	805.0	770.2	969.1	801.2	905.0	838.3	928.7	883.5
NCB226*	888.0	929.5	865.9	897.0	842.1	993.7	665.5	880.5	815.4	925.2	870.3
DMC 11-22	678.4	1432.3	783.5	854.6	563.8	804.7	609.0	1096.1	658.7	1046.9	852.8
SEN53*	939.6	1083.5	706.0	843.7	750.3	819.3	523.1	934.3	729.8	920.2	825.0
DMC 11-13	718.8	1244.3	830.6	906.5	502.3	669.3	661.0	937.6	678.2	939.4	808.8
DMC 11-02	763.0	1113.4	709.5	890.8	768.7	896.7	545.0	651.1	696.6	888.0	792.3
DMC 11-11	914.0	976.0	782.0	1017.5	482.8	545.6	745.0	820.0	730.9	839.8	785.4
SXB404*	986.0	1025.5	725.0	865.0	690.0	677.0	551.5	737.5	738.1	826.3	782.2
DMC 11-15	550.2	779.5	808.1	844.5	669.8	647.3	846.9	1088.9	718.7	840.1	779.4
DMC 11-03	738.1	1100.0	768.5	787.5	587.2	618.9	691.5	796.9	696.3	825.8	761.1
DMC 11-09	891.7	935.7	787.8	835.5	586.9	646.8	582.5	760.5	712.2	794.6	753.4
DMC 11-20	869.7	1378.6	461.5	515.5	557.6	605.5	587.5	877.7	619.1	844.3	731.7
DMC 11-12	800.4	1038.2	613.1	687.5	783.0	570.5	565.0	685.1	690.4	745.3	717.9
DMC 11-23	707.7	1053.3	843.6	803.4	445.9	604.6	509.9	701.0	626.8	790.6	708.7
DMC 11-18	981.2	1280.7	455.5	597.5	523.0	607.7	484.4	645.2	611.0	782.8	696.9
DMC 11-21	654.9	1058.5	739.0	692.6	512.0	690.5	533.0	662.5	609.7	776.0	692.9
DMC 11-06	688.8	769.0	608.0	767.5	514.6	631.8	704.1	856.1	628.9	756.1	692.5
DMC 11-05	888.1	1002.1	597.0	639.5	546.9	764.5	448.5	590.2	620.1	749.1	684.6

DMC 11-04	846.9	1208.1	447.5	540.5	567.8	671.7	515.3	611.2	594.4	757.9	676.2
GLPX92*	612.0	1135.3	707.1	552.1	582.8	574.9	534.5	698.3	609.1	740.1	674.6
DMC 11-19	834.7	1249.8	513.0	571.0	525.7	584.0	462.6	588.7	584.0	748.4	666.2
DMC 11-07	797.9	1054.9	579.0	574.9	515.3	599.6	563.8	637.5	614.0	716.7	665.4
DMC 11-17	842.9	833.1	480.5	574.5	624.0	697.0	396.1	669.0	585.9	693.4	639.7
DMC 11-16	708.0	905.5	485.5	577.5	469.7	700.5	481.8	599.0	536.2	695.6	615.9
SEN56*	518.8	650.5	511.0	635.5	607.0	547.7	520.5	743.5	539.3	644.3	591.8
DMC 11-14	701.7	903.5	391.5	437.5	723.2	504.7	511.4	559.8	581.9	601.4	591.7
DMC 11-08	558.2	660.4	617.4	578.8	480.8	509.0	534.7	632.1	547.8	595.1	571.5
KATB1*	521.0	594.5	474.0	631.0	467.3	579.3	531.5	764.7	498.5	642.4	570.5
Mean of genotypes	**819.0**	**1121.5**	**697.6**	**761.5**	**598.7**	**675.0**	**589.4**	**853.3**	**683.7**	**820.3**	**752.0**
Mean of checks	**777.4**	**922.0**	**684.9**	**747.0**	**572.8**	**637.3**	**589.7**	**809.1**	**661.2**	**803.9**	**732.6**
Overall mean	**798.2**	**1021.8**	**691.3**	**754.3**	**585.8**	**656.2**	**589.6**	**831.2**	**672.5**	**812.1**	**742.3**
%CV		**19.1**									
LSD(P≤0.05)S		334.3NS		**LSD(P≤0.05)SxT**		158.3NS		**LSD(P≤0.05)SxLxT**			121.4NS
LSD(P≤0.05)L		22.73**		**LSD(P≤0.05)LxT**		39.7NS		**LSD(P≤0.05)SxLxG**			213.21**
LSD(P≤0.05)T		40.19**		**LSD(P≤0.05)SxG**		156.68**		**LSD(P≤0.05)SxTxG**			214.8NS
LSD(P≤0.05)G		103.47**		**LSD(P≤0.05)LxG**		145.83**		**LSD(P≤0.05)LxTxG**			207.9NS
LSD(P≤0.05)SxL		285.90*		**LSD(P≤0.05)TxG**		148.3NS		**LSD(P≤0.05)SxLxTxG**			298.7NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.8: Yield in kg/ha of navy beans grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

	Grain yield (kg/ha)										
	Season 1				Season 2						
Line/market class	**Kabete**		**Mwea**		**Kabete**		**Mwea**				
Navys	**DS**	**NS**	**DS**	**NS**	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DNB 11-07	1539.0	1895.0	814.0	927.0	952.0	1094.4	569.9	741.9	968.7	1164.6	1066.7
DNB 11-15	1415.8	1537.0	826.0	906.0	836.3	1220.3	599.5	823.5	919.4	1121.7	1020.6
DNB 11-10	1086.5	1228.2	857.2	961.5	778.5	1169.6	881.5	936.7	900.9	1074.0	987.5
DNB 11-14	981.6	1095.8	1170.6	1189.0	818.4	865.7	744.5	881.1	928.8	1007.9	968.4
DNB 11-03	1135.4	1212.0	1078.0	1094.0	581.2	907.6	813.3	899.5	902.0	1028.3	965.2
DNB 11-01	1104.5	1472.6	675.0	903.5	767.2	979.3	581.0	738.2	781.9	1023.4	902.7
DNB 11-16	996.8	1332.6	793.4	915.5	667.0	855.6	652.8	852.5	777.5	989.1	883.3
DNB 11-06	1353.5	1627.1	608.3	859.7	618.6	972.2	463.3	550.8	760.9	1002.5	881.7
DNB 11-09	1062.9	1172.5	771.3	898.4	750.5	819.5	565.5	732.7	787.6	905.8	846.7
DNB 11-17	930.5	1343.9	725.5	903.2	555.0	774.7	590.5	812.7	700.4	958.6	829.5
DNB 11-12	706.0	1184.1	778.0	879.1	731.9	817.6	616.6	690.0	708.1	892.7	800.4
MEX142*	927.4	1318.3	746.1	809.0	537.2	874.6	467.0	539.7	669.4	917.2	793.3
DNB 11-04	1048.5	1245.0	473.6	574.8	646.0	1083.8	431.5	530.7	649.9	858.6	754.3
DNB 11-05	881.5	922.6	498.0	686.6	695.0	861.7	501.1	609.3	643.9	770.1	707.0
DNB 11-19	708.4	769.8	724.0	918.7	566.0	554.8	605.0	726.1	650.9	742.3	696.6
DNB 11-08	910.5	1217.8	494.5	564.0	563.5	732.6	459.0	579.4	606.9	773.5	690.2
DNB 11-18	694.9	843.9	491.5	518.0	547.5	549.6	490.7	676.0	556.1	646.9	601.5
DNB 11-13	582.9	828.9	546.4	574.0	578.3	609.0	448.7	616.9	539.1	657.2	598.2
Mean of genotypes	**1008.2**	**1231.1**	**746.0**	**839.6**	**685.5**	**1001.6**	**589.1**	**729.3**	**751.9**	**918.6**	**835.3**
Mean of checks	**927.4**	**1118.3**	**725.1**	**809.0**	**537.2**	**874.6**	**467.0**	**539.7**	**669.4**	**917.2**	**793.3**

Overall mean	**967.8**	**1174.7**	**735.6**	**824.3**	**611.4**	**938.1**	**528.1**	**634.5**	**710.7**	**917.9**	**814.3**
%CV		**19.1**									
LSD(P≤0.05)S	334.3NS		**LSD(P≤0.05)SxT**			158.3NS		**LSD(P≤0.05)SxLxT**			121.4NS
LSD(P≤0.05)L	22.73**		**LSD(P≤0.05)LxT**			39.7NS		**LSD(P≤0.05)SxLxG**			213.2**
LSD(P≤0.05)T	40.19**		**LSD(P≤0.05)SxG**			156.68**		**LSD(P≤0.05)SxTxG**			214.8NS
LSD(P≤0.05)G	103.47**		**LSD(P≤0.05)LxG**			145.83**		**LSD(P≤0.05)LxTxG**			207.9NS
LSD(P≤0.05)SxL	285.90*		**LSD(P≤0.05)TxG**			148.3NS		**LSD(P≤0.05)SxLxTxG**			298.7NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.9: Yield in kg/ha of small reds grown under drought stress (DS) and non drought stress (NS) treatment over two seasons in Kabete and Mwea

	Grain yield (kg/ha)										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-12	1284.8	1601.3	650.5	1133.3	625.2	813.7	671.3	854.3	808.0	1100.6	954.3
DSR 11-03	970.3	1203.0	895.7	1021.5	774.7	943.5	557.0	921.5	799.4	1022.4	910.9
SEA15*	848.2	943.6	969.6	1011.5	810.9	939.5	843.0	713.6	867.9	902.1	885.0
RCB592*	1168.5	1450.5	485.5	577.0	917.1	1058.5	584.5	665.5	788.9	937.9	863.4
DSR 11-02	959.0	1364.6	759.5	565.0	776.0	917.5	696.2	836.5	797.7	920.9	859.3
SER76*	1068.4	1195.4	714.4	835.5	717.5	799.8	681.9	844.5	795.6	918.8	857.2
DSR 11-15	1024.8	1257.2	510.5	792.6	856.5	878.7	635.4	789.2	756.8	929.4	843.1
DSR 11-19	1170.3	1173.8	759.5	945.5	680.3	978.0	533.4	454.1	785.9	887.8	836.9
DSR 11-21	1015.0	1230.3	597.7	909.5	691.8	900.0	633.4	691.1	734.5	932.7	833.6
DSR 11-13	1168.8	1387.9	673.7	849.0	585.4	868.0	522.8	558.5	737.7	915.8	826.8
RCB231*	875.5	1002.5	784.8	746.3	706.1	776.5	833.6	832.6	800.0	839.5	819.8
SER16*	1054.4	1091.5	616.5	796.5	829.5	829.5	567.4	771.8	767.0	872.3	819.7
DSR 11-14	1126.2	1408.3	547.5	598.3	632.1	884.5	590.3	694.5	724.0	896.4	810.2
DSR 11-20	1179.5	1207.5	695.7	611.5	804.1	881.0	499.0	575.5	794.6	818.9	806.8
DSR 11-10	994.6	1117.1	674.0	1104.7	553.8	810.6	501.3	692.5	680.9	931.2	806.1
RAB651*	958.5	1055.5	605.0	804.6	699.0	846.5	620.5	809.6	720.8	879.0	799.9
DSR 11-18	758.5	1126.7	541.5	768.8	834.8	946.0	679.3	667.6	703.5	877.3	790.4
DSR 11-09	774.6	880.5	891.7	957.7	652.0	921.3	573.5	632.9	722.9	848.1	785.5
SER155*	959.0	1038.5	519.2	890.5	733.5	794.0	519.2	823.5	682.7	886.6	784.7
DSR 11-05	1088.8	966.0	792.5	797.0	542.6	806.0	512.5	737.3	734.1	826.6	780.4
SER95*	959.7	984.8	781.6	806.7	597.4	680.3	553.0	857.7	722.9	832.4	777.7

DSR 11-24	1042.5	1267.8	501.3	655.2	738.8	740.5	575.5	589.8	714.5	813.3	763.9
DSR 11-11	832.1	1053.2	595.2	767.0	696.3	862.5	585.0	655.0	677.2	834.4	755.8
DSR 11-07	879.4	1206.7	542.7	694.0	609.8	939.8	565.6	568.7	649.4	852.3	750.9
DSR 11-06	960.0	1110.0	665.5	631.8	582.3	768.5	714.1	572.8	730.5	770.8	750.7
DSR 11-01	943.0	1192.8	599.8	760.0	797.3	602.2	518.0	566.8	714.5	780.4	747.5
DSR 11-04	904.7	1228.3	512.0	620.0	568.5	945.0	524.5	667.5	627.4	865.2	746.3
RCB270*	786.0	1105.3	579.8	596.3	626.5	800.5	699.9	750.9	673.0	813.2	743.1
TIO CANELA*	882.0	949.0	763.6	793.0	590.3	722.5	534.3	671.7	692.6	784.1	738.4
DSR 11-23	926.2	966.4	604.5	628.3	721.9	834.5	493.2	575.2	686.5	751.1	718.8
DSR 11-16	868.3	985.5	600.0	511.5	677.6	661.0	676.7	728.2	705.7	721.6	713.7
DSR 11-22	918.3	1216.5	652.5	653.0	620.0	725.5	428.3	488.1	654.8	770.8	712.8
DSR 11-08	929.5	1206.2	756.6	623.1	536.3	507.8	480.8	623.7	675.8	740.2	708.0
GLP585*	737.5	832.6	455.5	670.1	766.1	777.1	717.4	566.6	669.1	711.6	690.4
KATB9*	814.2	877.0	507.0	522.5	720.4	779.0	482.6	654.9	631.0	708.4	669.7
Mean of genotypes	**987.8**	**1189.5**	**653.0**	**765.1**	**876.4**	**832.0**	**672.5**	**758.3**	**750.4**	**861.2**	**805.8**
Mean of checks	**926.0**	**1043.9**	**648.5**	**754.2**	**726.2**	**817.0**	**636.4**	**746.9**	**734.3**	**840.5**	**787.4**
Overall mean	**956.9**	**1116.7**	**650.8**	**759.7**	**801.3**	**824.5**	**654.5**	**752.6**	**742.4**	**850.9**	**796.6**
%CV		**19.1**									

LSD(P≤0.05)S	334.3NS	**LSD(P≤0.05)SxT**	158.3NS	**LSD(P≤0.05)SxLxT**	121.4NS
LSD(P≤0.05)L	22.73**	**LSD(P≤0.05)LxT**	39.7NS	**LSD(P≤0.05)SxLxG**	213.2**
LSD(P≤0.05)T	40.19**	**LSD(P≤0.05)SxG**	156.7**	**LSD(P≤0.05)SxTxG**	214.8NS
LSD(P≤0.05)G	103.5**	**LSD(P≤0.05)LxG**	145.8**	**LSD(P≤0.05)LxTxG**	207.9NS
LSD(P≤0.05)SxL	285.9*	**LSD(P≤0.05)TxG**	148.3NS	**LSD(P≤0.05)SxLxTxG**	298.7NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.10: Yield comparison of the three market classes grown under drought stress (DS) and non drought stress (NS) treatments over two seasons in Kabete and Mwea

	Yield in kg/ha					
	Kabete		Mwea			
Market class	DS	NS	DS	NS	Mean DS	Mean NS
Mixed colours	712.5	882.8	622.7	750.5	667.6	816.7
Navys	840.5	1058.8	654.3	778.4	747.4	918.6
Small reds	830.1	983.2	623.0	725.1	726.6	853.7
CV (%)	11.9					
LSD (p<0.05)S	128.5NS	LSD (p<0.05)SXT	123.9NS	LSD (p<0.05)SXLXT	137.9	
LSD (p<0.05)L	76.1*	LSD (p<0.05)LXT	63.4*	LSD (p<0.05)SXLXG	149.3	
LSD (p<0.05)T	43.6**	LSD (p<0.05)SXG	31.7*	LSD (p<0.05)SXTXG	153.4	
LSD (p<0.05)G	23.2**	LSD (p<0.05)LXG	29.6*	LSD (p<0.05)LXTXG	79.3*	
LSD (p<0.05)SXL	69.7	LSD (p<0.05)TXG	51.1**	LSD (p<0.05)SXLXTXG	173.6	

NB: Means with the same letter are not significantly different at p<0.05. *,**, NS denote significant at p<0.05, 0.001 and not significant respectively.

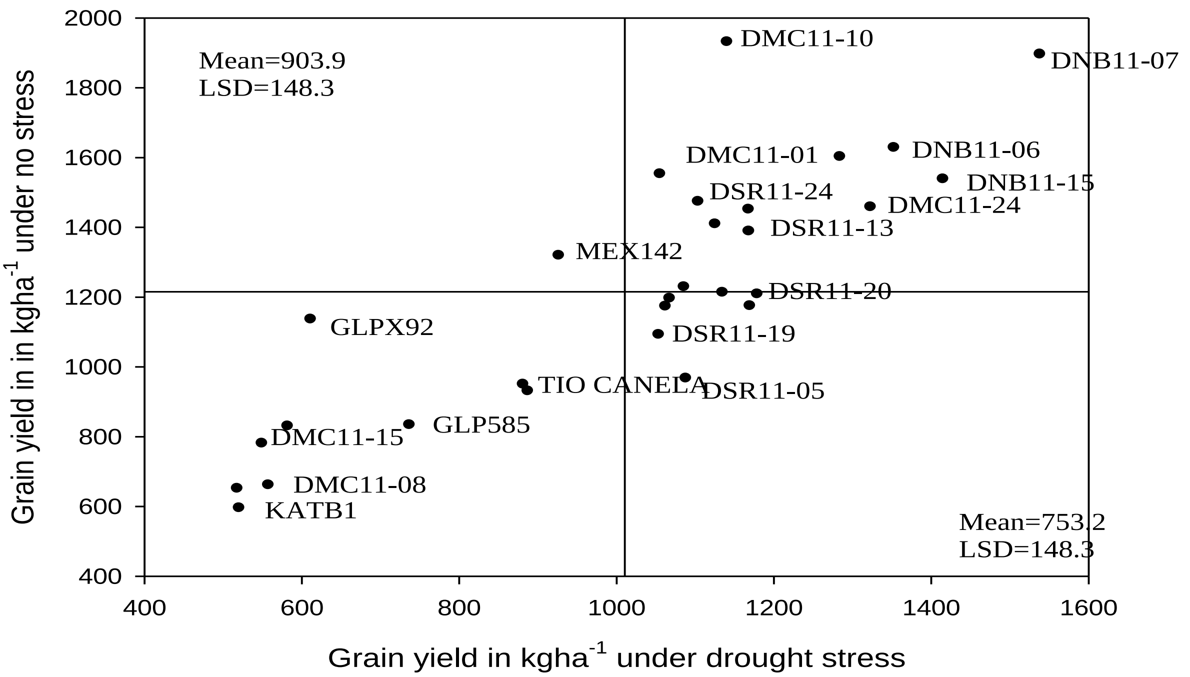


Figure 4.1: Represents mean yield of 29 genotypes selected at random from the three market classes and checks during the first season in Kabete.

4.5.5. Number of pods per plant

Mean number of pods per plant in the three market classes ranged between 4.0 and 7.0 under drought stress. Also, mean number of pods per plant of different genotypes in all the market classes differed significantly between seasons ($p<0.05$), across locations ($p<0.05$) and under irrigation treatments ($p<0.05$). Interactions between seasons, locations and genotypes had significant effects on the number of pods per plant with genotypes recording more pods per plant in the first season than in the second season in both sites (Table 4.11, 4.12, 4.13). Within the mixed colours, SEN56 (check), SEN53 (check), DMC11-22, DMC11-10 and DMC11-13 had the highest average pod count per plant which was above 7 pods compared to the other genotypes in the same class. Most genotypes in this class had at least 5-6 pods per plant but lines such as DMC11-04, DMC11-14, KATB1 (check) and DMC11-06 had less than 4 pods per plant on average. Local checks and some international drought lines had less pods per plant than most test lines (Table 4.11). Navy beans had the highest pod count per plant compared to the other market classes with genotypes such as DNB11-14, DNB11-03 and DNB11-07 having more than 8 pods per plant compared to the other genotypes in the same group and the check MEX142. Most genotypes in this market class had between 5 and 7 pods per plant but DNB11-12 and DNB11-08 had the lowest mean number of pods per plant (Table 4.12). Among the small reds, the best genotypes had on average 7 pods per plant and included Tio canela (check), DSR11-08, DSR11-21, DSR11-20 and SER76 (check). Other genotypes in this market class had between 5 and 6 pods per plant on average but RAB651 (check) had only 3 pods per plant on average which was the lowest in this class. On average, genotypes in this market class had more pods per plant than most checks (Table 4.13). The average pod count per plant of most genotypes in the three market classes was significantly lower under drought stress than under no stress conditions.

Table 4.11: Number of pods per plant of genotypes in the mixed colours market class grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete and Mwea

Line/market class	Number of pods per plant										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SEN56*	4.8	5.8	5.0	14.5	3.9	5.8	14.0	5.5	9.2	9.7	9.5
SEN53*	5.4	6.3	12.5	12.5	2.5	5.4	4.5	15.0	6.2	9.3	7.8
DMC 11-22	5.3	9.2	9.5	9.5	6.5	7.0	3.0	10.5	6.1	8.8	7.5
DMC 11-10	6.7	6.8	9.0	10.0	5.8	7.2	4.3	8.7	6.9	7.7	7.3
DMC 11-13	6.2	7.5	7.5	7.5	1.9	6.3	8.5	12.3	6.0	8.4	7.2
DMC 11-12	4.0	4.9	7.5	9.0	4.4	6.4	8.8	4.7	6.7	6.7	6.7
DMC 11-03	6.8	7.7	6.0	13.0	4.6	5.2	3.8	3.8	5.5	7.4	6.5
DMC 11-05	5.7	7.7	4.5	5.0	5.1	6.2	4.8	9.8	5.3	6.9	6.1
DMC 11-11	4.7	5.3	8.5	8.5	2.7	2.8	5.3	11.1	5.3	6.9	6.1
DMC 11-18	5.3	8.5	3.5	3.0	4.0	9.5	5.5	4.5	5.8	6.1	6.0
SXB404*	8.1	12.8	1.3	11.8	0.3	0.7	1.3	11.8	2.7	9.2	6.0
DMC 11-02	4.0	9.6	6.5	7.0	2.5	4.8	5.0	6.8	4.5	6.8	5.7
DMC 11-17	5.2	10.0	2.5	6.0	2.5	5.1	4.7	8.8	3.7	7.5	5.6
DMC 11-23	6.0	6.8	6.0	10.0	2.6	2.6	3.2	7.0	5.4	5.8	5.6
DMC 11-15	6.7	7.5	5.0	5.5	4.4	6.8	3.7	7.9	5.4	5.7	5.6
DMC 11-07	3.5	9.0	5.0	7.0	1.5	4.4	3.5	9.3	3.4	7.4	5.4
DMC 11-21	2.8	6.7	7.5	7.5	1.8	7.5	2.3	7.1	3.6	7.2	5.4
DMC 11-09	3.5	5.5	8.5	8.5	1.7	4.0	9.3	4.7	4.7	5.2	5.0
NCB226*	8.4	9.8	1.0	7.8	5.9	6.8	1.0	7.8	4.1	5.8	5.0
DMC 11-01	5.9	6.9	3.0	10.5	3.1	3.3	2.0	4.7	3.5	6.3	4.9

DMC 11-08	5.0	7.4	6.0	7.0	3.3	3.9	3.0	3.8	4.3	4.8	4.6
NCB280*	9.0	9.7	3.1	4.3	3.0	5.8	3.1	4.3	4.5	4.5	4.5
DMC 11-19	4.4	5.9	2.0	4.5	4.1	9.1	2.8	4.8	3.3	5.6	4.5
GLPX92*	3.5	5.2	4.0	7.0	3.6	3.9	1.7	1.8	3.9	4.5	4.2
DMC 11-16	5.6	8.2	2.0	3.0	2.2	4.6	3.7	2.5	3.4	4.6	4.0
DMC 11-20	3.8	6.2	1.5	3.0	1.5	5.2	2.8	7.0	2.4	5.4	3.9
DMC 11-24	6.1	6.3	4.0	5.0	3.0	4.3	0.5	4.3	3.7	4.0	3.9
DMC 11-04	5.5	6.0	3.0	4.0	2.8	3.4	1.0	3.5	3.3	4.0	3.7
DMC 11-14	4.9	5.3	1.0	2.5	1.3	3.7	1.8	0.8	2.7	3.6	3.2
KATB1*	3.1	4.1	3.0	3.0	3.0	3.5	0.7	4.5	2.4	3.8	3.1
DMC 11-06	2.6	5.0	4.0	6.0	1.7	3.0	1.0	1.8	2.3	3.0	2.7
Mean of genotypes	**5.0**	**6.6**	**6.7**	**7.8**	**3.7**	**4.7**	**3.9**	**7.2**	**4.6**	**6.8**	**5.7**
Mean of checks	**5.0**	**5.2**	**6.0**	**7.0**	**3.2**	**4.4**	**3.7**	**6.2**	**3.7**	**6.0**	**4.9**
Overall mean	**5.0**	**5.9**	**6.4**	**7.4**	**3.5**	**4.6**	**3.8**	**6.7**	**4.2**	**6.4**	**5.3**
%CV	**27.9**										

LSD(P≤0.05)S	1.93*	LSD(P≤0.05)SXT	1.08NS	LSD(P≤0.05)SXLXT	2.08NS
LSD(P≤0.05)L	2.56*	LSD(P≤0.05)LXT	2.03NS	LSD(P≤0.05)SXLXG	8.23*
LSD(P≤0.05)T	1.08*	LSD(P≤0.05)SXG	5.76**	LSD(P≤0.05)SXTXG	8.18NS
LSD(P≤0.05)G	4.09**	LSD(P≤0.05)LXG	5.88**	LSD(P≤0.05)LXTXG	8.26NS
LSD(P≤0.05)SXL	2.38NS	LSD(P≤0.05)TXG	5.80NS	LSD(P≤0.05)SXLXTXG	11.62NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.12: Number of pods per plant of genotypes in the navy beans market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

Line/market class	Number of pods per plant										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Navys	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-14	7.2	11.1	6.5	12.0	4.0	7.5	9.8	16.0	7.1	11.4	9.3
DNB 11-03	8.9	11.8	10.5	11.5	3.3	9.2	5.3	6.8	7.0	9.8	8.4
DNB 11-07	7.5	8.3	8.0	12.5	7.0	8.0	5.0	12.2	7.9	8.2	8.1
DNB 11-15	8.0	14.4	6.5	9.5	6.2	6.6	5.5	5.7	7.3	8.3	7.8
DNB 11-10	6.6	6.4	8.0	11.0	3.4	7.4	6.5	8.0	7.4	8.0	7.7
MEX142*	4.7	11.4	8.5	8.5	3.2	8.1	5.0	12.5	5.3	10.1	7.7
DNB 11-17	7.6	11.7	10.0	10.5	1.4	4.8	4.0	5.3	6.8	7.1	7.0
DNB 11-19	4.3	5.2	7.0	7.5	2.9	3.5	10.0	11.0	6.5	7.3	6.9
DNB 11-16	7.1	7.8	6.0	11.5	2.6	10.3	5.2	6.8	6.5	6.6	6.6
DNB 11-06	5.4	6.9	6.5	8.5	5.4	6.3	3.3	5.0	5.7	6.2	6.0
DNB 11-09	6.1	7.4	7.0	8.5	0.7	6.1	4.7	5.7	4.9	6.7	5.8
DNB 11-18	6.6	7.3	3.5	4.5	3.0	5.3	3.5	12.5	4.1	7.4	5.8
DNB 11-05	5.6	7.6	5.5	8.5	6.4	7.0	1.0	3.3	4.9	6.4	5.7
DNB 11-13	4.5	6.3	4.0	4.0	2.2	3.1	8.0	11.3	4.9	6.1	5.5
DNB 11-04	5.3	5.9	3.5	4.0	4.7	5.9	3.0	5.2	5.1	5.7	5.4
DNB 11-12	4.3	6.6	4.5	7.0	1.9	4.7	3.0	5.8	3.9	5.5	4.7
DNB 11-08	4.9	4.3	3.0	4.5	4.4	6.4	1.2	3.5	3.6	4.4	4.0
Mean of genotypes	**6.9**	**9.6**	**7.6**	**8.2**	**3.9**	**8.2**	**6.2**	**7.1**	**6.2**	**9.8**	**8.0**
Mean of checks	**4.7**	**7.4**	**7.5**	**7.5**	**3.2**	**8.1**	**5.0**	**5.5**	**5.3**	**7.1**	**6.2**
Overall mean	**5.8**	**8.5**	**7.6**	**7.9**	**3.6**	**8.2**	**5.6**	**6.3**	**5.8**	**8.5**	**7.1**

%CV	**27.9**				
LSD(P≤0.05)S	1.93*	LSD(P≤0.05)SXT	1.08NS	LSD(P≤0.05)SXLXT	2.08NS
LSD(P≤0.05)L	2.56*	LSD(P≤0.05)LXT	2.03NS	LSD(P≤0.05)SXLXG	8.23*
LSD(P≤0.05)T	1.08*	LSD(P≤0.05)SXG	5.76**	LSD(P≤0.05)SXTXG	8.18NS
LSD(P≤0.05)G	4.09**	LSD(P≤0.05)LXG	5.88**	LSD(P≤0.05)LXTXG	8.26NS
LSD(P≤0.05)SXL	2.38NS	LSD(P≤0.05)TXG	5.80NS	LSD(P≤0.05)SXLXTXG	11.62NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.13: Number of pods per plant of genotypes in the small reds market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	Number of pods per plant										
	Season 1				Season 2						
Line/market class	**Kabete**		**Mwea**		**Kabete**		**Mwea**				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
TIO CANELA*	5.4	6.0	6.5	11.0	2.2	6.6	11.5	12.3	6.1	9.5	7.8
DSR 11-08	4.5	7.5	9.5	12.5	2.3	4.5	5.3	14.5	7.4	7.8	7.6
DSR 11-21	5.0	6.0	6.5	8.0	3.5	7.0	10.3	12.3	6.1	8.8	7.5
DSR 11-20	6.3	16.6	7.0	8.0	2.2	4.9	4.8	9.8	6.3	8.6	7.5
SER76*	5.6	9.8	6.3	11.2	2.5	5.3	6.3	11.2	6.4	8.1	7.3
DSR 11-12	5.6	7.0	5.0	8.5	3.1	6.3	8.3	11.5	6.0	7.8	6.9
SER16*	5.6	6.3	4.0	13.0	4.0	6.0	5.8	10.8	5.3	8.5	6.9
DSR 11-01	6.5	9.1	4.0	11.0	3.9	6.0	4.4	8.8	5.9	7.5	6.7
SEA15*	4.9	5.7	9.0	9.5	3.6	5.0	6.6	10.5	5.5	7.9	6.7
DSR 11-03	7.3	9.4	8.5	9.0	2.0	6.5	5.0	6.8	5.4	7.9	6.7
DSR 11-13	6.7	11.6	4.5	5.0	4.9	6.6	5.8	7.3	6.5	6.6	6.6
DSR 11-04	7.0	7.8	7.5	8.0	2.7	4.8	6.8	7.2	6.3	6.7	6.5
DSR 11-11	3.3	6.5	4.0	11.0	2.7	8.5	3.8	12.3	4.9	8.1	6.5
RCB231*	5.0	6.5	7.5	7.5	4.8	5.4	7.7	7.7	6.5	6.5	6.5
RCB592*	4.5	6.2	6.8	6.8	4.4	6.7	8.2	8.2	5.7	6.9	6.3
DSR 11-05	2.1	5.5	6.5	8.5	3.7	4.9	7.0	12.2	5.6	7.0	6.3
DSR 11-15	4.7	6.9	3.5	6.0	3.3	4.8	5.9	8.5	5.6	6.8	6.2
DSR 11-02	4.1	5.0	7.0	9.0	3.6	4.7	8.1	9.0	5.7	6.2	6.0
DSR 11-18	6.2	6.4	5.5	7.0	2.7	4.7	5.1	10.1	5.4	6.5	6.0
DSR 11-06	3.1	5.2	5.5	8.5	3.1	3.2	6.6	8.3	5.6	6.3	6.0
DSR 11-22	4.5	5.8	4.5	8.5	2.9	4.8	6.7	9.5	5.6	5.9	5.8

DSR 11-23	5.0	6.0	6.5	7.5	2.8	3.3	4.3	8.3	5.3	6.0	5.7
SER155*	4.0	6.4	2.4	9.3	5.1	5.5	2.4	9.3	4.0	7.1	5.6
DSR 11-09	3.0	6.0	7.5	10.5	4.3	4.4	2.5	5.0	5.1	5.7	5.4
DSR 11-10	4.7	4.9	7.0	10.0	3.9	5.0	4.7	6.3	5.3	5.5	5.4
DSR 11-19	4.1	7.9	5.5	7.5	3.8	4.0	1.5	8.0	4.2	6.3	5.3
KATB9*	2.0	6.0	2.5	3.0	4.6	5.3	5.5	9.0	4.9	5.6	5.3
DSR 11-16	5.0	6.2	3.5	4.0	2.4	5.9	0.8	12.5	3.9	6.4	5.2
DSR 11-14	6.0	8.6	7.0	8.0	4.5	5.4	2.1	5.3	4.4	5.3	4.9
GLP585*	4.8	5.9	3.5	5.5	3.4	3.6	4.5	6.5	4.3	5.1	4.7
DSR 11-24	5.0	5.5	5.5	6.5	3.9	5.8	0.5	5.3	3.7	5.3	4.5
RCB270*	3.8	6.3	3.3	3.3	4.0	4.4	5.5	5.5	4.1	4.9	4.5
SER95*	2.5	7.0	1.3	9.0	2.6	3.4	1.3	9.0	3.2	5.8	4.5
DSR 11-07	4.2	5.1	4.0	4.5	2.7	3.3	4.5	6.6	3.9	4.1	4.0
RAB651*	5.0	6.5	1.3	6.0	3.0	5.9	1.3	6.0	2.9	4.6	3.8
Mean of genotypes	**6.5**	**6.7**	**6.7**	**7.3**	**5.6**	**6.4**	**7.2**	**8.6**	**6.0**	**6.0**	**6.0**
Mean of checks	**5.8**	**6.1**	**5.4**	**7.1**	**4.7**	**5.6**	**6.4**	**7.1**	**5.6**	**5.0**	**5.3**
Overall mean	**6.2**	**6.4**	**6.1**	**7.2**	**5.2**	**6.0**	**6.8**	**7.9**	**5.8**	**5.5**	**5.7**
%CV	**27.9**										

LSD(P≤0.05)S	1.93*	LSD(P≤0.05)SXT	1.08NS	LSD(P≤0.05)SXLXT	2.08NS
LSD(P≤0.05)L	2.56*	LSD(P≤0.05)LXT	2.03NS	LSD(P≤0.05)SXLXG	8.23*
LSD(P≤0.05)T	1.08*	LSD(P≤0.05)SXG	5.76**	LSD(P≤0.05)SXTXG	8.18NS
LSD(P≤0.05)G	4.09**	LSD(P≤0.05)LXG	5.88**	LSD(P≤0.05)LXTXG	8.26NS
LSD(P≤0.05)SXL	2.38NS	LSD(P≤0.05)TXG	5.80NS	LSD(P≤0.05)SXLXTXG	11.62NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

4.5.6. Number of seeds per pod

The average seed count per pod of most genotypes in the three market classes was significantly ($p<0.05$) lower under drought stress than under no stress treatment. The mean number of seeds in each pod in the three market classes ranged between 1.0 and 2.0 under drought stress compared to 3.0 and 4.0 under no stress (Table 4.14, 4.15, 4.16). A 42% reduction in the number of seeds per pod was observed under drought stress compared to non stress conditions. Within the mixed colours, DMC11-24 had the highest number of seeds per pod (4 seeds), compared to the other genotypes in the same market class and the checks. Most genotypes such as DMC11-17, DMC11-10, DMC11-23, DMC11-13 and checks like SEN53, SXB404, GLPX92 and SEN56 had on average 3 seeds per pod. Other genotypes in this market class including KATB1 (check), DMC11-19 and DMC11-14 had less than 2 seeds per pod across seasons and locations (Table 4.14). All navy beans except DNB11-13, DNB11-19 and DNB11-18 had at least 3 seeds per pod (Table 4.15). Among the small reds, checks such as RCB592, SER155, RCB231 and SER76 had on average 4 seeds per pod which was the highest compared to the other genotypes in this market class and the other two market classes. Most of the other test genotypes and checks in this market class including DSR11-01, DSR11-05, DSR11-04 and DSR11-23 had on average 3 seeds per pod but less than 3 seeds per pod were obtained from genotypes like DSR11-10, DSR11-19 and KATB9 (check) (Table 4.16).

Table 4.14: Number of seeds per pod of genotypes in the mixed colours market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	Number of seeds per pod										
	Season 1				**Season 2**						
Line/market class	**Kabete**		**Mwea**		**Kabete**		**Mwea**				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-24	2.3	4.7	3.5	3.5	4.3	4.4	0.2	5.2	3.1	4.0	3.6
SEN53*	2.5	3.9	2.0	3.5	2.4	3.0	0.6	4.6	2.6	3.3	3.0
SXB404*	2.1	4.8	2.0	3.8	0.0	0.5	2.0	3.8	2.0	3.7	2.9
DMC 11-17	3.8	4.1	2.5	3.0	2.8	3.2	0.7	5.0	2.4	3.3	2.9
DMC 11-02	3.4	4.0	3.5	3.5	1.9	2.7	0.7	1.9	2.4	3.0	2.7
DMC 11-10	3.3	3.4	3.0	3.0	2.8	3.4	0.5	2.0	2.4	3.0	2.7
DMC 11-18	3.5	4.9	1.5	2.5	1.9	2.3	0.2	0.8	2.3	3.1	2.7
DMC 11-23	3.0	4.7	3.0	3.5	2.0	2.6	0.1	2.4	2.3	3.1	2.7
DMC 11-13	3.0	4.5	2.5	3.0	2.6	3.0	0.4	3.2	2.6	2.7	2.7
GLPX92*	2.2	2.6	2.0	3.5	2.6	3.2	1.5	2.6	2.3	3.0	2.7
DMC 11-22	2.9	3.7	3.0	4.5	2.3	2.9	0.2	3.4	2.1	3.1	2.6
SEN56*	2.3	3.8	1.5	3.5	2.1	2.6	1.5	3.5	2.1	3.1	2.6
DMC 11-21	2.7	3.8	2.5	3.0	2.9	3.1	0.2	1.7	2.3	2.9	2.6
DMC 11-07	3.6	4.8	2.5	3.5	1.0	2.6	0.6	1.7	2.2	2.9	2.6
DMC 11-15	3.6	3.9	2.0	3.0	1.4	2.8	0.2	2.7	2.5	2.6	2.6
DMC 11-11	3.1	4.7	3.0	3.0	2.0	2.4	0.2	1.9	2.3	2.7	2.5
DMC 11-09	3.6	3.6	2.5	3.0	2.9	3.2	1.0	0.8	2.4	2.5	2.5
DMC 11-12	3.2	3.5	2.0	4.0	1.0	3.0	1.6	1.0	1.9	3.0	2.5
DMC 11-08	3.0	4.6	2.5	3.5	1.6	2.6	0.3	0.8	2.4	2.4	2.4
NCB226*	2.3	4.0	0.6	3.0	2.2	3.1	0.6	3.0	1.9	2.8	2.4

DMC 11-05	3.4	3.5	1.5	2.5	2.2	3.2	0.4	1.7	2.1	2.5	2.3
NCB280*	1.8	3.9	1.0	2.4	2.3	3.1	1.0	2.4	2.0	2.4	2.2
DMC 11-04	2.9	3.4	1.0	3.5	2.1	3.0	0.1	1.3	2.0	2.3	2.2
DMC 11-03	2.5	3.4	2.0	2.5	0.6	2.1	1.0	1.2	1.8	2.3	2.1
DMC 11-20	2.5	3.4	2.0	3.5	2.1	3.4	0.2	0.7	1.7	2.2	2.0
DMC 11-01	2.3	4.1	1.5	3.0	2.1	3.2	0.5	0.6	1.6	2.2	1.9
DMC 11-06	2.5	2.6	1.5	3.0	1.0	3.7	0.1	0.8	1.8	2.0	1.9
DMC 11-16	3.2	4.0	1.5	1.5	2.0	3.2	0.1	0.2	1.7	2.0	1.9
KATB1*	2.0	2.6	1.5	2.0	1.8	1.8	0.2	0.5	1.4	1.7	1.6
DMC 11-19	2.3	3.1	1.5	1.5	1.7	2.5	0.1	0.4	1.4	1.6	1.5
DMC 11-14	2.5	3.0	1.0	2.0	1.0	1.5	0.1	0.1	1.2	1.7	1.5
Mean of genotypes	**3.4**	**3.6**	**2.9**	**3.3**	**2.2**	**2.4**	**2.4**	**2.7**	**2.8**	**3.5**	3.2
Mean of checks	**3.3**	**3.5**	**2.7**	**3.2**	**2.1**	**2.3**	**2.2**	**2.1**	**2.6**	**3.3**	3.0
Overall mean	**3.4**	**3.6**	**2.8**	**3.3**	**2.2**	**2.4**	**2.3**	**2.4**	**2.7**	**3.4**	**3.1**
%CV			**30.7**								

LSD(P≤0.05)S	0.75*	LSD(P≤0.05)SXT	0.33*	LSD(P≤0.05)SXLXT	0.27NS
LSD(P≤0.05)L	0.29*	LSD(P≤0.05)LXT	0.24NS	LSD(P≤0.05)SXLXG	1.08*
LSD(P≤0.05)T	0.10*	LSD(P≤0.05)SXG	0.76*	LSD(P≤0.05)SXTXG	1.08NS
LSD(P≤0.05)G	0.54**	LSD(P≤0.05)LXG	0.77**	LSD(P≤0.05)LXTXG	1.08NS
LSD(P≤0.05)SXL	0.29NS	LSD(P≤0.05)TXG	0.76NS	LSD(P≤0.05)SXLXTXG	1.52NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.15: Number of seeds per pod of genotypes in the navy beans market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	Number of seeds per pod										
	Season 1				Season 2						
Line/market class	**Kabete**		**Mwea**		**Kabete**		**Mwea**				
Navys	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-14	3.8	5.6	2.0	3.0	2.1	4.7	1.3	2.6	2.6	3.7	3.2
DNB 11-15	4.5	5.4	3.0	3.5	3.1	4.4	0.4	1.2	2.7	3.6	3.2
DNB 11-07	4.8	5.7	2.0	3.5	3.8	4.4	1.2	2.1	3.0	3.2	3.1
DNB 11-05	4.2	4.5	2.5	3.0	3.5	4.6	0.0	0.5	2.8	2.9	2.9
DNB 11-03	3.0	5.7	2.0	4.5	2.6	3.6	0.5	0.5	2.0	3.6	2.8
DNB 11-10	3.7	4.0	2.0	3.0	3.6	4.3	0.4	1.2	2.7	2.9	2.8
DNB 11-04	3.6	4.3	2.5	2.5	3.7	4.2	0.3	0.8	2.5	3.0	2.8
DNB 11-08	4.5	7.6	1.5	2.0	3.1	3.1	0.2	0.2	2.3	3.2	2.8
DNB 11-06	3.5	4.8	2.5	3.0	3.0	3.9	0.4	0.5	2.4	3.0	2.7
DNB 11-12	3.7	4.8	2.0	3.0	3.0	3.6	0.6	1.5	2.6	2.7	2.7
DNB 11-09	4.3	4.4	3.0	3.0	1.5	3.5	0.5	0.4	2.3	2.8	2.6
DNB 11-16	3.5	4.3	2.0	3.0	2.4	4.2	1.0	2.3	2.7	2.4	2.6
MEX142*	3.5	4.4	2.0	3.5	2.4	3.2	0.1	1.3	2.3	2.8	2.6
DNB 11-17	4.7	5.5	2.5	3.0	1.4	1.8	0.1	0.7	2.4	2.5	2.5
DNB 11-13	2.8	3.1	2.0	3.5	2.4	3.2	0.7	1.6	2.2	2.3	2.3
DNB 11-19	2.2	3.1	2.0	3.5	2.3	2.8	0.7	1.6	2.0	2.5	2.3
DNB 11-18	2.5	3.6	1.5	2.0	2.1	3.8	0.3	1.5	1.8	2.0	1.9
Mean of genotypes	**4.1**	**4.3**	**2.6**	**3.6**	**2.8**	**3.4**	**0.5**	**1.0**	**2.5**	**2.8**	2.7
Mean of checks	**3.5**	**4.4**	**3.0**	**3.5**	**2.4**	**3.2**	**0.1**	**1.3**	**2.3**	**2.8**	2.6
Overall mean	**3.8**	**4.4**	**2.8**	**3.6**	**2.6**	**3.3**	**0.3**	**1.2**	**2.4**	**2.8**	**2.6**

%CV	**30.7**				
LSD(P≤0.05)S	0.75*	LSD(P≤0.05)SXT	0.33*	LSD(P≤0.05)SXLXT	0.27NS
LSD(P≤0.05)L	0.29*	LSD(P≤0.05)LXT	0.24NS	LSD(P≤0.05)SXLXG	1.08*
LSD(P≤0.05)T	0.10*	LSD(P≤0.05)SXG	0.76*	LSD(P≤0.05)SXTXG	1.08NS
LSD(P≤0.05)G	0.54**	LSD(P≤0.05)LXG	0.77**	LSD(P≤0.05)LXTXG	1.08NS
LSD(P≤0.05)SXL	0.29NS	LSD(P≤0.05)TXG	0.76NS	LSD(P≤0.05)SXLXTXG	1.52NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.16: Number of seeds per pod of genotypes in the small reds market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

Line/market class	Number of seeds per pod										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
RCB592*	3.4	3.6	2.2	2.2	2.3	3.5	2.4	2.4	4.6	4.9	4.8
SER155*	3.7	4.4	4.7	4.7	3.1	4.1	4.7	4.7	3.8	4.7	4.3
RCB231*	1.6	3.3	2.3	2.3	2.8	3.0	4.5	4.5	3.8	4.3	4.1
SER76*	3.8	4.4	3.7	4.6	2.3	2.8	3.7	4.6	3.3	4.6	4.0
RCB270*	3.3	3.8	1.2	1.2	2.6	3.3	5.6	5.6	3.3	3.3	3.3
DSR 11-01	3.7	4.3	2.0	4.0	2.2	2.7	0.5	3.0	2.8	3.7	3.3
DSR 11-02	2.7	3.8	2.5	3.5	2.4	3.0	1.1	1.7	2.7	3.5	3.1
DSR 11-04	3.5	4.4	3.0	3.0	2.8	2.8	1.1	1.0	2.6	3.5	3.1
DSR 11-23	3.4	4.0	2.5	3.0	2.9	3.2	1.5	2.6	2.6	3.4	3.0
DSR 11-24	3.1	4.6	2.5	3.0	2.3	3.4	1.0	2.8	2.5	3.2	2.9
SEA15*	2.7	4.2	2.0	3.5	2.4	3.4	2.3	3.0	2.6	3.0	2.8
TIO CANELA*	1.7	3.8	1.5	2.5	2.8	2.8	1.7	1.7	2.6	2.9	2.8
DSR 11-16	3.0	4.1	2.5	3.0	1.9	4.1	0.3	3.8	1.9	3.5	2.7
DSR 11-15	2.6	3.4	2.5	3.0	2.0	2.7	1.5	2.3	2.2	3.1	2.7
DSR 11-06	3.5	4.2	2.0	2.0	2.6	3.3	2.0	1.2	2.4	2.9	2.7
DSR 11-22	3.3	5.3	1.0	3.5	2.6	2.7	1.0	1.8	2.5	2.8	2.7
SER95*	1.8	3.1	0.3	4.9	2.5	3.4	0.3	4.9	2.0	3.3	2.7
DSR 11-13	3.7	3.8	2.5	3.0	3.2	3.2	0.3	1.4	2.4	2.8	2.6
DSR 11-07	3.9	4.7	1.0	3.0	2.7	3.5	0.8	0.9	2.1	3.0	2.6
DSR 11-08	2.7	3.4	2.5	2.5	2.0	2.6	1.3	2.2	2.4	2.7	2.6
DSR 11-12	3.6	4.0	2.5	3.0	2.1	2.4	0.7	2.3	2.2	2.9	2.6

DSR 11-18	3.0	3.4	2.5	2.5	2.2	2.8	0.6	2.9	2.1	2.9	2.5
DSR 11-20	2.3	3.9	2.0	2.5	2.8	2.3	0.4	0.8	2.1	2.9	2.5
GLP585*	2.6	3.9	2.0	3.0	2.8	3.2	0.7	1.5	2.3	2.7	2.5
DSR 11-03	3.9	4.8	2.0	3.0	2.4	2.9	0.3	1.0	2.2	2.7	2.5
DSR 11-05	1.2	4.9	2.0	3.5	2.6	2.7	1.0	1.7	2.2	2.7	2.5
SER16*	2.9	3.4	2.0	2.0	3.2	4.0	0.6	1.8	2.4	2.5	2.5
DSR 11-21	3.7	4.5	1.0	3.0	2.5	3.1	1.2	1.3	2.1	2.7	2.4
DSR 11-14	2.8	3.7	2.5	3.0	2.8	3.1	2.0	3.6	1.8	2.9	2.4
DSR 11-09	2.4	3.4	2.0	3.0	2.6	3.2	0.8	0.8	2.2	2.4	2.3
RAB651*	1.1	4.2	1.0	4.8	0.9	2.8	1.0	4.8	1.7	2.9	2.3
DSR 11-19	3.0	4.5	2.0	2.0	2.3	2.7	0.0	0.9	2.1	2.3	2.2
DSR 11-10	3.3	4.2	2.0	3.0	1.9	2.6	0.3	0.9	1.9	2.4	2.2
DSR 11-11	1.7	3.1	2.5	2.5	2.3	2.4	0.4	1.2	1.7	2.3	2.0
KATB9*	1.0	2.8	1.5	1.5	1.9	2.7	0.3	1.2	1.4	2.6	2.0
Mean of genotypes	**2.5**	**3.4**	**2.4**	**3.5**	**2.5**	**2.8**	**3.8**	**4.5**	**3.3**	**4.5**	**3.9**
Mean of checks	**2.3**	**3.0**	**2.4**	**2.9**	**2.7**	**2.7**	**3.5**	**4.3**	**3.2**	**4.0**	**3.6**
Overall mean	**2.4**	**3.2**	**2.4**	**3.2**	**2.6**	**2.8**	**3.7**	**4.4**	**3.3**	**4.3**	**3.8**
%CV			**30.7**								

LSD(P≤0.05)S	0.75*	LSD(P≤0.05)SXT	0.33*	LSD(P≤0.05)SXLXT	0.27NS
LSD(P≤0.05)L	0.29*	LSD(P≤0.05)LXT	0.24NS	LSD(P≤0.05)SXLXG	1.08*
LSD(P≤0.05)T	0.10*	LSD(P≤0.05)SXG	0.76*	LSD(P≤0.05)SXTXG	1.08NS
LSD(P≤0.05)G	0.54**	LSD(P≤0.05)LXG	0.77**	LSD(P≤0.05)LXTXG	1.08NS
LSD(P≤0.05)SXL	0.29NS	LSD(P≤0.05)TXG	0.76NS	LSD(P≤0.05)SXLXTXG	1.52NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

4.5.7. Effect of drought on 100-seed weight

Drought stress significantly ($p<0.001$) reduced 100-seed weight of all the test lines in the three market classes and their respective checks (Table 4.17, 4.18, 4.19). However, seed weight reduction due to drought varied with genotypes. On average, drought stress reduced seed mass of most genotypes in all the market classes by over 15%. Under drought stress, the mean weight of 100 seeds of genotypes in the three market classes ranged between 14.0 g and 18.0 g and up to 38 g under no stress. Within the mixed colours, KATB1 (check) had the highest average seed mass (34.1 g) followed by DMC11-20, DMC11-14, GLPX92 (check), DMC11-09 and DMC11-10 which had seed masses above 20.0 g. The lowest seed mass was obtained from SXB404 (10.7 g) (Table 4.17). In this market class, test genotypes were comparable to most checks in 100-seed mass. Navy beans such as DNB11-13, DNB11-19 and DNB11-08, DNB11-14 and DNB11-16 had higher seed weights of over 15 g compared to the other genotypes in the same market class and the check MEX142. Other genotypes in this market class like DNB11-12 and DNB11-17 had low seed masses which were less than 14 g (Table 4.18). Among the small reds, KATB9 (check), SEA15 (check), DSR11-16, GLP585 (check) and DSR11-06 had the highest 100-seed weight which ranged between 20.7 g and 32.8 g. The other genotypes in this market class had seed weights above 15 g except genotypes like DSR11-21, DSR11-13 and RAB651 (Table 4.19). Of the three market classes, navy beans recorded the lowest mean 100-seed weight while mixed colours had the highest mean 100-seed weight.

Table 4.17: One hundred seed weight of genotypes in the mixed colours market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	100 seed weight(g)										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Mixed colours	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
KATB1*	42.8	46.2	41.6	48.9	25.9	32.5	6.5	28.2	31.0	37.2	34.1
DMC 11-20	43.9	49.5	34.4	39.4	18.0	26.5	6.7	19.1	27.0	32.4	29.7
DMC 11-14	41.0	46.1	23.0	36.3	27.1	32.2	2.0	7.7	24.5	29.3	26.9
GLPX92*	31.5	33.0	27.8	29.9	22.9	25.4	11.3	23.3	24.9	26.4	25.7
SEN56*	20.7	25.9	25.1	36.5	15.4	17.5	25.1	36.5	21.6	29.1	25.4
DMC 11-19	33.5	40.7	22.2	36.4	22.0	24.7	7.4	11.4	23.3	26.3	24.8
DMC 11-06	27.3	33.1	33.4	33.8	13.7	22.5	13.1	17.8	23.4	25.1	24.3
DMC 11-09	28.4	30.8	23.8	28.6	17.3	23.1	3.8	11.7	18.3	23.6	21.0
DMC 11-10	24.6	28.5	24.2	24.8	17.9	19.7	8.8	14.8	18.9	21.9	20.4
DMC 11-21	26.8	27.4	20.5	24.2	16.7	22.2	5.8	13.2	18.4	20.8	19.6
DMC 11-02	25.8	28.1	22.6	28.2	15.4	20.1	2.3	12.5	19.3	19.5	19.4
DMC 11-16	24.7	28.3	26.6	34.7	12.7	19.0	2.0	3.8	18.5	19.0	18.8
SEN53*	20.4	25.0	18.5	22.8	20.7	23.5	3.4	16.0	17.5	20.0	18.8
DMC 11-22	25.7	27.6	21.2	24.1	16.8	21.5	1.2	10.6	17.0	20.2	18.6
DMC 11-24	23.8	26.6	19.2	24.3	14.5	20.1	4.6	15.6	16.8	20.4	18.6
DMC 11-11	24.0	28.0	17.4	23.7	15.5	21.6	3.9	10.1	16.7	19.3	18.0
DMC 11-05	24.0	26.1	21.5	23.7	14.2	16.9	2.8	8.7	16.1	18.3	17.2
DMC 11-17	21.1	22.3	13.6	24.4	16.1	23.3	6.2	9.7	17.0	17.2	17.1
NCB280*	15.8	27.7	10.1	18.7	16.1	17.9	10.1	18.7	16.3	17.5	16.9
DMC 11-12	23.7	25.0	20.0	30.4	7.7	13.8	4.7	7.8	18.0	15.3	16.7

DMC 11-13	20.5	27.6	18.3	27.9	13.1	16.4	1.8	6.2	15.7	17.3	16.5
DMC 11-03	21.0	25.2	20.6	24.0	9.1	18.9	4.1	8.6	13.7	19.2	16.5
DMC 11-07	20.6	23.4	17.0	20.8	7.0	14.7	3.0	20.9	12.6	19.2	15.9
DMC 11-23	23.2	23.8	21.0	22.7	11.2	12.8	1.2	7.5	14.1	16.7	15.4
NCB226*	14.2	30.7	6.2	15.5	14.4	19.0	6.2	15.5	14.2	16.2	15.2
DMC 11-04	21.1	22.9	15.1	18.7	14.3	15.3	2.9	9.0	13.4	16.4	14.9
DMC 11-15	19.9	19.9	15.1	16.2	15.0	15.4	6.4	10.1	14.4	15.2	14.8
DMC 11-01	25.6	27.2	9.5	21.1	8.3	9.7	2.2	8.0	11.7	16.3	14.0
DMC 11-18	18.5	20.7	13.3	16.9	11.8	13.2	1.7	8.6	12.1	13.3	12.7
DMC 11-08	19.4	20.6	15.8	16.5	7.0	13.7	0.8	5.5	11.0	13.8	12.4
SXB404*	22.5	24.2	5.7	13.1	0.0	0.8	5.7	13.1	8.5	12.8	10.7
Mean of genotypes	**20.6**	**27.9**	**18.8**	**25.4**	**19.4**	**17.9**	**14.3**	**19.5**	**19.3**	**22.7**	**21.0**
Mean of checks	**18.0**	**26.4**	**16.1**	**21.6**	**15.1**	**17.9**	**11.5**	**10.9**	**17.4**	**19.5**	**18.5**
Overall mean	**19.3**	**27.2**	**17.5**	**23.5**	**17.3**	**17.9**	**12.9**	**15.2**	**18.4**	**21.1**	**19.7**
%CV	**33.7**										

LSD(P≤0.05)S	1.93*	LSD(P≤0.05)SXT	1.08NS	LSD(P≤0.05)SXLXT	2.08NS
LSD(P≤0.05)L	2.56*	LSD(P≤0.05)LXT	2.03NS	LSD(P≤0.05)SXLXG	8.23*
LSD(P≤0.05)T	1.08*	LSD(P≤0.05)SXG	5.76**	LSD(P≤0.05)SXTXG	8.18NS
LSD(P≤0.05)G	4.09**	LSD(P≤0.05)LXG	5.88**	LSD(P≤0.05)LXTXG	8.26NS
LSD(P≤0.05)SXL	2.38NS	LSD(P≤0.05)TXG	5.80NS	LSD(P≤0.05)SXLXTXG	11.62N

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.18: One hundred seed weight of genotypes in the Navy beans market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	100 seed weight(g)										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Navys	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-13	22.3	25.7	23.2	24.3	11.2	15.8	10.1	12.4	16.9	19.3	18.1
DNB 11-04	25.0	28.2	15.1	21.1	16.4	19.8	3.5	6.5	15.0	18.9	17.0
DNB 11-19	21.9	22.9	21.6	22.5	11.1	14.6	6.6	12.1	15.6	18.0	16.8
DNB 11-06	23.4	24.9	19.0	23.0	13.6	13.6	7.5	8.8	16.1	17.3	16.7
DNB 11-08	23.2	25.6	16.5	24.1	9.7	19.4	7.8	10.2	15.5	17.3	16.4
DNB 11-15	22.3	24.8	16.3	21.1	12.8	16.8	2.4	10.7	14.7	17.1	15.9
DNB 11-18	21.4	25.0	11.5	22.0	16.3	16.3	5.3	8.0	13.6	17.8	15.7
DNB 11-09	24.2	27.2	18.8	19.7	6.0	18.5	4.1	6.4	13.3	17.9	15.6
DNB 11-14	20.4	22.5	17.2	20.1	9.8	15.4	6.9	8.9	14.3	16.0	15.2
DNB 11-16	20.1	22.1	17.8	20.2	13.2	17.4	5.8	9.5	15.2	14.8	15.0
DNB 11-07	20.2	22.1	18.7	19.5	12.2	15.8	7.3	8.3	14.8	14.9	14.9
MEX142*	20.3	22.7	14.2	21.9	9.6	17.7	1.2	9.0	13.1	16.1	14.6
DNB 11-05	21.4	22.2	16.7	18.6	14.5	16.9	0.0	6.7	13.6	15.6	14.6
DNB 11-03	18.9	25.5	18.4	20.7	10.4	14.7	4.9	6.6	13.6	15.4	14.5
DNB 11-10	18.2	19.4	15.5	19.3	14.8	15.3	4.3	6.5	13.2	14.9	14.1
DNB 11-12	19.3	20.4	15.6	21.0	10.3	15.4	3.9	4.6	13.8	13.9	13.9
DNB 11-17	17.8	22.3	14.5	17.3	5.1	13.7	6.0	11.0	12.1	14.8	13.5
Mean of genotypes	**21.4**	**23.6**	**19.2**	**22.4**	**11.9**	**17.7**	**5.9**	**9.8**	**14.5**	**17.4**	**16.0**
Mean of checks	**20.3**	**22.7**	**14.8**	**18.9**	**9.6**	**15.9**	**1.2**	**6.0**	**12.1**	**15.1**	**13.6**
Overall mean	**20.9**	**23.2**	**17.0**	**20.7**	**10.8**	**16.8**	**3.6**	**7.9**	**13.3**	**16.3**	**14.8**

%CV	**33.7**				
LSD(P≤0.05)S	1.93*	LSD(P≤0.05)SXT	1.08NS	LSD(P≤0.05)SXLXT	2.08NS
LSD(P≤0.05)L	2.56*	LSD(P≤0.05)LXT	2.03NS	LSD(P≤0.05)SXLXG	8.23*
LSD(P≤0.05)T	1.08*	LSD(P≤0.05)SXG	5.76**	LSD(P≤0.05)SXTXG	8.18NS
LSD(P≤0.05)G	4.09**	LSD(P≤0.05)LXG	5.88**	LSD(P≤0.05)LXTXG	8.26NS
LSD(P≤0.05)SXL	2.38NS	LSD(P≤0.05)TXG	5.80NS	LSD(P≤0.05)SXLXTXG	11.62NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.19: One hundred seed weight of genotypes in the small reds market class grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea

	100 seed weight(g)										
	Season 1				Season 2						
Line/market class	Kabete		Mwea		Kabete		Mwea				
Small reds	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
KATB9*	40.9	45.9	40.1	44.4	25.0	30.4	8.7	27.0	32.2	33.4	32.8
SEA15*	24.7	26.9	27.0	28.0	23.2	26.2	11.1	20.8	21.7	25.2	23.5
DSR 11-16	23.4	24.0	11.6	16.7	12.3	16.8	7.5	13.5	16.7	26.8	21.8
GLP585*	25.6	28.9	25.2	26.1	21.9	26.7	5.3	6.1	19.8	21.9	20.9
RCB592*	30.0	32.5	9.9	10.9	21.8	28.3	16.6	17.6	20.3	21.1	20.7
DSR 11-06	22.7	27.5	23.9	25.5	21.0	26.2	7.0	11.9	20.4	21.0	20.7
DSR 11-02	26.2	27.5	20.3	21.5	15.2	19.5	7.0	9.9	18.4	19.3	18.9
DSR 11-03	23.7	28.0	21.1	22.3	18.7	20.7	2.5	10.7	16.7	20.2	18.5
RCB270*	24.2	25.2	14.8	15.8	17.8	18.7	15.4	16.4	18.0	18.5	18.3
DSR 11-11	12.7	25.3	27.5	29.0	14.0	22.7	4.2	8.3	17.1	18.8	18.0
SER16*	24.7	25.6	15.8	17.2	14.0	22.1	8.1	15.6	17.7	18.1	17.9
SER155*	24.7	26.7	9.2	19.3	16.2	17.7	9.2	19.3	15.1	20.5	17.8
DSR 11-19	25.1	27.1	19.1	19.4	17.8	18.6	0.0	13.7	15.5	19.7	17.6
DSR 11-15	13.2	25.7	19.5	19.9	15.4	20.8	5.7	11.0	16.5	18.2	17.4
DSR 11-22	25.4	27.1	17.9	19.1	17.4	18.2	4.6	9.7	16.8	17.8	17.3
DSR 11-14	24.4	26.0	17.9	22.7	14.1	16.3	10.6	15.6	15.5	18.9	17.2
DSR 11-12	24.2	25.3	18.2	21.5	16.3	18.7	2.3	9.4	15.3	18.7	17.0
DSR 11-23	23.9	24.9	17.7	19.2	17.5	19.1	8.4	13.1	17.3	16.1	16.7
DSR 11-20	22.8	23.6	16.7	17.8	16.0	19.6	6.5	7.1	15.8	16.8	16.3
DSR 11-08	25.1	25.5	17.4	21.1	11.6	13.4	4.7	9.8	16.2	16.0	16.1
DSR 11-09	22.2	24.6	17.8	23.3	13.8	16.7	4.2	6.0	15.2	16.9	16.1

DSR 11-01	21.3	21.9	19.6	21.0	13.0	13.5	5.3	11.2	14.8	16.9	15.9
DSR 11-10	22.3	23.9	15.2	23.0	15.2	20.9	3.4	12.1	15.5	16.0	15.8
TIO CANELA*	11.6	20.2	15.3	29.7	13.7	13.2	10.7	11.2	15.1	16.3	15.7
DSR 11-18	22.3	23.9	17.9	18.6	15.7	16.1	2.5	8.1	14.9	16.2	15.6
DSR 11-07	23.9	24.7	9.1	19.1	14.4	16.6	8.2	10.8	13.9	17.1	15.5
SER95*	13.0	27.9	11.2	13.3	16.6	17.2	11.2	13.3	14.8	16.2	15.5
DSR 11-05	22.0	23.7	18.5	19.5	12.8	15.8	5.2	6.3	14.6	16.3	15.5
DSR 11-04	21.2	22.1	15.9	16.2	10.2	17.1	5.6	12.4	13.2	17.0	15.1
SER76*	25.5	26.7	7.1	9.1	12.2	19.6	7.1	9.1	14.7	15.4	15.1
DSR 11-21	20.7	21.2	12.3	19.1	12.4	15.2	6.1	11.9	12.9	16.8	14.9
RCB231*	14.1	27.5	9.3	10.3	14.0	16.2	12.4	13.4	12.4	16.4	14.4
DSR 11-13	18.4	18.8	17.0	18.6	13.0	15.2	5.6	7.9	13.7	14.8	14.3
DSR 11-24	22.5	22.7	12.1	20.4	14.5	16.3	0.5	4.8	12.4	13.6	13.0
RAB651*	15.4	22.9	8.0	10.8	9.4	15.8	8.0	10.8	11.4	13.8	12.6
Mean of genotypes	**24.7**	**26.5**	**18.4**	**19.7**	**18.5**	**20.0**	**10.1**	**14.8**	**18.2**	**20.0**	**19.1**
Mean of checks	**22.0**	**21.9**	**16.6**	**18.9**	**17.5**	**16.7**	**5.3**	**8.8**	**16.3**	**17.1**	**16.7**
Overall mean	**23.4**	**24.2**	**17.5**	**19.3**	**18.0**	**18.4**	**7.7**	**11.8**	**17.3**	**18.6**	**17.9**
%CV	**33.7**										
LSD(P≤0.05)S	1.93*		LSD(P≤0.05)SXT			1.08NS		LSD(P≤0.05)SXLXT			2.08NS
LSD(P≤0.05)L	2.56*		LSD(P≤0.05)LXT			2.03NS		LSD(P≤0.05)SXLXG			8.23*
LSD(P≤0.05)T	1.08*		LSD(P≤0.05)SXG			5.76**		LSD(P≤0.05)SXTXG			8.18NS
LSD(P≤0.05)G	4.09**		LSD(P≤0.05)LXG			5.88**		LSD(P≤0.05)LXTXG			8.26NS
LSD(P≤0.05)SXL	2.38NS		LSD(P≤0.05)TXG			5.80NS		LSD(P≤0.05)SXLXTXG			11.62NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

4.5.8. Effect of drought on harvest index (HI)

Drought stress significantly reduced the harvest index (HI) of most genotypes by about 15.4%. Harvest indices of genotypes under drought stress ranged between 35.0% and 55.0% while under no stress, up to 65.0% harvest indices were attained by some genotypes. The interaction between seasons, genotypes, and treatment significantly ($p \leq 0.001$) affected the dry bean harvest indices (Table 4.20, 4.21, 4.22). Of the three market classes, navy beans recorded the highest harvest indices while mixed colours had the lowest in all seasons and locations. Within the mixed colours, genotypes such as DMC11-04, DMC11-02, DMC11-10 and DMC11-05, NCB226 (check), DMC11-13 and DMC11-03 had higher harvest indices which were above 50.0% in the two seasons and locations. Most checks in this market class such as SXB404, KATB1, GLPX92 and SEN56 were comparable to most genotypes in their harvest indices which ranged between 41.0% and 49.0% (Table 4.20). Most navy beans recorded harvest indices above 50% and included DNB11-07, DNB11-03, DNB11-04, DNB11-05 and DNB11-15. Other genotypes in this market class had harvest indices of up to 40% and were comparable to the check MEX142 (Table 4.21). Among the small reds, most genotypes recorded more than 50% harvest indices and included DSR11-24, DSR11-04, DSR11-15, GLP585 (check), DSR11-22, DSR11-09 and DSR11-07. Most genotypes in this market class recorded high harvest indices compared to checks (Table 4.22). In correlation with grain yield, genotypes such as DNB11-07, DNB11-15 and DNB11-06 with high harvest indices had high yield under drought stress (Figure 4.2). Other genotypes including DMC11-24 and DSR11-12 with harvest indices below the mean also had high yield under drought stress. However, low yielding genotypes under drought stress such as KATB1, SEN56 and DMC11-15 recorded low harvest indices compared to the other genotypes (Figure 4.2).

Table 4.20: Harvest indices of mixed colours grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete

	Harvest Index (%)						
	Season 1		Season 2				
Line/market class							
Mixed colours	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-04	53.0	55.8	48.0	57.3	50.5	56.6	53.5
DMC 11-02	56.0	64.0	43.5	49.5	49.8	56.8	53.3
DMC 11-10	53.0	56.5	49.5	52.5	51.3	54.5	52.9
DMC 11-05	49.0	56.0	47.0	54.5	48.0	55.3	51.6
NCB226*	50.5	54.0	48.0	49.0	49.3	51.5	50.4
DMC 11-13	49.0	58.5	42.5	51.0	45.8	54.8	50.3
DMC 11-03	54.5	57.5	40.5	47.5	47.5	52.5	50.0
DMC 11-07	48.7	53.5	44.0	53.5	46.4	53.5	49.9
DMC 11-17	51.8	57.5	46.8	42.0	49.3	49.8	49.5
DMC 11-06	47.8	51.2	49.0	49.0	48.4	50.1	49.3
DMC 11-16	47.3	57.5	44.5	47.5	45.9	52.5	49.2
DMC 11-19	50.6	59.2	42.0	44.0	46.3	51.6	49.0
DMC 11-08	53.0	55.5	40.5	46.5	46.8	51.0	48.9
DMC 11-14	51.5	55.0	44.0	44.5	47.8	49.8	48.8
DMC 11-09	44.3	55.1	41.5	53.6	42.9	54.4	48.6
DMC 11-22	48.5	57.0	45.6	42.3	47.1	49.7	48.4
DMC 11-12	51.5	55.0	41.5	44.5	46.5	49.8	48.1
SEN53*	47.5	53.0	43.0	48.5	45.3	50.8	48.0
DMC 11-18	48.3	50.0	47.0	46.0	47.7	48.0	47.8
DMC 11-24	48.0	50.5	42.7	50.0	45.4	50.3	47.8
DMC 11-20	49.9	54.5	41.5	44.5	45.7	49.5	47.6
SXB404*	51.0	53.9	40.0	44.0	45.5	49.0	47.2
DMC 11-21	46.0	55.0	39.9	47.7	43.0	51.4	47.2
GLPX92*	42.9	55.5	42.0	47.2	42.5	51.4	46.9
DMC 11-23	47.5	52.5	43.0	44.5	45.3	48.5	46.9
NCB280*	47.5	50.5	44.5	44.0	46.0	47.3	46.6
DMC 11-11	46.0	52.0	39.0	46.2	42.5	49.1	45.8
KATB1*	47.0	51.0	39.0	46.0	43.0	48.5	45.8
DMC 11-15	40.0	44.5	42.5	48.0	41.3	46.3	43.8
SEN56*	41.7	45.8	42.9	42.0	42.3	43.9	43.1
DMC 11-01	44.5	47.0	34.5	40.5	39.5	43.8	41.6
Mean of genotypes	**49.2**	**54.6**	**43.4**	**47.8**	**46.3**	**51.2**	**48.8**
Mean of checks	**46.9**	**52.0**	**42.8**	**45.8**	**44.9**	**48.9**	**46.9**
Overall mean	**48.1**	**53.3**	**43.1**	**46.8**	**45.6**	**50.1**	**47.8**
CV(%)		7.2					
LSD(P≤0.05)S	13.1NS	LSD(P≤0.05)SXG		5.4**			
LSD(P≤0.05)T	1.2*	LSD(P≤0.05)TXG		4.9NS			
LSD(P≤0.05)G	3.5**	LSD(P≤0.05)SXTXG		7.3NS			
LSD(P≤0.05)SXT	10.1NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.21: Harvest indices of navy beans grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete

	Harvest Index (%)						
	Season 1		**Season 2**				
Market class							
Navys	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-07	50.3	58.0	56.0	52.0	53.2	55.0	54.1
DNB 11-15	52.5	56.0	51.5	54.1	52.0	55.1	53.5
DNB 11-04	54.0	58.5	46.0	53.6	50.0	56.1	53.0
DNB 11-09	52.0	57.0	50.0	53.0	51.0	55.0	53.0
DNB 11-13	58.6	62.0	43.0	45.5	50.8	53.8	52.3
DNB 11-10	49.0	54.0	51.5	54.0	50.3	54.0	52.1
DNB 11-05	53.0	56.0	48.0	50.8	50.5	53.4	52.0
DNB 11-03	52.0	58.0	47.5	47.2	49.8	52.6	51.2
DNB 11-14	53.4	54.5	41.1	54.0	47.3	54.3	50.8
DNB 11-01	49.5	54.0	47.0	52.0	48.3	53.0	50.6
DNB 11-16	53.5	56.0	44.5	48.0	49.0	52.0	50.5
DNB 11-06	52.8	54.8	46.3	47.5	49.6	51.2	50.4
DNB 11-17	51.0	53.5	46.5	50.0	48.8	51.8	50.3
DNB 11-12	47.5	51.5	44.5	46.0	46.0	48.8	47.4
DNB 11-08	43.5	51.2	39.0	44.1	41.3	47.7	44.5
DNB 11-19	45.8	51.5	40.0	40.5	42.9	46.0	44.5
MEX142*	49.0	44.0	37.5	47.0	43.3	45.5	44.4
DNB 11-18	35.5	41.7	39.5	45.0	37.5	43.4	40.4
Mean of genotypes	**50.2**	**54.6**	**46.0**	**49.3**	**48.1**	**52.0**	**50.0**
Mean of checks	**49.0**	**44.0**	**37.5**	**47.0**	**43.3**	**45.5**	**44.4**
Overall mean	**49.6**	**49.3**	**41.8**	**48.2**	**45.7**	**48.7**	**47.2**
CV(%)		7.2					
LSD(P≤0.05)S	13.1NS	LSD(P≤0.05)SXG		5.4**			
LSD(P≤0.05)T	1.2*	LSD(P≤0.05)TXG		4.9NS			
LSD(P≤0.05)G	3.5**	LSD(P≤0.05)SXTXG		7.3NS			
LSD(P≤0.05)SXT	10.1NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 4.22: Harvest indices of small reds grown under drought stress (DS) and non drought stress (NS) conditions over two seasons in Kabete

	Harvest Index (%)						
	Season 1		Season 2				
Line/market class Small reds	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-24	61.5	63.0	45.5	53.5	53.5	58.3	55.9
DSR 11-04	59.0	64.0	43.5	56.5	51.3	60.3	55.8
DSR 11-15	51.5	57.4	50.0	55.6	50.8	56.5	53.6
GLP585*	55.0	58.0	47.0	53.0	51.0	55.5	53.3
DSR 11-13	54.9	59.5	43.0	54.0	49.0	56.8	52.9
DSR 11-23	54.5	60.5	45.0	50.5	49.8	55.5	52.6
DSR 11-20	52.5	56.6	50.0	49.5	51.3	53.1	52.2
DSR 11-01	52.0	57.0	44.5	54.0	48.3	55.5	51.9
DSR 11-16	55.0	57.0	47.5	48.0	51.3	52.5	51.9
DSR 11-14	50.7	58.6	44.5	53.0	47.6	55.8	51.7
DSR 11-12	54.0	56.0	43.0	52.0	48.5	54.0	51.3
DSR 11-22	48.5	57.5	48.3	48.7	48.4	53.1	50.8
DSR 11-10	50.4	53.5	44.5	54.5	47.5	54.0	50.7
DSR 11-05	50.0	52.5	44.5	55.2	47.3	53.9	50.6
DSR 11-21	50.0	53.5	45.5	53.0	47.8	53.3	50.5
RAB651*	51.0	53.0	45.5	52.5	48.3	52.8	50.5
RCB592*	50.0	52.5	47.5	52.0	48.8	52.3	50.5
DSR 11-19	53.1	53.0	47.5	47.8	50.3	50.4	50.4
DSR 11-03	48.0	53.0	46.5	53.2	47.3	53.1	50.2
DSR 11-07	52.0	52.2	44.0	52.5	48.0	52.4	50.2
DSR 11-09	50.0	55.5	47.4	47.0	48.7	51.3	50.0
KATB9*	54.5	57.5	46.0	41.5	50.3	49.5	49.9
DSR 11-02	48.5	52.9	43.7	53.6	46.1	53.3	49.7
DSR 11-18	47.6	53.5	48.5	47.0	48.1	50.3	49.2
SEA15*	50.5	51.5	44.0	50.5	47.3	51.0	49.1
DSR 11-11	51.0	53.0	41.0	48.5	46.0	50.8	48.4
SER155*	48.5	50.5	42.0	50.0	45.3	50.3	47.8
SER95*	49.6	49.5	45.5	46.0	47.6	47.8	47.7
RCB270*	41.9	54.5	44.0	48.0	43.0	51.3	47.1
SER76*	46.0	50.5	44.0	47.0	45.0	48.8	46.9
DSR 11-06	48.0	50.5	38.5	47.0	43.3	48.8	46.0
RCB231*	44.5	48.0	41.5	43.0	43.0	45.5	44.3
SER16*	42.5	47.0	43.5	43.1	43.0	45.1	44.0
DSR 11-08	43.5	50.0	37.5	45.0	40.5	47.5	44.0
TIO CANELA*	45.4	48.0	37.0	37.0	41.2	42.5	41.9
Mean of genotypes	**51.6**	**55.7**	**45.0**	**51.3**	**48.3**	**53.5**	**50.9**
Mean of checks	**48.3**	**51.7**	**44.0**	**47.0**	**46.2**	**49.4**	**47.8**
Overall mean	**50.0**	**53.7**	**44.5**	**49.2**	**47.2**	**51.4**	**49.3**
CV(%)		7.2					
LSD(P≤0.05)S	13.1NS	LSD(P≤0.05)SXG		5.4**			
LSD(P≤0.05)T	1.2*	LSD(P≤0.05)TXG		4.9NS			
LSD(P≤0.05)G	3.5**	LSD(P≤0.05)SXTXG		7.3NS			
LSD(P≤0.05)SXT	10.1NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

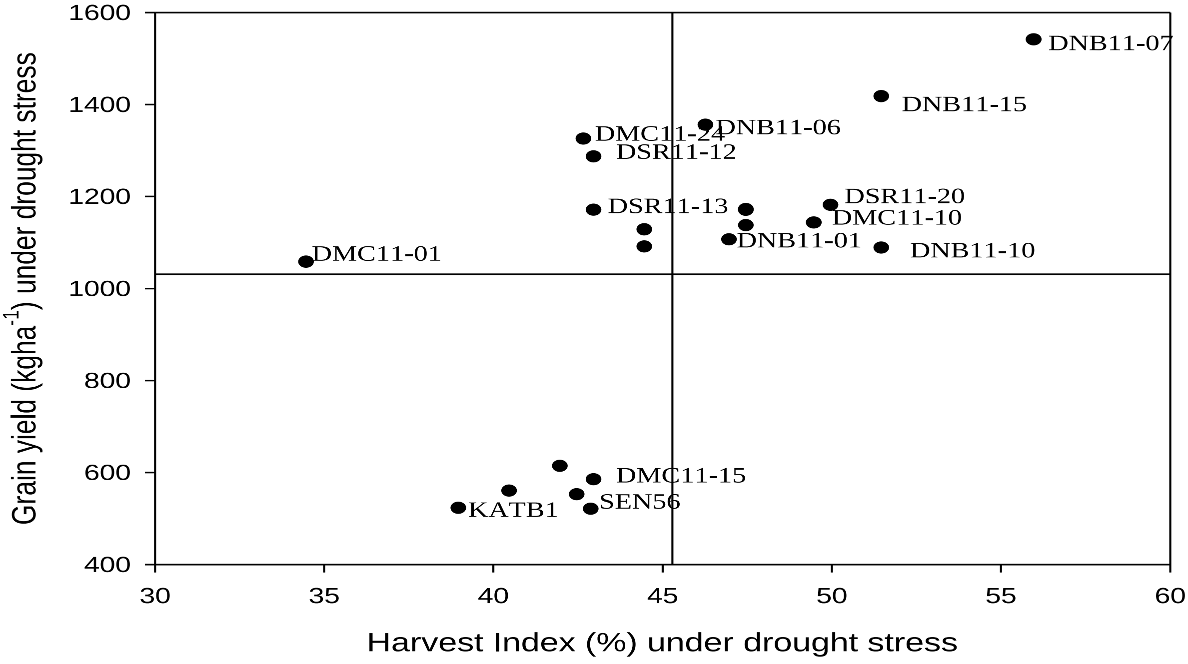


Figure 4.2: Correlation between rainfed grain yield and harvest indices of 21 lines selected at random from the total 85 lines grown at Kabete Field Station over two seasons.

4.6. Discussion

Drought significantly reduced the number of days to flowering and the number of days to physiological maturity of many genotypes including DMC11-10, DMC11-22, DNB11-09, DNB11-13 and DSR11-04. This can be attributed to genetic differences among genotypes (Teran and Singh, 2002). In addition, early flowering could be a mechanism of drought escape by these genotypes and most local checks like KATB1, GLPX92 and KATB9 which also appeared to have accelerated phenological development. Across the three market classes, the reduction in days to physiological maturity under drought stress was as high as 7 days in both seasons and locations in genotypes such as DMC11-01, DMC11-10 (mixed colours), DNB11-14, DNB11-15 (navys) and DSR11-02, DSR11-21(small reds) especially in off season planting at Kabete during the second season. This can be attributed to the plant escape from severe drought effects through accelerated phenological development (Teran and Singh, 2002; Lizana et al., 2006). However, most genotypes within the navy beans market class such as DNB11-14, DNB11-15 and DNB11-19 were late maturing compared to the other two market classes and had more yield even under drought stress. This shows that other mechanisms of adaptation to drought stress are used by these genotypes other than accelerated maturity.

In this study, bean genotypes grown under water stress had a reduced number of pods per plant, seeds per pod and 100-seed weight. Under drought stress, as few as four pods per plant and one seed per pod were obtained. Pods per plant were reduced by over 30% under drought stress for most genotypes in all the market classes. This may have resulted from excessive pod and flower abortion and increased flower failure under drought stress (Lizana et al., 2006). It has been reported that drought stress reduces the mean weight of 100 seeds of most common beans by about 5g (14%). Similar findings were reported by Munoz-Perea, (2006), Singh, (1995) and Teran and Singh, (2002). In this study, drought stress reduced 100 seed weight by 15% (>10g) validating previous findings.

Harvest indices of many dry bean genotypes were reduced under drought stress compared to no stress conditions. However, genotypes like DMC11-02, DMC11-10, DNB11-07, DNB11-15, DSR11-24 and DSR11-04 maintained high harvest indices and were high yielding even under drought stress. Reduction in harvest indices of many genotypes can be attributed to poor seed set as a result of severe drought that increased flower and pod drops leaving only few pods on every plant as well as reducing shoot biomass (George, 2001). Similar results were reported by Teran and Singh, (2002) hence the validity of this research result.

Drought effect on common bean led to a yield loss of about 20% in all the three market classes. Average grain yield obtained from most genotypes grown under well watered conditions was about 900 $kgha^{-1}$ compared to the mean yield of genotypes under drought stress which was about 500 $kgha^{-1}$. This reduction can be attributed to the extent and duration of drought effects on yield components including pods per plant, seeds per pod, 100 seed weight as well as harvest index (Abebe and Brick, 2003; Munoz- Perea et al., 2006). Yield reduction was consistent in the two seasons and locations but was more severe during the second season. Under drought stress, most genotypes in all the three market classes performed better than local checks such as GLPX92, KATB1, GLP585 and KATB9 with a yield advantage of over 20%, but were comparable to international drought lines like NCB226, NCB280, SER16 and SEA15. This shows that the test lines are of international standard.

CHAPTER FIVE

GENOTYPIC VARIATION IN SHOOT BIOMASS ACCUMULATION, ASSIMILATE PARTITIONING AND STOMATAL CONTROL IN MESOAMERICAN DRY BEAN GENOTYPES UNDER DROUGHT STRESS CONDITIONS

5.1. Abstract

Drought is a major limitation to plant growth. It reduces the entire size of plants and their ability to photosynthesize efficiently due to reduced leaf area which results in low shoot biomass production. Under drought stress, mechanisms such as assimilate partitioning and redistribution towards the developing grain and stomatal control are adopted by plants in order to deal with drought effects. It is therefore important to identify the drought tolerance mechanisms employed by different dry bean genotypes in order to develop selection criteria that can be used in breeding beans for adaptation to drought stress. Such information is necessary to reduce the time taken to come up with new drought varieties. Therefore, the objective of the study was to identify the physiological mechanisms adopted by different Mesoamerican dry bean genotypes under drought stress conditions. Two on-station field experiments were conducted in Kabete during the dry periods of 2010 and 2011. Eighty five Mesoamerican dry bean genotypes including local and international checks with variable drought responses were tested under non- drought stress and drought stress conditions. A split plot design with three replicates was used. Both experiments were initially grown under irrigation during which the soil moisture level was maintained at 80% field capacity. In moisture stressed plots, irrigation was withheld two weeks before flowering to simulate drought conditions. Shoot biomass and grain yield were determined. Leaf chlorophyll concentration, canopy temperature and stomatal conductance were measured at flowering and mid-pod filling growth stages. Total canopy biomass, pod harvest index, pod partitioning index, pod wall biomass proportion and stem biomass reduction and their correlations were calculated. Correlations between canopy temperature, pod harvest index, pod partitioning index and yield under rainfed conditions were also done. The results indicated that under drought stress, some genotypes such as DNB11-07, DMC11-10 and DMC11-24 tended to improve partitioning of dry matter by channeling their photosynthates to the developing grain resulting in high yields of 1218, 1005, and 1027 kgha^{-1} respectively in moisture stress conditions. These lines were also high yielding in non drought stress conditions. Under drought stress, canopy temperature was significantly higher especially at mid- pod filling than at flowering. Drought stress did not affect the leaf chlorophyll at both flowering and mid-pod filling growth stages. However, genotypes were significantly different in leaf chlorophyll. A positive stem biomass reduction was recorded under drought stress but was negative under no stress. Pod partitioning was significantly high under drought stress than under no stress conditions. Pod partitioning index (r=0.89***) and stem biomass reduction (r=0.32**) were significantly correlated with grain yield under drought stress conditions. Significant differences were also observed in stomatal conductance recorded by genotypes under drought stress and non stress conditions. It was concluded that the ability of dry beans to give high yield under drought stress resulted from a combination of drought tolerance mechanisms including stomatal control and efficient photosynthates remobilization. These traits could be used as indirect selection criteria in breeding beans for adaptation to drought. Drought tolerant genotypes were also high yielding under no stress.

Key words: physiological, correlation, stomatal conductance, yield, selection criteria

5.2. Introduction

Efficiency and precision in breeding for drought tolerance can be accelerated if the physiological traits related to water stress could be identified and used as alternative strategies for selection of drought tolerant dry bean genotypes (Beebe et al., 2008). Bean plants have developed several strategies to cope with drought which include drought escape, drought avoidance and drought tolerance (Rao et al., 2001). In common bean, the mechanisms of drought avoidance include the development of an elaborate root system, efficient stomatal closure, increase of the leaf chlorophyll pigmentation, reduction of leaf area and leaf movements (Miyashita et al., 2004). With extended drought, plants change their physiological functions in order to maintain physiological integrity. These changes occur at the expense of growth (Amede, 1998). Stomatal closure is one of the first steps of dealing with drought in beans since it is a more rapid and flexible process than other mechanisms like root growth or reduction in leaf area (Rao, 2001).

Partitioning of shoot vegetative dry matter to pods and remobilization from pod walls to the developing grain is also a vital mechanism of adaptation to drought stress among dry bean genotypes (Rao et al., 2007). Genotypes vary in shoot accumulation and partitioning of dry matter which in turn causes a variation in their grain harvest indices (Rao et al., 2009) as drought stress reduces pod harvest index and harvest index of many genotypes which subsequently influence grain yield (Teran and Singh, 2002). Drought resistant bean varieties also have better yield in favorable conditions and within a reduced growth period (Beebe et al., 2008). However, some genotypes fail to yield well under stress "just at the last stages of seed production'' (Beebe et al., 2008).

Adaptation mechanisms to drought vary from one genotype to another leading to the differences observed in seed yield under drought stress among common bean varieties (Beebe et al., 2008). Detailed studies looking at mechanisms of drought tolerance in common bean have not been undertaken in Kenya and the rest of Africa (Kimani et al., 2005). Some work has been done on developing new varieties which are believed to be drought tolerant but the source of their drought tolerance is not well understood. Despite the urgency and high demand for drought tolerant varieties in efforts to deal with the changing climate, plant breeders have been very slow in developing such varieties due to the challenge of identifying traits that confer drought tolerance in beans. Therefore, new strategies are needed to identify close relationships between yield parameters and specific physiological traits especially under drought stress. The main objective of this work was to determine variation for physiological traits associated with drought tolerance and their relationship with grain yield in small and medium seeded bean lines under moisture stressed conditions.

5.3. Materials and Methods

5.3.1. Experimental site

Field experiments were conducted for two seasons; on-farm at Mwea between April 2011 and February 2012 and on-station at Kabete Field Station between June 2011 and March 2012 during the dry periods of the year. Detailed descriptions of the two sites are given in sections 3.3.1.1 and 3.3.1.2 respectively.

5.3.2. Experimental design, treatments and trial management

Eighty five lines of Mesoamerican dry beans comprising drought navy beans (DNB), drought mixed colours (DMC), drought small reds (DSR), local checks and international checks were used (Table 3.1). The experiments were laid out in a split plot design with three replicates. Irrigation levels were the main plots and the 85 lines and checks, the subplots. Main plots were either irrigated (NS) or rainfed (DS). The plot size was 3 m long planted with two rows each consisting of 30 plants at a spacing of 50 cm x 10 cm. Both DS and NS plots were initially grown under irrigation in which soil moisture level was maintained at field capacity. Stress was induced by withholding irrigation from pre-flowering to physiological maturity for the DS treatment.

5.3.3. Data collection

Data was recorded on canopy temperature, leaf chlorophyll content, stomatal conductance and total shoot biomass at mid pod filling and at physiological maturity. Biomass was measured by destructive sampling of a 0.5 m row of plants in each plot. Sampled plants were counted, separated into leaves, stem, pod wall and seed. The plant parts were oven dried at 60°C for two days and dry weights recorded. Canopy temperature was measured on three plants in each plot using an infrared thermometer (Telatemp model AG-42D, Telatemp CA, USA) held 50 cm above the plant at an angle of 45ºC. The infrared thermometer measures the difference in temperature between the leaf canopy and the surrounding air temperature. Ambient temperature was measured at four points within a block and the average recorded. Leaf chlorophyll was measured on one fully expanded young leaf of three plants per row of each genotype in the three replications using a non-destructive, hand-held chlorophyll meter (SPAD-502 Chlorophyll Meter, Minolta Camera Co., Ltd., Japan). SPAD-502 determines the relative amount of chlorophyll present in the leaf by measuring the absorbance of the leaf in two wavelength regions. Chlorophyll has absorbance peaks in the blue (400-500 nm) and red (600-700 nm) regions, with no transmittance in the near-infrared region. SPAD-502 measures the absorbance of the leaf in the red and near-infrared regions. Using these two transmittances, the meter calculates a numerical SPAD (Soil Plant Analysis Development) value, ranging from 0 to 80 which is proportional to the amount of chlorophyll present in the leaf. Stomatal conductance was measured using a porometer which was placed on young fully expanded leaves of six plants of every genotype in the three replications. These measurements were done at flowering and mid pod filling growth stages. Grain yield was measured by counting and harvesting the remaining plants in each plot at maturity and recording the weight. Soil moisture was monitored from the time of stress induction to physiological maturity using the gravimetric method in order to determine when to irrigate the non stressed plots. Soil moisture content of both stressed and non stressed plots was monitored every week. This involved sampling soil from depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-40 cm, 40-60 cm and 60-80 cm. About 100 g of soil from each depth was weighed to determine the fresh weight and oven dried at a temperature of 105ºC for 24 hours after which the samples were weighed to determine the dry weight. Soil moisture content was calculated based on the method by Black (1965)

Important attributes that indicate improved plant performance under drought stress were calculated according to Beebe et al (2010) as follows:

a) **Pod harvest index (PHI)** as the seed biomass dry weight at harvest/pod biomass dry weight at harvest x 100),

b**) Pod wall biomass proportion (PWBP)** as pod wall biomass dry weight at harvest/pod biomass dry weight at harvest x 100),

c**) Pod partitioning index (PPI)** was calculated as pod biomass dry weight at harvest/total shoot biomass dry weight at mid-pod filling x 100)

d**) Stem biomass reduction (SBR)** is the stem biomass dry weight at mid-pod filling – stem biomass dry weight at harvest) / (stem biomass dry weight at mid-pod filling) x 100).

5.3.4. Data analysis

Analysis of variance was conducted using Genstat Release 13.3 (VSN international Ltd. 2010). Seasons and locations were considered random effects while treatment and genotypes were fixed effects. A combined data analysis was done for all measurements. The least significant difference (LSD, $\alpha = 0.05$) was used to compare the seasonal, locational and genotypic means. To analyze the results in graphical form, sigma biplots (Sigma plot 10 systat software, 2006) were plotted. Vertical and horizontal lines in the plot were placed to represent trial mean yield under drought stress or non stress conditions in order to categorize the genotypes (Mead et al., 2003).

5.4. Results

5.4.1. Canopy temperature at flowering

Canopy temperature recorded at flowering of most genotypes was comparable under drought stress and non stress conditions (Table 5.1, 5.2, 5.3). In Kabete, canopy temperature for all genotypes was lower in the first season (June to September 2011) and ranged between 14.0ºC and 17.0ºC. In the second season (November 2011 to March 2012), both locations recorded higher canopy temperatures which ranged between 19.0ºC and 21.0ºC for most genotypes of the three market classes but higher temperatures of up to 25ºC were recorded in Mwea in both seasons. However, the mean canopy temperature recorded under drought stress was 19.0ºC and 18.0ºC under no stress plots over the two seasons and locations.

Season and location effects significantly affected ($p<0.05$) the canopy temperature of most genotypes in all the market classes at flowering growth stage. Genotypes in the various market classes differed significantly ($p\leq0.001$) in their canopy temperatures during the flowering period with mixed colours recording the highest canopy temperature among the three market classes. The interaction between the genotype and location or season significantly affected ($p\leq0.05$) the bean canopy temperature in all the three market classes at flowering stage (Table 5.1, 5.2, 5.3). Within the mixed colours, genotypes such as DMC11-20, DMC11-19, DMC11-14 and GLPX92 (check) recorded higher canopy temperatures (above 20ºC) than the other genotypes in this market class and most checks. The lowest canopy temperature was recorded on DMC11-08 (17.8ºC) but the canopy temperature of most test genotypes and checks in this class ranged between 18 ºC and 19ºC (Table 5.1). Most genotypes within the navy beans market class like DNB11-09, DNB11-12, DNB11-10, DNB11-13 and the check MEX142 recorded temperatures of between 18ºC and 19ºC except DNB11-19 which had a higher mean canopy temperature of above 20ºC (Table 5.2). Among the small reds, high canopy temperatures above 20ºC were recorded on checks including SER95, RAB651, SER155, KATB9 and SER76. Most test genotypes and checks in this group such as DSR11-16, DSR11-18, DSR11-24, DSR11-09 and DSR11-06 had moderate canopy temperatures of between 18ºC and 19ºC (Table 5.3).

Table 5.1: Canopy temperature (°C) at flowering of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	Canopy temperature at flowering (◦C)										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-20	14.3	14.7	21.6	21.6	23.2	21.0	23.7	23.4	20.7	20.2	20.5
DMC 11-19	15.1	14.7	21.3	21.3	23.2	19.9	24.1	23.4	20.4	20.1	20.3
DMC 11-14	14.4	14.6	20.9	22.6	23.8	20.3	22.7	21.7	20.2	20.0	20.1
GLPX92*	14.7	15.0	21.3	20.7	23.6	21.7	23.7	20.1	19.8	20.4	20.1
KATB1*	15.3	14.7	21.5	21.3	23.9	20.6	21.9	21.0	20.4	19.4	19.9
NCB226*	14.8	15.0	21.7	21.5	21.2	19.6	21.7	21.5	19.9	19.4	19.7
DMC 11-06	14.6	15.0	20.1	19.7	23.4	21.2	24.4	18.5	20.6	18.6	19.6
SXB404*	15.0	14.3	20.4	19.9	23.8	20.7	21.4	20.9	19.9	19.2	19.6
NCB280*	14.7	15.1	21.7	20.8	22.0	19.4	21.7	20.8	19.5	19.5	19.5
DMC 11-15	14.4	14.9	20.6	18.9	19.5	21.5	23.2	23.2	19.2	19.6	19.4
DMC 11-16	14.5	14.7	19.6	18.5	21.0	20.3	23.8	22.5	19.2	19.2	19.2
DMC 11-22	14.4	14.6	22.9	19.9	23.2	18.8	21.7	17.8	19.8	18.5	19.2
DMC 11-02	14.4	14.7	20.5	20.5	19.8	20.8	21.4	19.9	19.0	19.0	19.0
DMC 11-04	14.2	15.2	19.8	19.1	22.2	21.2	21.8	17.4	19.5	18.5	19.0
DMC 11-18	14.3	14.5	19.9	19.6	22.0	19.8	23.2	18.4	19.8	18.1	19.0
DMC 11-05	14.4	14.9	20.6	20.1	21.3	20.6	22.1	17.8	19.3	18.4	18.9
SEN53*	14.6	14.8	19.4	18.7	22.4	19.5	21.1	20.7	19.1	18.6	18.9
DMC 11-24	14.3	15.1	21.3	20.6	21.3	20.5	19.4	17.8	19.1	18.5	18.8
DMC 11-09	14.6	14.7	21.2	20.0	22.1	19.9	20.6	17.0	19.6	17.9	18.8
DMC 11-17	14.5	14.4	20.1	19.4	19.8	20.9	21.2	19.7	18.9	18.6	18.8
SEN56*	15.0	15.1	19.9	19.6	21.7	20.2	19.9	19.6	18.9	18.6	18.8

DMC 11-01	14.7	14.4	20.3	18.7	24.6	18.3	20.4	17.4	20.0	17.2	18.6
DMC 11-13	14.2	14.9	19.9	19.4	19.0	19.5	21.9	21.1	18.4	18.8	18.6
DMC 11-10	14.6	14.7	19.5	18.4	21.6	19.8	21.9	17.8	19.4	17.7	18.6
DMC 11-07	14.5	14.7	20.4	20.1	20.4	18.8	21.2	18.6	18.9	18.0	18.5
DMC 11-12	14.2	14.7	20.7	20.0	19.7	21.7	20.0	16.3	18.5	18.3	18.4
DMC 11-21	14.4	14.7	20.2	18.3	21.5	20.4	20.0	17.5	19.0	17.7	18.4
DMC 11-23	14.4	14.7	19.8	19.2	21.0	20.6	20.2	17.1	18.8	17.9	18.4
DMC 11-11	14.5	14.6	21.5	19.4	18.8	19.6	21.2	16.5	18.5	18.0	18.3
DMC 11-03	14.8	14.8	19.8	19.7	20.7	19.0	19.9	17.2	18.3	18.1	18.2
DMC 11-08	14.4	14.5	18.7	18.3	18.6	20.1	19.1	18.3	17.7	17.8	17.8
Mean of genotypes	**14.4**	**14.7**	**20.1**	**19.0**	**21.3**	**20.2**	**21.3**	**19.9**	**19.3**	**18.5**	**18.9**
Mean of checks	**14.8**	**14.8**	**20.3**	**19.8**	**22.6**	**20.2**	**21.7**	**21.3**	**19.6**	**19.3**	**19.5**
Overall mean	**14.6**	**14.8**	**20.2**	**19.4**	**22.0**	**20.2**	**21.5**	**20.6**	**19.5**	**18.9**	**19.2**
%CV		**8.6**									

LSD(P≤0.05)S	1.7*	LSD(P≤0.05)SXT	0.9NS	LSD(P≤0.05)SXLXT	1.8NS
LSD(P≤0.05)L	2.2*	LSD(P≤0.05)LXT	1.8NS	LSD(P≤0.05)SXLXG	2.5NS
LSD(P≤0.05)T	0.8NS	LSD(P≤0.05)SXG	1.6*	LSD(P≤0.05)SXTXG	2.4NS
LSD(P≤0.05)G	1.1**	LSD(P≤0.05)LXG	2.0**	LSD(P≤0.05)LXTXG	2.6NS
LSD(P≤0.05)SXL	2.1*	LSD(P≤0.05)TXG	1.7NS	LSD(P≤0.05)SXLXTXG	3.5NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.2: Canopy temperature (°C) at flowering of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012

	Canopy temperature at flowering (°C)										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-19	14.5	14.7	22.7	22.1	23.2	22.1	22.5	21.7	20.0	20.1	20.1
DNB 11-09	14.4	14.6	22.0	20.8	20.6	19.6	23.2	20.0	19.5	19.2	19.4
DNB 11-12	14.5	14.3	20.8	20.5	20.7	19.2	23.9	20.8	20.0	18.7	19.4
DNB 11-13	14.7	14.5	20.1	18.9	21.9	21.0	24.2	20.4	19.9	18.7	19.3
DNB 11-10	15.0	14.9	22.1	20.5	20.2	19.6	22.5	19.5	19.4	19.1	19.3
DNB 11-18	14.7	14.6	21.8	19.5	20.8	20.3	23.0	19.4	19.6	18.9	19.3
DNB 11-15	14.6	14.7	20.8	18.3	20.9	19.6	22.7	21.9	19.7	18.6	19.2
DNB 11-17	14.7	14.4	21.4	19.9	22.8	17.4	21.7	20.9	19.6	18.6	19.1
DNB 11-08	14.6	14.6	21.5	19.5	20.8	17.3	23.1	20.4	19.6	18.4	19.0
MEX142*	14.9	14.5	21.6	21.1	20.9	19.8	21.6	18.5	19.5	18.5	19.0
DNB 11-04	14.9	14.6	20.1	18.4	20.7	19.2	22.8	21.3	19.6	18.3	19.0
DNB 11-07	14.5	14.5	21.1	20.2	20.5	18.6	22.1	19.2	19.3	18.4	18.9
DNB 11-05	14.5	14.9	19.9	19.1	20.9	19.0	22.8	19.3	19.3	18.3	18.8
DNB 11-06	14.7	14.6	19.6	18.1	19.9	18.7	23.7	21.2	19.5	18.1	18.8
DNB 11-01	14.6	14.7	19.9	19.8	21.5	18.9	20.9	19.6	19.2	18.2	18.7
DNB 11-14	14.9	14.6	20.5	20.2	19.3	18.7	21.2	19.4	18.7	18.2	18.5
DNB 11-03	14.6	14.2	19.0	19.0	20.4	18.8	22.6	18.4	19.1	17.6	18.4
DNB 11-16	14.6	14.6	20.7	20.2	19.5	18.1	21.3	18.7	18.8	17.9	18.4
Mean of genotypes	**14.6**	**14.6**	**19.9**	**20.4**	**20.8**	**19.2**	**22.5**	**20.1**	**19.5**	**18.6**	**19.05**
Mean of checks	**14.9**	**14.5**	**20.6**	**21.1**	**20.9**	**19.8**	**21.6**	**18.5**	**19.5**	**18.5**	**19**
Overall mean	**14.75**	**14.55**	**20.25**	**20.75**	**20.85**	**19.50**	**22.05**	**19.30**	**19.50**	**18.55**	**19.03**

%CV		**8.6**					
LSD(P≤0.05)S	1.7*		LSD(P≤0.05)SXT	0.9NS		LSD(P≤0.05)SXLXT	1.8NS
LSD(P≤0.05)L	2.2*		LSD(P≤0.05)LXT	1.8NS		LSD(P≤0.05)SXLXG	2.5NS
LSD(P≤0.05)T	0.8NS		LSD(P≤0.05)SXG	1.6*		LSD(P≤0.05)SXTXG	2.4NS
LSD(P≤0.05)G	1.1**		LSD(P≤0.05)LXG	2.0**		LSD(P≤0.05)LXTXG	2.6NS
LSD(P≤0.05)SXL	2.1*		LSD(P≤0.05)TXG	1.7NS		LSD(P≤0.05)SXLXTXG	3.5NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.3: Canopy temperature (°C) at flowering of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	Canopy temperature at flowering (°C)										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SER95*	14.9	14.8	25.3	21.6	21.7	21.1	25.3	21.6	21.5	19.8	20.7
RAB651*	15.0	15.1	24.8	21.1	21.8	21.7	24.8	21.1	21.3	19.7	20.5
SER155*	15.0	14.7	23.6	22.1	21.9	20.5	23.6	23.1	20.3	20.6	20.5
KATB9*	14.7	15.1	22.0	21.0	22.8	20.8	22.9	22.1	20.1	20.0	20.1
SER76*	15.0	14.9	23.2	21.2	22.6	19.2	23.2	21.2	20.2	19.8	20.0
RCB270*	15.0	14.7	23.0	23.0	21.4	18.9	21.3	21.3	20.1	19.5	19.8
DSR 11-16	15.1	14.5	20.9	20.8	23.6	20.8	22.6	20.6	19.7	19.9	19.8
GLP585*	14.9	15.0	21.8	21.7	22.9	20.2	22.2	21.5	19.4	20.1	19.8
SEA15*	17.4	18.7	24.4	22.2	17.9	17.8	20.8	20.6	19.7	19.8	19.8
DSR 11-18	15.1	14.6	21.1	20.8	22.6	20.7	22.0	20.1	19.9	19.3	19.6
RCB592*	14.9	14.7	21.6	21.6	22.3	21.4	21.0	21.0	19.2	19.9	19.6
DSR 11-11	15.0	14.8	20.2	20.1	23.1	20.0	23.6	19.2	19.7	19.3	19.5
DSR 11-24	14.9	14.3	20.5	20.3	21.4	21.2	23.1	19.4	20.0	18.8	19.4
DSR 11-07	15.0	14.5	20.9	20.4	21.1	20.6	22.6	20.3	19.6	19.0	19.3
DSR 11-04	14.8	14.4	20.2	19.8	23.9	21.1	19.3	20.8	19.0	19.5	19.3
DSR 11-09	15.3	14.6	21.5	21.3	23.3	21.3	18.8	18.5	19.1	19.4	19.3
DSR 11-01	15.4	14.2	19.6	18.6	22.9	21.7	21.9	18.6	19.7	18.5	19.1
DSR 11-06	15.1	14.7	21.2	19.9	20.9	20.6	21.0	19.2	19.5	18.6	19.1
DSR 11-15	15.6	14.6	20.6	20.5	20.9	20.8	21.9	18.4	19.5	18.6	19.1
DSR 11-10	15.2	14.9	20.4	19.3	22.3	21.0	19.3	18.9	18.8	19.2	19.0
DSR 11-22	15.3	14.2	20.5	19.4	22.1	20.8	20.5	19.4	18.8	19.2	19.0

RCB231*	14.8	15.2	20.8	20.8	20.6	20.1	20.3	20.3	18.9	19.1	19.0
TIO CANELA*	14.9	14.4	19.9	19.6	21.5	22.0	20.7	19.9	18.8	19.2	19.0
DSR 11-13	15.6	14.7	20.0	19.8	23.3	21.0	19.4	18.8	18.8	19.1	19.0
SER16*	14.8	14.9	21.8	21.2	19.5	18.3	22.1	20.2	18.3	19.6	19.0
DSR 11-05	15.3	14.5	19.4	18.5	22.3	20.4	22.8	18.5	19.4	18.4	18.9
DSR 11-08	15.5	14.4	20.0	18.5	21.4	19.9	23.1	18.7	19.5	18.3	18.9
DSR 11-12	14.9	14.4	19.8	19.3	22.5	20.6	21.0	18.9	19.5	18.3	18.9
DSR 11-20	15.0	14.4	21.0	18.8	22.5	18.4	20.6	20.5	18.8	19.0	18.9
DSR 11-21	15.0	14.3	21.2	21.2	21.4	20.9	18.9	18.1	18.6	18.9	18.8
DSR 11-23	15.2	15.0	20.7	19.9	22.4	19.8	19.5	19.0	18.4	19.1	18.8
DSR 11-14	15.3	14.6	19.7	19.6	19.6	19.4	20.6	19.3	18.8	18.2	18.5
DSR 11-19	15.2	14.4	19.7	18.7	20.7	20.7	19.7	19.7	18.6	18.4	18.5
DSR 11-02	15.4	14.2	20.4	18.5	21.6	20.0	18.9	18.6	18.8	18.1	18.5
DSR 11-03	15.4	14.4	20.7	19.4	19.5	18.7	20.1	18.8	18.7	18.0	18.4
Mean of genotypes	**15.2**	**14.5**	**21.2**	**19.8**	**20.6**	**21.7**	**21.7**	**19.3**	**19.9**	**18.8**	**19.4**
Mean of checks	**15.1**	**15.1**	**22.1**	**21.6**	**20.2**	**20.8**	**21.9**	**21.5**	**19.8**	**18.7**	**19.3**
Overall mean	**15.2**	**14.8**	**21.7**	**20.7**	**20.4**	**21.3**	**21.8**	**20.4**	**19.9**	**18.8**	**19.3**
%CV		**8.6**									

LSD(P≤0.05)S	1.7*	LSD(P≤0.05)SXT	0.9NS	LSD(P≤0.05)SXLXT	1.8NS
LSD(P≤0.05)L	2.2*	LSD(P≤0.05)LXT	1.8NS	LSD(P≤0.05)SXLXG	2.5NS
LSD(P≤0.05)T	0.8NS	LSD(P≤0.05)SXG	1.6*	LSD(P≤0.05)SXTXG	2.4NS
LSD(P≤0.05)G	1.1**	LSD(P≤0.05)LXG	2.0**	LSD(P≤0.05)LXTXG	2.6NS
LSD(P≤0.05)SXL	2.1*	LSD(P≤0.05)TXG	1.7NS	LSD(P≤0.05)SXLXTXG	3.5NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

5.4.2. Canopy temperature at mid-pod filling

Canopy temperatures of beans recorded at mid-pod filling was significantly ($p<0.001$) higher under drought stress than under non stress conditions (Table 5.4, 5.5, 5.6). The mean canopy temperatures recorded on genotypes under drought stress and no stress conditions were 23.0ºC and 19.0ºC respectively. Season and location effects significantly affected ($p<0.05$) the canopy temperatures of beans in all the market classes at mid pod filling growth stage. Also, the interaction between the genotypes and the locations had a significant ($p\leq0.05$) effect (Table 5.4, 5.5, 5.6). Genotypes differed significantly ($p<0.001$) in their canopy temperatures at mid pod filling with navy beans recording slightly lower canopy temperature compared to mixed colours and small reds (Table 5.4, 5.5, 5.6). Within the mixed colours, canopy temperatures of up to 23ºC were recorded on DMC11-19, DMC11-14, DMC11-20, DMC11-01, DMC11-06, DMC11-23 and checks like NCB280, KATB1, NCB226, GLPX92 and SXB404. Lower canopy temperatures of 19ºC were recorded on DMC11-12, SEN56 (check) and SEN53 (check) over the two seasons (Table 5.4). The highest canopy temperature recorded on navy beans was 22ºC and was recorded on DNB11-03, DNB11-16, DNB11-05, DNB11-10 and DNB11-12. Other genotypes such as DNB11-19, DNB11-17, DNB11-13 and DNB11-07 were comparable to the check MEX142 and had an average canopy temperature of 21ºC. The lowest average canopy temperature of 20ºC was recorded on DNB11-18, DNB11-15 and DNB11-01 (Table 5.5). Among the small reds, most genotypes recorded average canopy temperatures of up to 22ºC and included DSR11-06, KATB9 (check), SER16 (check), DSR11-01, DSR11-23 and DSR11-16. Most test genotypes in this market class were comparable to both local and international drought lines in the canopy temperature recorded at mid pod filling but SER155 (check), DSR11-19, RCB592 (check), DSR11-04, RAB651 (check), DSR11-12 and RCB231 recorded lower average canopy temperatures of 19ºC (Table 5.6). Genotypes DMC11-10, DNB11-15 and DMC11-24 with low canopy temperature had higher yield under drought stress compared to the local checks KATB9 and KATB1 with high canopy temperature. Other genotypes such as RCB231, DSR11-18 and DSR11-01 with high canopy temperature had high yield under drought stress (Figure 5.1).

Table 5.4: Canopy temperature (°C) at mid pod filling of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	Canopy temperature at mid pod filling (°C)										
	Season 1				**Season 2**						
	Kabete		**Mwea**		**Kabete**		**Mwea**				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-19	20.5	15.4	32.1	24.1	23.2	22.0	27.1	20.8	25.7	20.6	23.2
DMC 11-14	20.8	15.7	29.6	25.8	22.8	22.2	25.1	21.4	24.5	21.3	22.9
DMC 11-20	20.1	15.0	29.8	23.7	23.7	23.4	25.6	20.2	24.8	20.6	22.7
DMC 11-24	20.8	15.1	25.9	22.6	26.4	21.7	23.9	18.1	24.2	19.4	21.8
DMC 11-01	25.1	15.0	30.5	18.8	24.3	15.9	24.9	19.5	26.2	17.3	21.8
DMC 11-06	20.7	15.2	23.9	18.3	26.9	22.5	24.9	20.3	24.1	19.1	21.6
DMC 11-02	21.2	14.4	24.2	22.7	25.4	20.8	22.0	20.8	23.2	19.7	21.5
DMC 11-10	21.3	14.4	27.2	20.3	26.0	21.7	22.2	18.0	24.2	18.6	21.4
DMC 11-23	20.6	15.0	22.7	18.9	26.1	23.9	25.1	18.8	23.6	19.1	21.4
DMC 11-03	19.9	14.9	28.7	22.8	26.3	17.9	23.1	17.0	24.5	18.1	21.3
DMC 11-04	20.2	15.5	26.8	19.8	22.5	20.7	23.3	21.3	23.2	19.3	21.3
DMC 11-17	20.0	15.0	27.8	20.4	24.2	19.9	23.8	19.2	23.9	18.6	21.3
DMC 11-16	20.0	15.1	23.4	17.8	24.8	22.4	24.4	21.3	23.1	19.1	21.1
DMC 11-07	20.9	14.7	23.4	22.2	26.6	20.4	24.6	14.8	23.9	18.0	21.0
DMC 11-05	16.2	15.6	28.6	20.9	23.7	17.0	22.6	21.5	22.8	18.7	20.8
DMC 11-09	20.1	15.1	25.6	22.3	24.7	19.9	21.2	17.2	22.9	18.6	20.8
DMC 11-18	19.9	15.4	25.4	19.0	24.8	21.2	21.4	18.7	22.9	18.6	20.8
NCB280*	24.5	17.5	21.5	19.4	21.9	20.6	21.5	19.4	22.3	19.2	20.8
DMC 11-15	20.1	15.0	26.0	18.4	26.4	17.1	24.9	18.0	24.3	17.1	20.7
DMC 11-08	21.2	15.7	24.2	17.0	27.1	17.6	25.1	17.6	24.4	17.0	20.7
KATB1*	20.2	14.7	27.8	25.9	26.6	20.4	17.7	11.7	23.1	18.2	20.7

DMC 11-21	20.6	14.6	20.7	20.4	25.3	20.1	24.5	18.3	22.7	18.3	20.5
NCB226*	23.9	18.7	20.1	19.4	24.2	18.3	20.1	19.4	22.1	18.9	20.5
GLPX92*	19.9	14.1	21.5	20.9	25.8	20.5	21.0	20.3	22.0	18.9	20.5
DMC 11-11	19.9	15.1	22.1	19.1	24.7	18.6	24.6	19.3	22.8	18.0	20.4
SXB404*	18.7	14.7	22.4	20.2	24.9	19.7	22.4	20.2	22.1	18.7	20.4
DMC 11-13	20.8	14.9	21.8	18.0	25.5	18.7	21.1	20.8	22.3	18.1	20.2
DMC 11-22	20.0	14.0	21.9	20.8	22.8	18.5	23.9	18.8	22.1	18.0	20.1
DMC 11-12	20.6	15.2	20.0	19.2	24.8	16.6	22.4	20.0	21.9	17.7	19.8
SEN56*	20.1	14.0	21.0	20.1	22.0	19.2	21.0	20.1	21.0	18.3	19.7
SEN53*	19.5	14.3	22.2	21.3	20.7	16.8	19.8	19.9	20.5	18.1	19.3
Mean of genotypes	**20.5**	**15.0**	**25.5**	**20.5**	**24.9**	**20.0**	**23.8**	**19.2**	**23.7**	**18.7**	**21.2**
Mean of checks	**21.0**	**15.4**	**22.3**	**21.0**	**23.7**	**19.3**	**20.5**	**18.7**	**21.9**	**18.6**	**20.3**
Overall mean	**20.8**	**15.2**	**23.9**	**20.8**	**24.3**	**19.7**	**22.2**	**19.0**	**22.8**	**18.7**	**20.7**

%CV	**15.9**				
LSD(P≤0.05)S	3.3NS	LSD(P≤0.05)SXT	1.9NS	LSD(P≤0.05)SXLXT	4.2NS
LSD(P≤0.05)L	5.4NS	LSD(P≤0.05)LXT	4.3NS	LSD(P≤0.05)SXLXG	5.4NS
LSD(P≤0.05)T	2.0*	LSD(P≤0.05)SXG	3.3NS	LSD(P≤0.05)SXTXG	4.8NS
LSD(P≤0.05)G	2.3*	LSD(P≤0.05)LXG	4.4*	LSD(P≤0.05)LXTXG	5.5NS
LSD(P≤0.05)SXL	5.1NS	LSD(P≤0.05)TXG	3.6NS	LSD(P≤0.05)SXLXTXG	7.3NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.5: Canopy temperature (°C) at mid pod filling of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	Canopy temperature at mid pod filling(◦C)										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-03	23.4	15.0	26.2	23.0	25.3	25.4	23.7	19.2	24.6	20.6	22.6
DNB 11-16	23.5	15.3	30.7	20.9	24.6	24.8	22.2	18.3	25.2	19.8	22.5
DNB 11-05	19.4	15.0	28.7	21.5	26.0	25.8	22.0	20.1	24.0	20.6	22.3
DNB 11-10	19.5	15.2	27.0	26.8	23.8	21.2	24.3	21.0	23.6	21.0	22.3
DNB 11-12	23.9	15.5	23.5	22.4	25.4	23.7	24.9	19.4	24.4	20.2	22.3
DNB 11-04	23.9	15.2	29.0	20.7	22.2	24.1	25.2	17.7	25.1	19.4	22.3
DNB 11-06	23.6	15.0	23.7	17.7	26.3	25.8	23.3	20.5	24.2	19.8	22.0
DNB 11-09	23.7	15.2	23.5	23.9	25.3	22.8	24.6	16.5	24.3	19.6	22.0
DNB 11-08	19.6	14.3	27.6	18.3	26.2	25.5	23.3	20.8	24.2	19.7	22.0
DNB 11-19	19.8	14.9	25.1	20.1	27.1	26.8	24.4	17.0	24.1	19.7	21.9
DNB 11-17	19.4	15.1	24.3	21.1	27.2	25.1	24.7	17.2	23.9	19.6	21.8
MEX142*	24.1	14.7	26.2	21.6	25.1	25.6	21.1	15.8	24.1	19.4	21.8
DNB 11-13	24.4	15.2	21.2	20.8	23.3	23.9	26.7	18.2	23.9	19.5	21.7
DNB 11-07	23.4	13.8	20.9	19.7	24.0	23.5	23.9	19.3	23.0	19.1	21.1
DNB 11-14	23.4	15.1	22.6	18.8	24.4	24.4	22.8	16.7	23.3	18.7	21.0
DNB 11-18	18.7	15.0	21.0	21.2	25.9	25.8	22.4	16.9	22.0	19.7	20.9
DNB 11-15	19.2	15.0	16.9	26.1	25.0	24.2	21.8	18.2	20.7	20.9	20.8
DNB 11-01	23.9	15.4	20.4	18.4	24.5	20.2	24.7	16.3	23.4	17.6	20.5
Mean of genotypes	**21.9**	**15.0**	**24.2**	**21.2**	**25.1**	**24.3**	**23.8**	**18.4**	**23.7**	**19.7**	**21.7**
Mean of checks	**24.1**	**14.7**	**26.2**	**21.6**	**25.1**	**25.6**	**21.1**	**15.8**	**24.1**	**19.4**	**21.8**
Overall mean	**23.0**	**14.9**	**25.2**	**21.4**	**25.1**	**25.0**	**22.5**	**17.1**	**23.9**	**19.6**	**21.7**

%CV	**15.9**				
LSD(P≤0.05)S	3.3NS	LSD(P≤0.05)SXT	1.9NS	LSD(P≤0.05)SXLXT	4.2NS
LSD(P≤0.05)L	5.4NS	LSD(P≤0.05)LXT	4.3NS	LSD(P≤0.05)SXLXG	5.4NS
LSD(P≤0.05)T	2.0*	LSD(P≤0.05)SXG	3.3NS	LSD(P≤0.05)SXTXG	4.8NS
LSD(P≤0.05)G	2.3*	LSD(P≤0.05)LXG	4.4*	LSD(P≤0.05)LXTXG	5.5NS
LSD(P≤0.05)SXL	5.1NS	LSD(P≤0.05)TXG	3.6NS	LSD(P≤0.05)SXLXTXG	7.3NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.6: Canopy temperature (ºC) at mid pod filling of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	Canopy temperature at mid pod filling(°C)										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-06	19.9	17.2	29.0	22.0	29.3	23.0	21.3	17.3	24.9	19.9	22.4
KATB9*	24.9	16.7	29.2	20.4	26.2	23.8	19.6	17.5	24.9	19.6	22.3
SER16*	24.8	15.6	29.4	17.3	24.7	24.8	24.0	17.4	25.7	18.7	22.2
DSR 11-01	23.1	16.9	27.1	20.4	26.2	25.7	19.8	18.0	24.0	20.2	22.1
DSR 11-23	23.9	16.0	25.7	24.7	25.4	22.2	19.8	19.1	23.7	20.5	22.1
DSR 11-16	23.7	16.5	33.5	23.9	22.1	18.9	19.4	17.4	24.7	19.2	22.0
DSR 11-21	24.6	16.6	24.7	23.9	23.4	22.4	20.1	18.2	23.2	20.3	21.8
TIO CANELA*	23.8	17.6	24.9	22.4	22.9	22.4	20.6	17.8	23.0	20.0	21.5
DSR 11-11	21.2	14.7	29.6	21.6	23.1	22.7	20.9	17.6	23.7	19.2	21.5
DSR 11-15	18.6	13.8	31.5	23.0	25.3	19.6	21.9	17.3	24.3	18.4	21.4
DSR 11-22	24.0	17.0	23.0	23.3	24.0	21.5	20.5	16.4	22.9	19.5	21.2
DSR 11-03	24.2	15.1	26.7	21.2	24.2	20.3	20.6	15.8	23.9	18.1	21.0
DSR 11-18	20.4	15.5	25.5	20.8	25.1	24.3	19.2	16.7	22.5	19.3	20.9
GLP585*	24.8	15.5	23.2	20.7	25.8	21.2	19.8	16.2	23.4	18.4	20.9
DSR 11-09	24.2	16.9	25.6	19.1	22.7	21.9	19.9	16.6	23.1	18.6	20.9
DSR 11-14	23.6	16.6	25.4	19.4	23.1	22.2	20.3	16.3	23.1	18.6	20.9
SEA15*	23.1	17.5	21.9	21.2	24.8	19.8	21.3	16.6	22.8	18.8	20.8
DSR 11-02	23.7	15.5	23.3	18.2	23.9	23.9	20.4	17.0	22.8	18.6	20.7
DSR 11-07	19.5	15.7	23.4	21.3	24.3	23.9	19.7	17.7	21.7	19.6	20.7
SER95*	24.0	17.6	23.5	16.4	24.4	19.7	23.5	16.4	23.8	17.5	20.7
DSR 11-20	19.4	16.5	25.4	22.2	22.6	20.1	21.3	16.8	22.1	18.9	20.5

DSR 11-10	19.0	14.7	25.5	17.6	24.3	22.8	21.8	17.7	22.7	18.2	20.5
DSR 11-08	23.4	16.8	21.6	19.6	21.9	20.8	21.9	17.5	22.2	18.6	20.4
DSR 11-13	17.4	15.4	24.8	21.6	25.4	19.1	21.2	17.4	22.2	18.4	20.3
SER76*	19.6	15.6	22.8	17.2	24.5	21.1	22.8	17.2	22.4	17.7	20.1
DSR 11-24	18.9	15.0	26.7	19.1	22.8	19.5	21.5	16.6	22.5	17.5	20.0
DSR 11-05	19.4	15.6	25.6	17.4	24.7	18.9	21.4	16.4	22.8	17.1	20.0
RCB270*	19.4	15.0	21.1	21.1	26.4	25.5	15.7	15.7	20.6	19.3	20.0
SER155*	19.7	14.8	18.6	18.3	25.0	23.5	18.6	18.3	20.5	18.7	19.6
DSR 11-19	20.1	15.2	20.0	18.2	26.5	19.0	20.2	17.5	21.7	17.4	19.6
RCB592*	19.2	14.7	20.5	20.5	24.8	20.5	17.8	17.8	20.6	18.4	19.5
DSR 11-04	18.8	15.0	22.3	18.1	23.5	21.2	19.9	16.0	21.1	17.5	19.3
RAB651*	24.3	17.7	18.4	16.8	21.5	20.6	18.4	16.8	20.6	18.0	19.3
DSR 11-12	19.3	15.4	24.9	20.3	20.8	18.0	18.7	17.0	20.9	17.7	19.3
RCB231*	21.6	17.0	20.9	20.9	21.8	18.4	16.3	16.3	20.1	18.1	19.1
Mean of genotypes	**21.3**	**15.8**	**25.7**	**20.7**	**24.1**	**21.4**	**20.5**	**17.1**	**22.9**	**18.7**	**20.8**
Mean of checks	**22.4**	**16.3**	**22.8**	**19.4**	**24.4**	**21.8**	**19.8**	**17.0**	**22.4**	**18.6**	**20.5**
Overall mean	**21.9**	**16.1**	**24.3**	**20.1**	**24.3**	**21.6**	**20.2**	**17.1**	**22.7**	**18.7**	**20.7**
%CV	**15.9**										
LSD(P≤0.05)S	3.3NS	LSD(P≤0.05)SXT	1.9NS	LSD(P≤0.05)SXLXT	4.2NS						
LSD(P≤0.05)L	5.4NS	LSD(P≤0.05)LXT	4.3NS	LSD(P≤0.05)SXLXG	5.4NS						
LSD(P≤0.05)T	2.0*	LSD(P≤0.05)SXG	3.3NS	LSD(P≤0.05)SXTXG	4.8NS						
LSD(P≤0.05)G	2.3*	LSD(P≤0.05)LXG	4.4*	LSD(P≤0.05)LXTXG	5.5NS						
LSD(P≤0.05)SXL	5.1NS	LSD(P≤0.05)TXG	3.6NS	LSD(P≤0.05)SXLXTXG	7.3NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

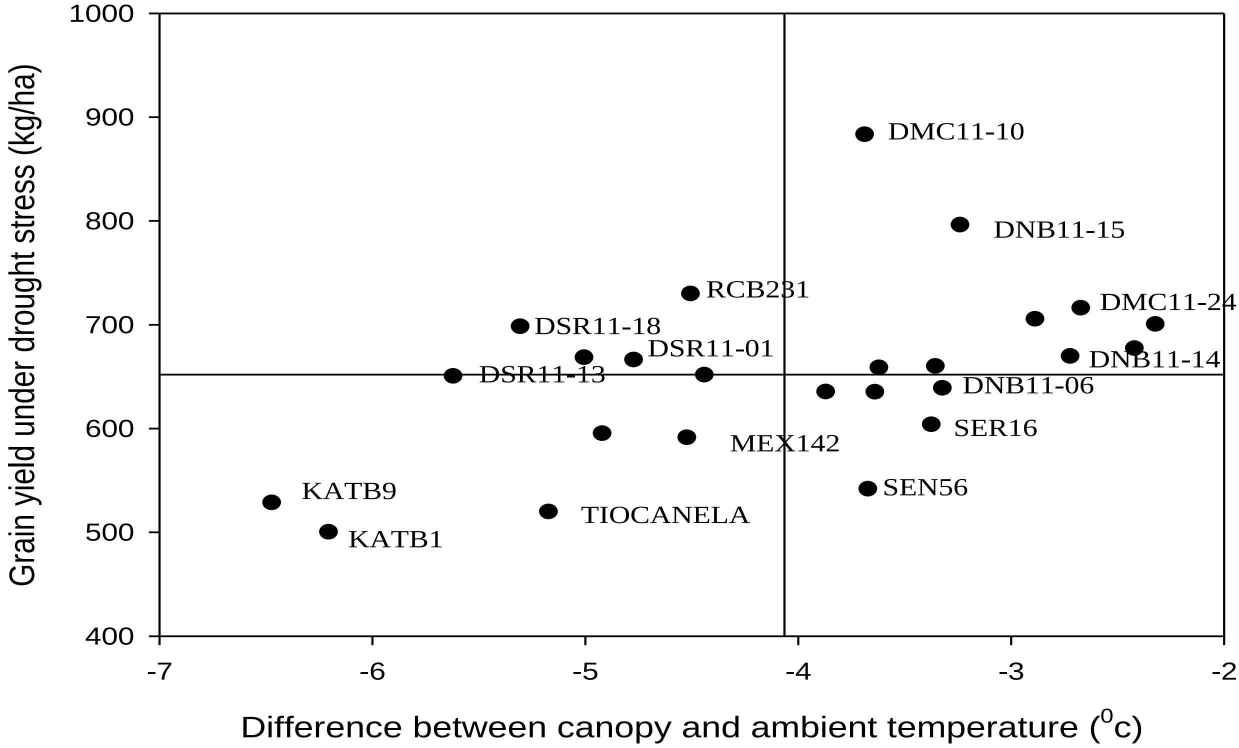


Figure 5.1: Correlation between grain yield and canopy temperature of 23 genotypes selected at random from the three market classes under rainfed conditions.

5.4.3. Leaf chlorophyll at flowering

Leaf chlorophyll recorded at flowering was significantly ($p<0.05$) lower under drought stress than under non stress conditions (Table 5.7, 5.8, 5.9). Leaf chlorophyll at flowering did not significantly differ between the seasons and ranged between 28 and 40 units for most genotypes in the diverse market classes under drought stress and no stress respectively. However, leaf chlorophyll content differed between the locations with Kabete recording higher values (>35) than Mwea.

Leaf chlorophyll content at flowering was significantly different ($p\leq0.001$) among genotypes in the three diverse market classes. In addition, location and irrigation treatment significantly affected ($p\leq0.05$) leaf chlorophyll content. Interaction between season, location water treatment and genotype had a significant effect ($p\leq0.05$) on total leaf chlorophyll content at flowering (Table 5.7, 5.8, 5.9). Of the three market classes, navy beans had the higher mean leaf chlorophyll concentration compared to mixed colours and small red genotypes (Table

5.7, 5.8, 5.9). Within the mixed colours, SEN56 (check), DMC11-10, and GLPX92 had high chlorophyll contents which were above 40. Other genotypes in the same market class including DMC11-13, NCB226 (check), DMC11-08, DMC11-21, DMC11-23 and DMC11-15 had chlorophyll concentrations above 35. Most genotypes in this market class were comparable to respective checks in total chlorophyll content but DMC11-04, DMC11-18 and DMC11-14 had the lowest chlorophyll content which was 32 on average (Table 5.7). All navy beans including DNB11-04, DNB11-17, DNB11-03, DNB11-10, DNB11-16 and DNB11-07 recorded high leaf chlorophyll contents which ranged between 36 and 39 and were comparable to the check MEX142 (Table 5.8). Among the small reds, RCB270 and DSR11-02 recorded the highest leaf chlorophyll content which was above 40 units. Other genotypes in this market class had leaf chlorophyll contents ranging between 35 to 39. These included DSR11-06, DSR11-10 and DSR11-12 and checks like RCB231, SER155 and SEA15 (Table 5.9).

Table 5.7: Leaf chlorophyll at flowering of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012

	SPAD at flowering										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SEN56*	43.0	42.3	42.1	38.9	43.9	41.2	42.1	38.9	42.8	40.3	41.6
DMC 11-10	42.6	44.8	39.9	37.8	43.1	42.2	39.0	39.7	41.1	41.1	41.1
GLPX92*	47.2	44.1	36.7	37.5	41.9	41.8	38.7	40.4	41.1	40.9	41.0
DMC 11-13	41.0	43.5	38.8	40.3	42.9	40.4	36.6	34.9	39.8	39.8	39.8
NCB226*	41.8	38.6	41.5	37.4	40.2	38.8	41.5	37.4	41.2	38.0	39.6
DMC 11-08	41.6	42.1	38.8	34.8	38.9	38.7	37.5	40.0	39.2	38.9	39.1
DMC 11-21	42.3	43.6	40.2	34.2	37.9	40.5	38.4	34.8	39.7	38.3	39.0
DMC 11-23	38.0	38.4	41.1	38.3	38.5	38.7	38.8	38.0	39.1	38.3	38.7
DMC 11-15	40.3	38.8	37.5	37.0	39.5	37.5	38.3	38.6	38.9	38.0	38.5
KATB1*	43.3	40.6	33.8	34.6	38.6	39.7	38.8	38.0	38.6	38.2	38.4
DMC 11-22	41.0	40.9	39.4	32.6	40.8	37.3	36.5	38.7	39.4	37.4	38.4
DMC 11-02	41.2	39.8	35.2	38.1	39.2	39.9	36.7	36.1	38.1	38.5	38.3
DMC 11-17	39.4	41.9	34.8	36.4	40.1	38.9	35.3	38.0	37.4	38.8	38.1
DMC 11-24	38.8	40.0	40.5	34.9	39.9	34.9	37.4	37.1	39.1	36.7	37.9
DMC 11-03	38.2	40.0	37.4	35.1	38.3	40.4	37.3	36.6	37.8	38.0	37.9
SEN53*	42.1	41.2	37.9	34.4	39.5	37.0	35.5	35.6	38.7	37.0	37.9
NCB280*	40.8	34.9	37.0	35.6	43.4	38.2	37.0	35.6	39.5	36.1	37.8
DMC 11-09	37.4	38.7	36.3	37.0	39.3	40.3	35.0	35.0	37.0	37.7	37.4
DMC 11-07	42.1	39.3	37.6	36.5	37.9	35.2	33.4	33.9	37.7	36.2	37.0
DMC 11-05	38.0	40.7	37.2	28.3	38.9	39.4	37.0	34.9	37.8	35.8	36.8
DMC 11-06	37.7	45.3	33.6	35.2	39.4	33.3	32.6	37.1	35.8	37.7	36.8

SXB404*	36.5	37.1	37.6	30.6	37.5	41.5	37.6	30.6	37.3	34.9	36.1
DMC 11-19	38.4	40.1	33.0	33.1	37.8	33.8	34.0	34.7	35.8	35.4	35.6
DMC 11-12	35.7	36.7	35.0	35.6	36.1	37.5	34.8	32.9	35.4	35.7	35.6
DMC 11-01	34.8	35.5	33.5	35.6	40.6	36.0	27.2	32.2	34.0	34.8	34.4
DMC 11-20	36.7	39.6	31.1	28.4	36.4	33.0	33.5	32.2	34.4	33.3	33.9
DMC 11-11	34.3	33.6	32.1	31.4	34.8	32.2	34.9	32.2	34.0	32.4	33.2
DMC 11-16	32.6	37.7	32.0	27.4	33.5	36.0	32.2	30.5	32.6	32.9	32.8
DMC 11-04	33.2	36.3	30.5	27.4	33.8	35.3	30.0	31.1	31.9	32.5	32.2
DMC 11-18	33.8	37.8	33.1	27.0	32.0	34.2	29.1	29.0	32.0	32.0	32.0
DMC 11-14	40.4	37.8	26.5	27.3	31.9	29.8	32.0	28.9	32.7	30.9	31.8
Mean of genotypes	**38.3**	**39.7**	**33.6**	**35.7**	**36.0**	**38.9**	**34.9**	**34.9**	**36.7**	**38.3**	**37.5**
Mean of checks	**42.1**	**39.8**	**38.1**	**35.6**	**40.7**	**39.7**	**38.7**	**36.6**	**39.9**	**37.9**	**38.9**
Overall mean	**40.2**	**39.8**	**35.9**	**35.7**	**38.4**	**39.3**	**36.8**	**35.8**	**38.3**	**38.1**	**38.2**
%CV		**7.3**									

LSD(P≤0.05)S	4.8NS	LSD(P≤0.05)SXT	2.5NS	LSD(P≤0.05)SXLXT	1.6NS
LSD(P≤0.05)L	1.3*	LSD(P≤0.05)LXT	1.0*	LSD(P≤0.05)SXLXG	3.9*
LSD(P≤0.05)T	0.5*	LSD(P≤0.05)SXG	2.8NS	LSD(P≤0.05)SXTXG	3.9NS
LSD(P≤0.05)G	1.9**	LSD(P≤0.05)LXG	2.7*	LSD(P≤0.05)LXTXG	3.8NS
LSD(P≤0.05)SXL	1.9NS	LSD(P≤0.05)TXG	2.7NS	LSD(P≤0.05)SXLXTXG	5.4NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.8: Leaf chlorophyll at flowering of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	SPAD at flowering										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-04	41.1	43.0	40.0	35.4	41.0	37.5	39.9	37.3	40.5	38.3	39.4
DNB 11-17	43.2	42.5	34.2	38.2	40.6	39.8	36.8	38.7	38.7	39.8	39.3
DNB 11-03	36.4	40.8	40.0	35.5	40.6	42.9	40.7	33.1	39.4	38.1	38.8
DNB 11-10	42.5	40.3	38.8	37.4	37.2	37.8	37.4	36.7	39.0	38.1	38.6
DNB 11-16	41.3	37.9	38.0	34.8	42.3	41.3	37.8	34.3	39.8	37.0	38.4
DNB 11-07	38.8	39.5	38.8	35.9	37.9	37.9	40.0	34.8	38.9	37.0	38.0
DNB 11-01	39.6	38.2	37.3	37.0	38.2	38.2	37.4	37.7	38.1	37.7	37.9
DNB 11-09	37.9	38.8	36.1	35.4	40.2	38.9	39.1	36.7	38.3	37.4	37.9
DNB 11-12	38.7	40.9	40.4	36.9	37.9	37.5	36.2	34.1	38.3	37.3	37.8
DNB 11-13	41.5	40.6	36.8	35.8	38.9	38.9	35.3	34.5	38.1	37.4	37.8
DNB 11-18	41.2	40.6	33.7	33.0	39.4	39.4	37.2	37.2	37.9	37.5	37.7
DNB 11-14	40.1	41.0	37.9	34.8	38.8	34.9	38.0	34.6	38.7	36.3	37.5
DNB 11-19	37.2	43.1	40.5	37.2	32.9	40.0	32.7	35.3	35.8	38.9	37.4
DNB 11-15	40.4	39.5	37.2	31.7	40.8	35.1	38.5	35.1	39.2	35.3	37.3
MEX142*	35.6	43.0	33.4	31.8	37.5	38.9	38.9	38.0	36.3	37.9	37.1
DNB 11-08	39.4	43.0	32.8	27.8	36.9	39.6	38.1	36.7	36.8	36.8	36.8
DNB 11-06	38.7	38.8	35.1	32.8	39.1	36.8	35.4	34.3	37.0	35.7	36.4
DNB 11-05	38.4	40.7	35.3	34.0	37.9	38.8	29.8	36.3	35.3	37.4	36.4
Mean of genotypes	**39.8**	**40.5**	**34.2**	**37.9**	**37.8**	**38.5**	**35.0**	**37.7**	**38.2**	**39.4**	**38.8**
Mean of checks	**35.6**	**43.0**	**31.4**	**33.8**	**37.5**	**38.9**	**38.9**	**38.0**	**36.3**	**37.9**	**37.1**
Overall mean	**37.7**	**41.8**	**32.8**	**35.9**	**37.7**	**38.7**	**37.0**	**37.9**	**37.3**	**38.7**	**38.0**

%CV	**7.3**				
LSD(P≤0.05)S	4.8NS	LSD(P≤0.05)SXT	2.5NS	LSD(P≤0.05)SXLXT	1.6NS
LSD(P≤0.05)L	1.3*	LSD(P≤0.05)LXT	1.0*	LSD(P≤0.05)SXLXG	3.9*
LSD(P≤0.05)T	0.5*	LSD(P≤0.05)SXG	2.8	LSD(P≤0.05)SXTXG	3.9NS
LSD(P≤0.05)G	1.9**	LSD(P≤0.05)LXG	2.7*	LSD(P≤0.05)LXTXG	3.8NS
LSD(P≤0.05)SXL	1.9NS	LSD(P≤0.05)TXG	2.7NS	LSD(P≤0.05)SXLXTXG	5.4NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.9: Leaf chlorophyll at flowering of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012

	SPAD at flowering										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
RCB270*	40.5	44.3	42.3	42.3	41.3	40.0	40.0	40.0	41.0	41.6	41.3
DSR 11-02	42.9	42.6	40.8	34.5	43.5	42.0	43.7	39.4	42.7	39.6	41.2
DSR 11-12	39.9	41.3	34.9	38.2	42.3	42.3	41.1	39.1	39.5	40.2	39.9
RCB231*	36.8	40.9	39.4	39.4	42.4	38.0	41.1	41.1	39.9	39.8	39.9
DSR 11-06	39.8	40.3	40.5	37.1	39.8	41.7	40.2	38.2	40.1	39.3	39.7
DSR 11-23	39.2	42.3	39.1	38.2	38.9	38.4	37.6	43.1	38.7	40.5	39.6
SER155*	39.8	38.4	37.9	38.6	41.1	41.3	37.9	38.6	39.2	39.2	39.2
DSR 11-10	40.9	41.2	40.0	34.8	39.8	38.3	38.0	36.7	39.7	37.7	38.7
DSR 11-09	36.7	38.8	39.7	37.6	40.3	38.4	39.8	37.2	39.1	38.0	38.6
SEA15*	41.2	39.2	41.2	34.3	38.2	43.8	35.4	34.2	39.0	37.9	38.5
SER95*	37.5	39.3	35.9	38.6	41.7	40.1	35.9	38.6	37.7	39.1	38.4
RCB592*	40.2	39.0	37.7	37.7	37.8	38.4	37.7	37.7	38.3	38.2	38.3
GLP585*	42.2	46.1	35.6	36.4	38.0	37.5	35.4	34.4	37.8	38.6	38.2
KATB9*	39.3	39.0	34.1	29.7	40.8	40.9	40.3	39.7	38.6	37.3	38.0
DSR 11-18	38.4	39.7	37.2	36.3	36.8	39.7	39.3	35.6	37.9	37.8	37.9
DSR 11-14	39.7	37.8	34.9	38.9	36.0	41.7	36.4	36.4	36.7	38.7	37.7
DSR 11-15	41.2	40.1	33.7	36.7	39.3	36.4	37.9	35.6	38.0	37.2	37.6
DSR 11-16	40.2	40.9	35.8	35.3	38.2	39.4	35.8	35.2	37.5	37.7	37.6
DSR 11-07	36.0	40.9	38.0	33.2	40.8	36.7	38.7	36.3	38.3	36.8	37.6
SER76*	39.0	38.5	37.5	33.9	39.5	38.9	37.5	33.9	38.4	36.3	37.4
DSR 11-24	41.2	42.0	33.9	32.5	37.1	37.5	37.7	34.5	37.5	36.6	37.1

DSR 11-11	39.1	38.8	34.4	35.2	36.2	35.1	37.1	38.0	36.7	36.8	36.8
RAB651*	39.9	35.7	34.5	35.6	36.9	37.3	34.5	35.6	36.4	36.0	36.2
DSR 11-03	39.5	39.1	33.1	34.4	37.7	35.1	35.5	33.1	36.4	35.4	35.9
DSR 11-04	37.5	39.3	33.2	33.6	35.5	37.7	33.7	37.2	34.9	36.9	35.9
SER16*	36.7	38.4	33.6	33.1	38.1	38.9	33.8	34.0	35.5	36.1	35.8
TIO CANELA*	37.6	37.4	35.4	37.1	35.9	37.0	30.5	34.9	34.9	36.6	35.8
DSR 11-21	40.4	39.8	30.8	35.3	34.4	38.0	34.4	32.6	35.0	36.4	35.7
DSR 11-13	39.6	39.3	32.6	34.9	33.8	36.8	33.2	33.6	34.8	36.1	35.5
DSR 11-08	38.2	33.2	40.1	30.2	34.2	37.1	34.3	34.6	36.7	33.8	35.3
DSR 11-19	39.4	36.9	36.8	30.5	37.8	34.5	31.5	33.8	36.4	33.9	35.2
DSR 11-22	37.8	38.3	35.8	31.5	36.2	34.4	34.9	31.9	36.2	34.0	35.1
DSR 11-20	37.4	36.3	32.4	31.1	35.3	35.0	35.4	31.1	35.1	33.4	34.3
DSR 11-01	37.8	35.4	32.6	31.8	30.8	39.2	30.6	34.3	32.9	35.1	34.0
DSR 11-05	35.9	33.6	30.8	32.0	34.7	33.4	31.7	32.7	33.3	32.9	33.1
Mean of genotypes	**39.0**	**39.0**	**34.7**	**35.5**	**37.3**	**37.8**	**35.4**	**36.6**	**37.1**	**38.7**	**37.9**
Mean of checks	**39.2**	**39.6**	**36.1**	**37.4**	**39.3**	**39.3**	**36.7**	**36.9**	**37.1**	**38.1**	**37.6**
Overall mean	**39.1**	**39.3**	**35.4**	**36.5**	**38.3**	**38.6**	**36.1**	**36.8**	**37.1**	**38.4**	**37.8**
%CV		**7.3**									

LSD(P≤0.05)S	4.8NS	LSD(P≤0.05)SXT	2.5NS	LSD(P≤0.05)SXLXT	1.6NS
LSD(P≤0.05)L	1.3*	LSD(P≤0.05)LXT	1.0*	LSD(P≤0.05)SXLXG	3.9*
LSD(P≤0.05)T	0.5*	LSD(P≤0.05)SXG	2.8NS	LSD(P≤0.05)SXTXG	3.9NS
LSD(P≤0.05)G	1.9**	LSD(P≤0.05)LXG	2.7*	LSD(P≤0.05)LXTXG	3.8NS
LSD(P≤0.05)SXL	1.9NS	LSD(P≤0.05)TXG	2.7NS	LSD(P≤0.05)SXLXTXG	5.4NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

5.4.4. Leaf chlorophyll at mid-pod filling

Leaf chlorophyll content of most genotypes was higher at mid pod filling than at flowering. At mid pod filling, there were significant genotypic differences ($p \leq 0.001$) in leaf chlorophyll content within the various market classes. Water stress significantly reduced ($p \leq 0.05$) the bean leaf chlorophyll content. The interactions between the season and location or genotype were also significant $p \leq 0.05$ in influencing the leaf chlorophyll content of most genotypes (Table 5.10, 5.11, 5.12). Of the three market classes, navy beans had the highest mean leaf chlorophyll concentration (Table 5.11). Within the mixed colours, SEN56 (check), GLPX92 (check), DMC11-10, DMC11-08, SEN53 (check), DMC11-02 and DMC11-21 recorded high leaf chlorophyll contents of above 40 units. Other genotypes and most checks in this market class had high leaf chlorophyll contents which ranged between 36 and 39 units. However, some genotypes had very low chlorophyll contents of up to 32 units and included DMC11-20, DMC11-04, DMC11-14, DMC11-16 and DMC11-18 (Table 5.10). Most navy bean lines recorded higher leaf chlorophyll contents which were greater than 40 units and included DNB11-04, DNB11-17, MEX142 (check), DNB11-05, DNB11-09 and DNB11-18. Genotypes in this market class maintained high leaf chlorophyll content above 36 units and were comparable to the check MEX142 (Table 5.11). Genotypes within the small reds with high leaf chlorophyll content included DSR11-12, GLP585 (check), DSR11-23, DSR11-18, SEA15 (check), RCB231 (check) and DSR11-19. Checks including RAB651 and SER155 had very low leaf chlorophyll contents of up to 29 units compared to the other genotypes in the same market class. However, most genotypes were comparable to checks in total leaf chlorophyll content at mid pod filling growth stage (Table 5.12).

Table 5.10: Leaf chlorophyll at mid-pod filling of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	SPAD at mid pod filling										
	Season 1				**Season 2**						
	Kabete		**Mwea**		**Kabete**		**Mwea**				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SEN56*	40.1	41.1	44.7	47.1	36.8	39.2	44.7	47.1	41.6	43.6	42.6
GLPX92*	35.6	40.9	43.3	48.9	41.1	40.0	43.5	37.1	43.4	39.2	41.3
DMC 11-10	38.4	42.1	46.2	37.3	41.8	44.8	37.6	39.6	41.0	41.0	41.0
DMC 11-08	31.2	38.1	45.7	38.3	46.6	43.3	36.6	37.5	42.5	39.3	40.9
SEN53*	40.5	40.4	43.3	41.5	39.2	41.9	42.3	38.4	41.3	40.5	40.9
DMC 11-02	38.8	39.8	43.5	41.1	41.2	42.9	39.6	39.3	40.8	40.8	40.8
DMC 11-21	36.7	39.5	43.1	39.6	44.4	47.4	39.4	35.1	40.9	40.4	40.7
NCB226*	33.8	37.7	42.8	41.7	44.6	40.2	42.8	41.7	42.0	39.3	40.7
DMC 11-23	32.7	34.8	42.9	44.2	44.3	43.9	38.7	42.5	39.6	41.3	40.5
DMC 11-22	39.6	42.0	46.5	40.5	44.1	41.9	28.9	39.5	40.5	40.2	40.4
DMC 11-03	35.7	36.3	41.6	40.6	41.8	40.1	41.3	43.3	40.1	40.0	40.1
DMC 11-05	34.4	42.5	44.7	42.0	40.6	42.8	36.2	36.2	39.0	40.9	40.0
DMC 11-06	40.9	39.7	41.7	39.4	41.9	39.1	36.3	38.4	40.2	39.1	39.7
DMC 11-19	36.8	37.6	44.3	41.4	44.3	43.2	35.9	33.8	40.3	39.0	39.7
DMC 11-15	39.3	38.1	47.2	41.1	41.7	41.2	32.0	36.3	40.0	39.1	39.6
DMC 11-07	34.5	33.9	45.6	44.0	38.0	43.0	33.8	41.8	38.0	40.7	39.4
DMC 11-13	40.8	42.0	37.5	42.6	42.8	41.8	31.4	35.4	38.1	40.4	39.3
DMC 11-09	37.4	39.5	40.6	43.3	41.6	39.7	31.4	39.3	37.7	40.4	39.1
DMC 11-17	37.6	38.0	42.1	40.8	38.2	37.4	37.8	32.6	38.9	37.2	38.1
KATB1*	41.5	39.6	42.2	35.8	40.6	43.1	16.2	42.1	35.1	40.1	37.6
NCB280*	38.5	33.6	39.7	35.3	36.0	38.7	39.7	35.3	38.5	35.7	37.1

DMC 11-24	33.6	38.8	40.4	44.2	38.0	36.0	31.1	34.2	35.8	38.3	37.1
DMC 11-12	33.4	34.7	40.7	41.0	41.3	39.6	30.7	34.7	36.5	37.5	37.0
SXB404*	35.0	38.5	32.4	39.7	37.0	41.0	32.4	39.7	34.2	39.7	37.0
DMC 11-11	30.0	34.1	45.9	42.1	34.1	37.1	34.4	37.0	36.1	37.6	36.9
DMC 11-01	30.0	28.6	45.4	39.9	40.6	36.2	33.6	34.8	37.4	34.8	36.1
DMC 11-20	32.4	35.5	38.7	39.0	39.8	34.8	35.7	29.2	36.6	34.6	35.6
DMC 11-04	36.5	36.5	40.2	35.1	36.6	32.7	28.5	33.7	35.4	34.5	35.0
DMC 11-14	36.6	35.7	32.4	41.5	36.1	33.7	29.0	32.8	33.5	35.9	34.7
DMC 11-16	33.0	35.7	33.7	34.9	37.7	36.3	31.3	31.8	33.9	34.7	34.3
DMC 11-18	31.7	36.5	34.8	35.5	32.4	34.4	26.7	31.0	31.4	34.3	32.9
Mean of genotypes	**36.0**	**37.4**	**40.9**	**41.4**	**39.4**	**40.7**	**34.1**	**36.2**	**37.1**	**38.4**	**37.8**
Mean of checks	**38.8**	**39.2**	**40.2**	**41.0**	**39.3**	**40.6**	**37.3**	**40.2**	**39.4**	**39.7**	**39.6**
Overall mean	**37.4**	**38.3**	**40.6**	**41.2**	**39.4**	**40.7**	**35.7**	**38.2**	**38.3**	**39.1**	**38.7**
%CV	**9.6**										

LSD(P≤0.05)S	10.7NS	LSD(P≤0.05)SXT	3.8NS	LSD(P≤0.05)SXLXT	3.7NS
LSD(P≤0.05)L	1.2NS	LSD(P≤0.05)LXT	2.0NS	LSD(P≤0.05)SXLXG	5.5*
LSD(P≤0.05)T	2.0NS	LSD(P≤0.05)SXG	4.1**	LSD(P≤0.05)SXTXG	5.7NS
LSD(P≤0.05)G	2.6**	LSD(P≤0.05)LXG	3.7**	LSD(P≤0.05)LXTXG	5.4NS
LSD(P≤0.05)SXL	7.3*	LSD(P≤0.05)TXG	3.9NS	LSD(P≤0.05)SXLXTXG	7.8NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.11: Leaf chlorophyll at mid-pod filling of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	SPAD at mid pod filling										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-04	39.5	40.1	44.0	43.2	40.8	40.6	42.1	39.7	41.6	40.9	41.3
DNB 11-17	39.0	37.4	44.8	43.3	44.5	44.6	31.7	42.4	40.0	41.9	41.0
MEX142*	37.7	38.4	44.0	39.2	46.8	45.1	34.8	39.7	40.8	40.6	40.7
DNB 11-05	35.4	42.8	45.1	41.9	41.8	43.2	40.2	34.8	40.6	40.6	40.6
DNB 11-09	40.3	36.7	40.6	41.2	43.5	43.2	40.1	38.3	41.1	39.8	40.5
DNB 11-18	39.5	35.9	45.3	40.0	45.0	41.0	37.8	38.9	41.9	38.9	40.4
DNB 11-16	37.3	35.8	46.0	40.4	44.3	44.2	33.7	40.1	40.3	40.1	40.2
DNB 11-03	36.9	35.9	44.3	40.2	46.1	46.3	30.5	39.8	39.4	40.5	40.0
DNB 11-06	36.1	34.1	40.2	42.8	39.6	44.4	37.4	45.1	38.3	41.6	40.0
DNB 11-13	43.7	41.3	43.0	43.1	42.2	40.1	32.0	31.8	40.2	39.0	39.6
DNB 11-10	36.1	37.0	39.0	40.6	41.3	43.7	39.7	38.5	39.0	39.9	39.5
DNB 11-07	36.0	36.5	44.1	40.5	42.4	41.0	38.2	35.1	40.1	38.3	39.2
DNB 11-12	37.5	35.3	38.1	43.6	39.1	41.7	38.1	37.6	38.2	39.5	38.9
DNB 11-01	36.5	36.9	42.8	37.5	44.1	40.5	37.9	32.4	40.3	36.8	38.6
DNB 11-08	35.7	36.4	44.9	41.1	41.8	40.1	31.3	37.4	38.4	38.7	38.6
DNB 11-14	32.7	38.4	41.3	37.8	40.1	42.1	39.4	35.6	38.4	38.5	38.5
DNB 11-15	38.7	35.7	35.1	38.2	41.7	43.8	31.3	37.0	36.7	38.7	37.7
DNB 11-19	37.8	38.4	45.8	41.1	35.4	34.7	25.2	34.5	36.0	37.2	36.6
Mean of genotypes	**37.5**	**37.3**	**41.6**	**42.0**	**42.0**	**42.0**	**35.6**	**37.6**	**37.4**	**39.5**	**38.5**
Mean of checks	**37.7**	**38.4**	**39.0**	**44.2**	**45.8**	**46.1**	**34.8**	**39.7**	**39.8**	**40.6**	**40.2**
Overall mean	**37.6**	**37.9**	**40.3**	**43.1**	**43.9**	**44.1**	**35.2**	**38.7**	**38.6**	**40.1**	**39.3**

%CV	**9.6**				
LSD(P≤0.05)S	10.7NS	LSD(P≤0.05)SXT	3.8NS	LSD(P≤0.05)SXLXT	3.7NS
LSD(P≤0.05)L	1.2NS	LSD(P≤0.05)LXT	2.0NS	LSD(P≤0.05)SXLXG	5.5*
LSD(P≤0.05)T	2.0NS	LSD(P≤0.05)SXG	4.1**	LSD(P≤0.05)SXTXG	5.7NS
LSD(P≤0.05)G	2.6**	LSD(P≤0.05)LXG	3.7**	LSD(P≤0.05)LXTXG	5.4NS
LSD(P≤0.05)SXL	7.3*	LSD(P≤0.05)TXG	3.9NS	LSD(P≤0.05)SXLXTXG	7.8NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.12: Leaf chlorophyll at mid-pod filling of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete and Mwea, Kenya, 2011/2012.

	SPAD AT MID POD FILLING										
	Season 1				Season 2						
	Kabete		Mwea		Kabete		Mwea				
Genotype	DS	NS	DS	NS	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-12	40.6	43.1	42.3	48.4	42.3	41.9	41.7	43.3	41.7	44.2	43.0
GLP585*	45.7	42.8	41.8	39.5	41.5	43.3	39.2	41.4	42.0	41.7	41.9
DSR 11-23	37.4	41.1	45.4	42.5	41.1	40.1	37.2	44.3	40.3	42.0	41.2
DSR 11-18	38.9	38.4	43.5	46.3	42.0	40.6	37.9	39.6	40.5	41.2	40.9
SEA15*	43.8	35.7	42.5	45.7	42.6	42.5	40.2	32.1	42.3	39.0	40.7
RCB231*	36.5	38.4	43.5	43.5	44.2	42.0	37.7	37.7	40.5	40.4	40.5
DSR 11-19	34.4	35.9	46.0	45.8	41.0	41.3	37.6	39.5	39.7	40.6	40.2
RCB270*	37.7	38.1	34.1	34.1	47.6	45.1	42.1	42.1	40.4	39.8	40.1
DSR 11-14	38.9	39.2	45.6	46.1	41.1	38.6	29.8	41.3	38.8	41.3	40.1
DSR 11-15	38.0	30.7	46.9	45.1	42.7	40.3	39.6	35.9	41.8	38.0	39.9
DSR 11-02	36.2	39.2	45.1	33.3	48.4	43.4	33.2	40.0	40.7	39.0	39.9
DSR 11-10	34.8	39.4	40.7	43.6	42.8	36.8	36.0	41.9	38.6	40.4	39.5
TIO CANELA*	34.8	33.0	45.7	43.2	41.0	43.1	34.9	40.4	39.1	39.9	39.5
DSR 11-04	39.1	39.8	45.5	40.1	37.0	37.5	38.7	37.8	40.1	38.8	39.5
KATB9*	45.4	39.7	41.8	42.1	37.8	39.5	32.5	35.5	39.4	39.2	39.3
DSR 11-06	41.7	30.9	45.9	46.0	41.4	40.3	27.2	40.6	39.0	39.4	39.2
DSR 11-11	34.1	36.8	43.0	40.2	44.9	40.2	35.4	38.2	39.3	38.8	39.1
DSR 11-16	41.0	39.1	37.9	37.7	36.2	40.7	42.6	37.5	39.4	38.7	39.1
DSR 11-24	40.0	42.2	39.2	39.6	38.4	38.2	41.4	33.7	39.7	38.4	39.1
DSR 11-13	35.6	38.2	42.1	46.8	41.5	34.8	38.2	34.7	39.3	38.6	39.0
DSR 11-09	33.8	40.0	38.5	41.2	43.3	40.1	32.6	40.6	37.0	40.5	38.8

DSR 11-20	36.3	34.5	44.2	42.5	38.3	40.9	34.4	36.8	38.3	38.7	38.5
SER16*	40.1	38.3	43.4	38.0	39.7	41.1	30.9	35.5	38.5	38.2	38.4
DSR 11-07	37.0	38.5	37.9	42.3	41.1	38.0	33.2	37.0	37.3	38.9	38.1
DSR 11-03	37.3	37.0	39.7	36.2	45.0	36.9	36.8	35.5	39.7	36.4	38.1
SER76*	37.4	38.4	27.6	42.4	41.9	42.6	27.6	42.4	33.6	41.4	37.5
DSR 11-22	35.2	36.0	37.2	38.4	40.8	40.0	38.2	33.5	37.8	36.9	37.4
DSR 11-21	34.4	37.8	37.1	40.3	36.9	36.1	37.3	38.7	36.4	38.2	37.3
SER95*	36.6	33.4	27.5	42.1	43.4	37.8	27.5	42.1	33.8	38.9	36.4
DSR 11-05	33.2	29.4	37.7	41.9	36.7	38.0	37.3	35.7	36.2	36.2	36.2
RCB592*	38.3	34.9	26.4	26.4	41.7	41.5	40.2	40.2	36.6	35.7	36.2
DSR 11-01	33.4	32.2	39.7	37.5	38.1	32.9	36.4	34.5	36.9	34.3	35.6
DSR 11-08	33.7	33.5	41.9	27.2	36.5	40.9	30.3	35.1	35.6	34.1	34.9
RAB651*	40.7	33.5	24.0	32.8	42.7	36.2	24.0	32.8	32.8	33.8	33.3
SER155*	38.7	38.0	12.3	29.2	39.6	36.4	12.3	29.2	25.7	33.2	29.5
Mean of genotypes	**36.7**	**37.1**	**41.9**	**41.2**	**39.7**	**40.0**	**36.2**	**38.1**	**37.9**	**39.8**	**38.9**
Mean of checks	**39.6**	**37.0**	**34.2**	**38.2**	**40.0**	**42.9**	**32.4**	**37.6**	**37.0**	**38.4**	**37.7**
Overall mean	**38.2**	**37.1**	**38.1**	**39.7**	**39.9**	**41.5**	**34.3**	**37.9**	**37.5**	**39.1**	**38.3**
%CV	**9.6**										

LSD(P≤0.05)S	10.7NS	LSD(P≤0.05)SXT	3.8NS	LSD(P≤0.05)SXLXT	3.7NS
LSD(P≤0.05)L	1.2NS	LSD(P≤0.05)LXT	2.0NS	LSD(P≤0.05)SXLXG	5.5*
LSD(P≤0.05)T	2.0NS	LSD(P≤0.05)SXG	4.1**	LSD(P≤0.05)SXTXG	5.7NS
LSD(P≤0.05)G	2.6**	LSD(P≤0.05)LXG	3.7**	LSD(P≤0.05)LXTXG	5.4NS
LSD(P≤0.05)SXL	7.3*	LSD(P≤0.05)TXG	3.9NS	LSD(P≤0.05)SXLXTXG	7.8NS

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

5.4.5. Effect of drought on pod partitioning index

There were significant genotypic differences ($p<0.05$) in pod partitioning indices (PPI) under drought stress and non stress conditions with most genotypes under drought stress recording a higher PPI than those under no stress. The PPI for most genotypes ranged between 60% and 77% under drought stress (Table 5.13, 5.14, 5.15). Navy beans recorded higher PPI than small reds and mixed colours. As high as 90% PPI was recorded by some genotypes in all the market classes across the locations and seasons. Within the mixed colours market class, DMC11-22, DMC11-10, DMC11-23, DMC11-13, DMC11-24 and DMC11-05 had high PPI (over 85%) compared to the other genotypes in the same market class and most checks. In this market class, test genotypes had better PPIs than most checks (Table 5.13). Most navy beans including DNB11-14, DNB11-09, DNB11-03, DNB11-01, DNB11-05 and DNB11-06 recorded over 70% PPI except DNB11-13 which had the lowest PPI of 32%. In this market class, most genotypes were better than the check MEX142 (Table 5.14). Pod partitioning indices were lower in small red lines compared with navy beans and mixed colours. However, some genotypes in this market class recorded above 70% PPI. These included SER76 (check), SER16 (check), DSR11-22, SEA15 (check), DSR11-14, DSR11-09 and DSR11-13. Very low PPIs of up to 30% were recorded by DSR11-19, DSR11-11, GLP585 (check), and DSR11-16. Most test genotypes among the small reds were comparable to checks in PPI (Table 5.15). Other genotypes including DMC11-15, DMC11-01, DSR11-08 and DMC11-10 recorded high PPI under both drought stress and no stress conditions (Figure 5.2).

Table 5.13: Pod partitioning indices (PPI) of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012

	PPI (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-22	94.0	90.0	92.5	85.0	93.3	87.5	90.4
DMC 11-10	90.0	90.0	90.2	89.0	90.1	89.5	89.8
DMC 11-23	95.0	80.5	93.5	85.0	94.3	82.8	88.5
DMC 11-13	90.0	84.3	93.5	81.5	91.8	82.9	87.3
DMC 11-24	92.5	85.3	90.0	80.5	91.3	82.9	87.1
DMC 11-05	92.5	77.5	92.5	85.7	92.5	81.6	87.1
DMC 11-03	92.5	77.5	92.5	82.5	92.5	80.0	86.3
DMC 11-08	92.5	81.5	91.6	78.0	92.1	79.8	85.9
DMC 11-11	92.9	66.3	96.2	87.0	94.6	76.7	85.6
DMC 11-15	95.0	75.8	92.5	73.3	93.8	74.6	84.2
DMC 11-06	88.0	76.8	89.5	82.0	88.8	79.4	84.1
DMC 11-16	83.0	80.5	93.5	78.9	88.3	79.7	84.0
DMC 11-09	77.0	84.1	92.0	80.0	84.5	82.1	83.3
DMC 11-07	83.1	74.5	94.0	79.5	88.6	77.0	82.8
DMC 11-19	85.8	79.4	96.5	69.1	91.2	74.3	82.7
DMC 11-17	73.8	83.7	91.5	79.0	82.7	81.4	82.0
DMC 11-20	83.4	80.0	80.5	82.9	82.0	81.5	81.7
DMC 11-12	88.5	74.5	88.0	75.0	88.3	74.8	81.5
DMC 11-14	89.7	80.0	84.1	68.8	86.9	74.4	80.7
DMC 11-21	78.4	70.5	88.0	82.0	83.2	76.3	79.7
DMC 11-02	83.9	87.5	75.0	71.5	79.5	79.5	79.5
DMC 11-04	77.4	65.0	95.5	77.8	86.5	71.4	78.9
SEN53*	84.0	73.5	79.2	69.0	81.6	71.3	76.4
DMC 11-01	92.3	68.0	77.0	62.7	84.7	65.4	75.0
SEN56*	81.1	64.2	77.0	66.5	79.1	65.4	72.2
SXB404*	75.5	67.5	70.0	59.5	72.8	63.5	68.1
DMC 11-18	90.0	45.1	87.0	40.9	88.5	43.0	65.8
NCB226*	73.0	49.6	72.5	67.8	72.8	58.7	65.7
GLPX92*	59.1	52.5	69.0	53.3	64.1	52.9	58.5
NCB280*	59.6	49.5	65.5	54.7	62.6	52.1	57.3
KATB1*	62.5	46.0	63.5	51.2	63.0	48.6	55.8
Mean of genotypes	**74.6**	**64.4**	**68.9**	**67.4**	**71.8**	**65.9**	**68.8**
Mean of checks	**60.7**	**57.6**	**61.0**	**60.3**	**60.9**	**59.0**	**59.9**
Overall mean	**67.7**	**61.0**	**65.0**	**63.9**	**66.3**	**62.4**	**64.4**
CV(%)		12.1					
LSD(P≤0.05)S	10.2NS	LSD(P≤0.05)SXG		11.8*			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		11.8**			
LSD(P≤0.05)G	8.3**	LSD(P≤0.05)SXTXG		16.7NS			
LSD(P≤0.05)SXT	4.6NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.14: Pod partitioning indices (PPI) of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PPI (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-14	79.0	76.0	96.6	88.3	87.8	82.2	85.0
DNB 11-09	92.5	86.0	85.0	74.5	88.8	80.3	84.5
DNB 11-03	90.5	82.0	79.5	67.0	85.0	74.5	79.8
DNB 11-01	84.0	64.5	88.5	78.0	86.3	71.3	78.8
DNB 11-05	75.0	70.5	92.0	76.5	83.5	73.5	78.5
DNB 11-06	86.0	75.6	86.7	63.5	86.4	69.6	78.0
DNB 11-15	84.0	78.5	73.1	75.5	78.6	77.0	77.8
DNB 11-10	79.0	70.0	79.5	80.0	79.3	75.0	77.1
DNB 11-07	81.5	74.0	82.0	68.5	81.8	71.3	76.5
DNB 11-19	81.1	75.5	74.5	72.0	77.8	73.8	75.8
DNB 11-08	67.8	70.8	77.5	79.0	72.7	74.9	73.8
DNB 11-16	80.5	74.5	71.0	64.5	75.8	69.5	72.6
DNB 11-12	81.2	71.2	68.0	66.5	74.6	68.9	71.7
DNB 11-17	91.5	55.0	85.5	48.2	88.5	51.6	70.1
DNB 11-04	88.1	61.5	61.0	61.5	74.6	61.5	68.0
MEX142*	66.5	66.5	68.0	65.0	67.3	65.8	66.5
DNB 11-18	65.5	60.7	62.0	58.0	63.8	59.4	61.6
DNB 11-13	32.5	20.5	51.0	27.0	41.8	23.8	32.8
Mean of genotypes	**78.8**	**68.6**	**77.3**	**67.6**	**78.1**	**68.1**	**73.1**
Mean of checks	**66.5**	**66.5**	**68.0**	**65.0**	**67.3**	**65.8**	**66.5**
Overall mean	**72.7**	**67.6**	**72.7**	**66.3**	**72.7**	**66.9**	**69.8**
CV(%)		12.1					
LSD(P≤0.05)S	10.2NS	LSD(P≤0.05)SXG		11.8*			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		11.8**			
LSD(P≤0.05)G	8.3**	LSD(P≤0.05)SXTXG		16.7NS			
LSD(P≤0.05)SXT	4.6NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.15: Pod partitioning indices (PPI) of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PPI (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SER76*	84.1	68.9	82.5	69.5	83.3	69.2	76.3
SER16*	79.5	67.5	74.5	78.5	77.0	73.0	75.0
DSR 11-22	72.5	66.0	78.5	79.5	75.5	72.8	74.1
SEA15*	74.3	64.5	78.5	78.7	76.4	71.6	74.0
DSR 11-14	82.3	82.0	74.0	53.7	78.2	67.9	73.0
DSR 11-09	79.5	61.8	73.3	77.2	76.4	69.5	73.0
DSR 11-13	70.5	70.0	80.4	69.5	75.5	69.8	72.6
RCB231*	74.1	64.0	78.0	68.0	76.1	66.0	71.0
DSR 11-20	77.5	65.0	75.5	64.5	76.5	64.8	70.6
DSR 11-02	80.5	66.5	63.7	70.9	72.1	68.7	70.4
RAB651*	79.5	56.5	69.5	74.4	74.5	65.5	70.0
DSR 11-15	72.5	64.5	73.0	69.3	72.8	66.9	69.8
DSR 11-01	71.5	69.3	75.5	60.0	73.5	64.7	69.1
DSR 11-04	69.0	60.0	73.5	63.3	71.3	61.7	66.5
DSR 11-06	69.4	55.5	79.1	61.5	74.3	58.5	66.4
DSR 11-05	65.3	59.0	71.5	68.3	68.4	63.7	66.0
DSR 11-08	71.5	62.9	63.2	62.5	67.4	62.7	65.0
DSR 11-23	66.5	50.0	74.0	67.8	70.3	58.9	64.6
DSR 11-18	72.0	54.5	63.5	65.0	67.8	59.8	63.8
DSR 11-24	83.7	44.5	73.0	44.2	78.4	44.4	61.4
SER155*	73.5	55.5	68.5	47.5	71.0	51.5	61.3
RCB270*	56.6	52.7	72.3	58.0	64.5	55.4	59.9
DSR 11-12	66.0	55.8	61.0	55.5	63.5	55.7	59.6
TIO CANELA*	56.8	54.5	67.5	56.0	62.2	55.3	58.7
DSR 11-03	81.5	36.0	79.0	36.0	80.3	36.0	58.1
DSR 11-21	70.3	37.5	68.6	34.3	69.5	35.9	52.7
RCB592*	58.5	49.7	63.5	35.8	61.0	42.8	51.9
DSR 11-10	55.3	41.8	58.7	44.2	57.0	43.0	50.0
SER95*	64.0	39.5	51.0	26.0	57.5	32.8	45.1
DSR 11-07	38.0	38.0	66.6	32.5	52.3	35.3	43.8
KATB9*	64.0	27.0	49.1	32.8	56.6	29.9	43.2
DSR 11-19	45.0	22.5	51.0	31.5	48.0	27.0	37.5
DSR 11-11	43.0	27.5	48.5	29.0	45.8	28.3	37.0
GLP585*	37.0	28.5	35.2	28.5	36.1	28.5	32.3
DSR 11-16	34.5	25.5	29.5	26.5	32.0	26.0	29.0
Mean of genotypes	**66.9**	**52.9**	**70.3**	**55.1**	**68.6**	**54.0**	**61.3**
Mean of checks	**66.8**	**52.4**	**65.8**	**54.5**	**66.3**	**53.5**	**59.9**
Overall mean	**66.9**	**52.7**	**68.1**	**54.8**	**67.5**	**53.7**	**60.6**
CV(%)		12.1					
LSD(P≤0.05)S	10.2NS	LSD(P≤0.05)SXG		11.8*			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		11.8**			
LSD(P≤0.05)G	8.3**	LSD(P≤0.05)SXTXG		16.7NS			
LSD(P≤0.05)SXT	4.6NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

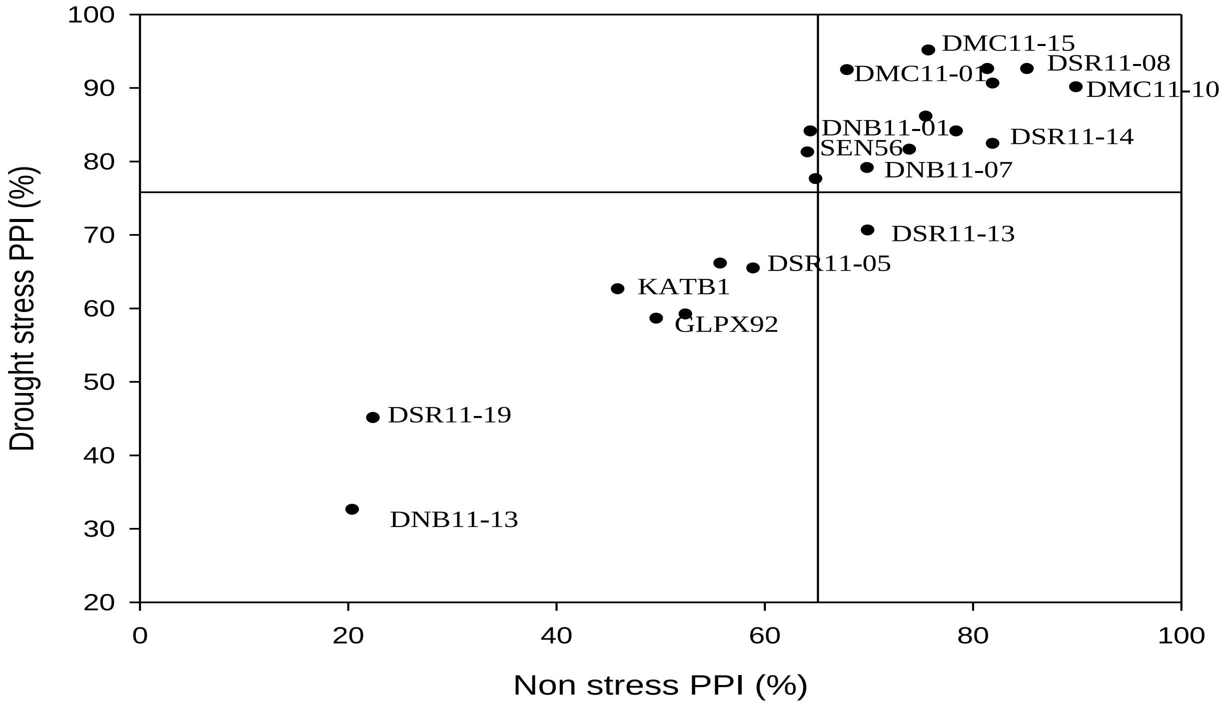


Figure 5.2: Correlation between non stress and drought stress pod partitioning indices of 23 small seeded bean lines grown at Kabete Field Station over two seasons.

5.4.6. Effect of drought on pod harvest index

Pod harvest indices (PHI) of most genotypes differed in the two seasons. During the first season when drought was less severe, genotypes showed high PHI of above 60% (Table 5.16, 5.17, 5.18). However, during the second season when drought stress was more severe, they showed low PHI which ranged between 40% and 46%. Genotypes significantly differed ($p \leq 0.001$) in their PHI ranging from 35% to 77% especially under drought stress. The interaction of season with genotype had a significant effect ($p \leq 0.001$) on the PHI of beans (Table 5.16, 5.17, 5.18). In both seasons, navy beans recorded the highest PHI under both drought stress and non stress conditions followed by small reds and mixed colours. Mixed coloured genotypes such as DMC11-01, DMC11-24, NCB226 (check), NCB280 (check), DMC11-02, DMC11-14 and DMC11-20 recorded high PHI (>60%) compared to the other genotypes and most checks in the same market class. All genotypes in this market class recorded harvest indices of over 50% and were comparable to the checks (Table 5.16). Navy beans such as DNB11-15, DNB11-07, DNB11-06, DNB11-05, DNB11-10 and DNB11-01 recorded PHI of over 65% in the two seasons compared to the other genotypes in the same market class and the check MEX142. All the genotypes in this market class recorded over 54% pod harvest indices which was similar to that of mixed colours (Table 5.17). Among the small reds, DSR11-04, DSR11-23, DSR11-13, DSR11-03 and SER95 recorded over 65% PHI in the two seasons. However, other genotypes in this market class were comparable to checks with 57% pod harvest indices (Table 5.18).

Pod harvest indices of genotypes such as DNB11-06, DNB11-15, DMC11-24 and DMC11-01 were high under both drought stress and non stress treatments. Other genotypes including DSR11-13, DSR11-18 and DNB11-07 recorded below average pod harvest indices under non stress conditions (Figure 5.3). In correlation with grain yield under drought stress, genotypes such as DMC11-10 with high pod harvest indices had high yield (Figure 5.4). However, a high pod harvest index did not always translate to higher yield. For instance, checks including KATB9, KATB1, SER16 and GLPX92 had high PHI but low yield (Figure 5.4).

Table 5.16: Pod harvest indices (PHI) of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012

	PHI (%)						
	Season 1		**Season 2**				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-01	71.0	87.0	62.5	78.5	66.8	82.8	74.8
DMC 11-24	70.2	74.8	61.0	64.5	65.6	69.7	67.6
NCB226*	72.0	73.2	55.0	65.5	63.5	69.4	66.4
NCB280*	69.2	72.7	52.0	65.0	60.6	68.9	64.7
DMC 11-02	61.7	74.0	61.0	60.0	61.4	67.0	64.2
DMC 11-14	70.9	75.3	53.0	57.1	62.0	66.2	64.1
DMC 11-20	68.9	74.7	53.8	56.5	61.4	65.6	63.5
DMC 11-10	69.6	74.3	49.0	60.6	59.3	67.5	63.4
DMC 11-22	66.2	72.9	54.0	58.5	60.1	65.7	62.9
DMC 11-09	72.0	77.2	50.5	50.0	61.3	63.6	62.4
DMC 11-21	62.1	75.7	57.0	54.5	59.6	65.1	62.3
DMC 11-05	69.0	74.4	44.5	59.0	56.8	66.7	61.7
DMC 11-17	69.4	69.4	49.0	58.5	59.2	64.0	61.6
DMC 11-03	69.3	73.8	39.5	63.0	54.4	68.4	61.4
DMC 11-04	65.0	74.2	46.0	60.1	55.5	67.2	61.3
DMC 11-07	65.7	76.9	42.0	60.6	53.9	68.8	61.3
DMC 11-06	61.5	69.0	42.5	67.5	52.0	68.3	60.1
DMC 11-23	65.7	67.0	51.0	56.0	58.4	61.5	59.9
DMC 11-16	65.6	71.5	43.0	59.5	54.3	65.5	59.9
DMC 11-13	57.3	69.0	53.0	58.0	55.2	63.5	59.3
DMC 11-15	58.0	64.5	56.0	57.5	57.0	61.0	59.0
SEN53*	62.7	65.4	52.5	54.5	57.6	60.0	58.8
GLPX92*	64.2	73.8	38.0	58.0	51.1	65.9	58.5
DMC 11-18	64.5	76.5	44.1	48.5	54.3	62.5	58.4
DMC 11-19	60.5	75.9	35.5	60.1	48.0	68.0	58.0
DMC 11-08	65.8	70.2	42.3	52.5	54.1	61.4	57.7
DMC 11-12	58.7	67.6	49.0	54.0	53.9	60.8	57.3
SXB404*	61.5	63.6	48.5	54.5	55.0	59.1	57.0
KATB1*	63.2	71.8	36.5	55.5	49.9	63.7	56.8
DMC 11-11	58.5	63.3	47.0	55.0	52.8	59.2	56.0
SEN56*	57.3	66.3	46.5	53.0	51.9	59.7	55.8
Mean of genotypes	**65.3**	**72.9**	**49.4**	**58.8**	**57.4**	**65.9**	**61.6**
Mean of checks	**64.3**	**69.5**	**47.0**	**58.0**	**55.7**	**63.8**	**59.7**
Overall mean	**64.8**	**71.2**	**48.2**	**58.4**	**56.5**	**64.8**	**60.7**
CV(%)		7.3					
LSD(P≤0.05)S	22.8NS	LSD(P≤0.05)SXG		7.8**			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		6.5**			
LSD(P≤0.05)G	4.5**	LSD(P≤0.05)SXTXG		9.9NS			
LSD(P≤0.05)SXT	17.4NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.17: Pod harvest indices (PHI) of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PHI (%)						
	Season 1		**Season 2**				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-15	70.7	73.7	63.5	70.0	67.1	71.9	69.5
DNB 11-07	69.2	72.5	66.5	69.5	67.9	71.0	69.4
DNB 11-06	73.2	74.9	60.0	66.5	66.6	70.7	68.7
DNB 11-05	71.3	75.6	56.5	65.5	63.9	70.6	67.2
DNB 11-10	72.6	74.9	58.8	62.5	65.7	68.7	67.2
DNB 11-01	69.4	73.6	61.5	62.0	65.5	67.8	66.6
DNB 11-12	68.5	76.3	54.0	67.0	61.3	71.7	66.5
DNB 11-04	70.2	75.5	53.5	62.5	61.9	69.0	65.4
DNB 11-17	68.1	73.4	54.5	63.0	61.3	68.2	64.8
DNB 11-13	64.4	76.4	54.0	64.0	59.2	70.2	64.7
DNB 11-14	70.6	71.8	52.5	62.5	61.6	67.2	64.4
DNB 11-03	67.2	74.5	48.0	67.5	57.6	71.0	64.3
DNB 11-16	72.8	74.0	49.7	60.5	61.3	67.3	64.3
DNB 11-09	69.5	76.4	48.0	58.0	58.8	67.2	63.0
DNB 11-19	60.4	72.0	55.3	60.5	57.9	66.3	62.1
DNB 11-08	63.2	72.5	48.5	55.0	55.9	63.8	59.8
MEX142*	61.1	68.2	46.2	59.0	53.7	63.6	58.6
DNB 11-18	56.0	59.7	45.3	57.5	50.7	58.6	54.6
Mean of genotypes	**68.1**	**73.4**	**54.7**	**63.2**	**61.4**	**68.3**	**64.9**
Mean of checks	**61.1**	**68.2**	**46.2**	**59.0**	**53.7**	**63.6**	**58.6**
Overall mean	**64.6**	**70.8**	**50.5**	**61.1**	**57.5**	**66.0**	**61.7**
CV(%)		7.3					
LSD(P≤0.05)S	22.8NS	LSD(P≤0.05)SXG		7.8**			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		6.5**			
LSD(P≤0.05)G	4.5**	LSD(P≤0.05)SXTXG		9.9NS			
LSD(P≤0.05)SXT	17.4NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.18: Pod harvest indices (PHI) of advanced small red lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PHI (%)						
	Season 1		**Season 2**				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-04	71.8	74.5	54.3	67.5	63.1	71.0	67.0
DSR 11-23	65.6	73.2	62.5	66.5	64.1	69.9	67.0
DSR 11-13	71.8	72.3	53.5	67.5	62.7	69.9	66.3
DSR 11-03	66.0	72.8	59.5	66.5	62.8	69.7	66.2
SER95*	69.5	73.5	57.5	62.4	63.5	68.0	65.7
DSR 11-09	60.6	68.2	63.6	70.0	62.1	69.1	65.6
RCB231*	69.4	74.9	55.0	60.5	62.2	67.7	65.0
DSR 11-12	67.0	71.5	57.5	62.5	62.3	67.0	64.6
DSR 11-19	69.9	72.1	55.5	61.0	62.7	66.6	64.6
DSR 11-06	64.9	73.9	52.0	67.0	58.5	70.5	64.5
RCB592*	65.0	73.5	59.5	59.5	62.3	66.5	64.4
DSR 11-01	67.5	73.9	58.0	57.3	62.8	65.6	64.2
DSR 11-05	68.4	72.3	54.0	61.5	61.2	66.9	64.1
DSR 11-02	66.6	70.6	57.0	62.0	61.8	66.3	64.1
DSR 11-22	66.3	76.3	53.0	59.4	59.7	67.9	63.8
TIO CANELA*	61.3	72.3	52.0	68.0	56.7	70.2	63.4
DSR 11-20	71.1	72.3	51.5	57.5	61.3	64.9	63.1
RCB270*	63.7	72.6	57.0	56.9	60.4	64.8	62.6
DSR 11-18	64.9	71.3	55.0	56.8	60.0	64.1	62.0
SER76*	60.9	75.5	54.0	57.0	57.5	66.3	61.9
DSR 11-21	56.8	71.7	54.5	63.6	55.7	67.7	61.7
SER16*	65.9	70.9	54.0	55.5	60.0	63.2	61.6
SER155*	64.1	69.5	51.8	60.5	58.0	65.0	61.5
DSR 11-07	64.3	74.8	51.8	54.8	58.1	64.8	61.4
KATB9*	66.5	65.5	56.5	57.0	61.5	61.3	61.4
RAB651*	62.6	60.5	55.5	66.5	59.1	63.5	61.3
DSR 11-16	66.0	73.0	48.0	57.5	57.0	65.3	61.1
DSR 11-11	60.5	69.3	56.5	57.5	58.5	63.4	61.0
GLP585*	68.7	71.6	44.5	59.0	56.6	65.3	61.0
DSR 11-08	64.4	70.9	52.0	55.5	58.2	63.2	60.7
DSR 11-10	66.1	72.3	49.0	54.4	57.6	63.4	60.5
DSR 11-14	64.7	68.8	50.5	57.0	57.6	62.9	60.3
DSR 11-15	56.9	65.0	55.5	62.5	56.2	63.8	60.0
DSR 11-24	64.4	64.2	50.5	55.7	57.5	60.0	58.7
SEA15*	56.0	60.3	54.0	61.0	55.0	60.7	57.8
Mean of genotypes	**65.5**	**71.5**	**54.6**	**60.9**	**60.1**	**66.2**	**63.1**
Mean of checks	**64.5**	**70.0**	**54.3**	**60.3**	**59.4**	**65.2**	**62.3**
Overall mean	**65.0**	**70.8**	**54.5**	**60.6**	**59.7**	**65.7**	**62.7**
CV(%)		7.3					
LSD(P≤0.05)S	22.8NS	LSD(P≤0.05)SXG		7.8**			
LSD(P≤0.05)T	2.1*	LSD(P≤0.05)TXG		6.5**			
LSD(P≤0.05)G	4.5**	LSD(P≤0.05)SXTXG		9.9NS			
LSD(P≤0.05)SXT	17.4NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

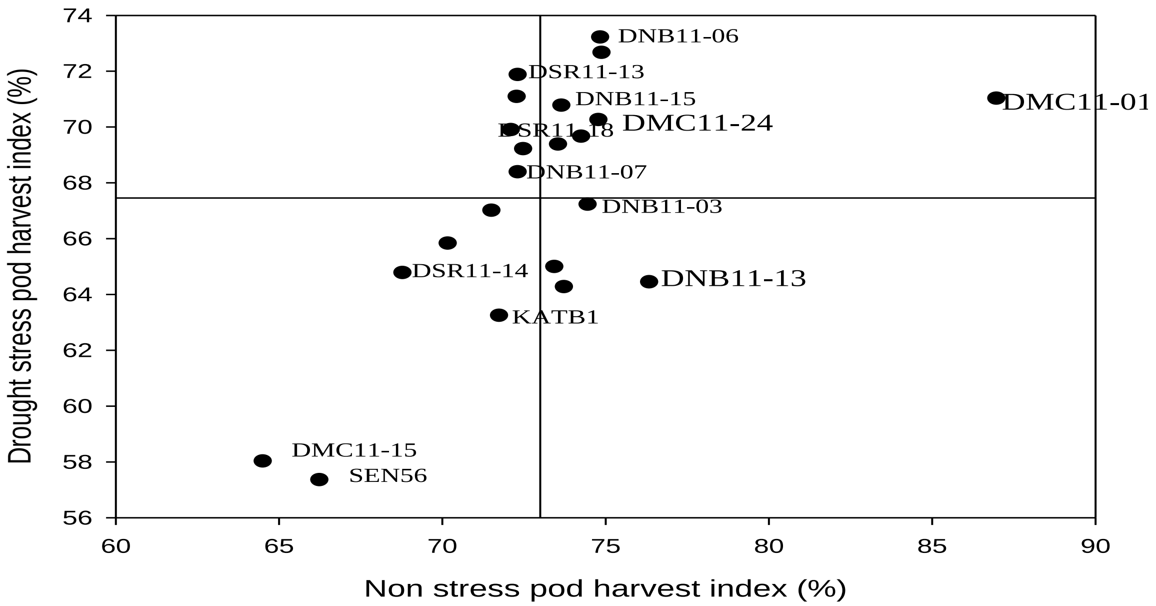


Figure 5.3: Comparison between irrigated and non irrigated PHI of the top 23 genotypes grown over two seasons in Kabete.

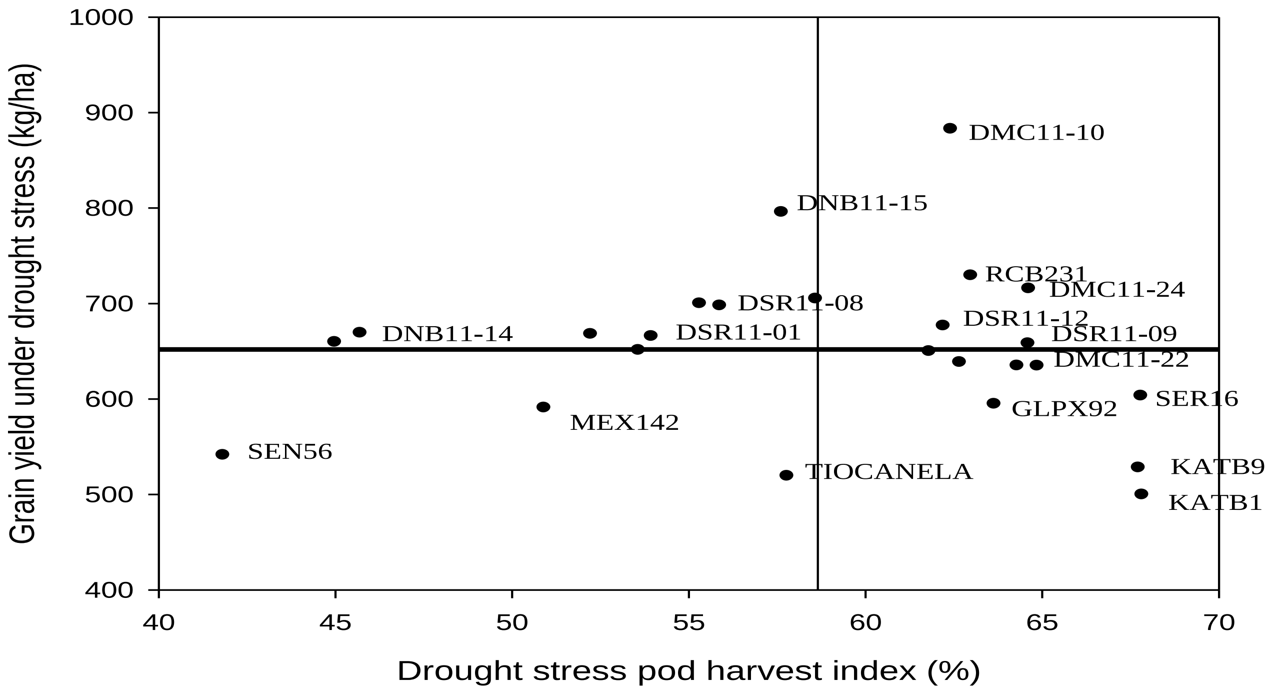


Figure 5.4: Correlation between grain yield and pod harvest index of 23 genotypes selected at random from the three market classes under rainfed conditions.

5.4.7. Effect of drought on pod wall biomass proportion

Pod wall biomass of most genotypes under the two treatments differed between the two seasons with the first season recording higher PWBP values than the second season (Table 5.19, 5.20, 5.21). Significant differences ($p \leq 0.001$) were observed in the pod wall biomasses among the genotypes under the two treatments. Season did not have an effect on the pod biomass accumulation by genotypes but its interaction with drought stress or genotype had significant effects. The interaction between treatment and genotype had a significant effect ($p \leq 0.001$) on the pod wall biomass proportion (Table 5.19). Mixed coloured genotypes recorded higher pod wall biomass proportion than small reds and navy beans. Within the mixed colours, genotypes such as DMC11-12, DMC11-01, DMC11-13, SEN56 (check) and DMC11-13 had the highest pod wall biomasses of over 36% in the two seasons compared to the other genotypes in the same market class and most checks. However, less than 25% pod wall biomass proportions were recorded on some genotypes in this market class including DMC11-06, DMC11-24 and SEN53 (Table 5.19). Most navy beans including DNB11-08, DNB11-18, DNB11-01, DNB11-16, DNB11-12 and DNB11-19 had high pod wall biomass of over 25% compared to the check MEX142 and DNB11-03 which had pod wall biomass of 23% (Table 5.20). Among the small reds, DSR11-09 had the highest pod wall biomass of 43% compared to the other genotypes in the same market class and the checks. Most genotypes and checks in this market class including DSR11-05, RCB592 (check), DSR11-06, KATB9 (check), RAB651 (check), DSR11-24, SER155 (check), DSR11-15 and DSR11-14 recorded over 30% pod wall biomass proportion. Less than 23 % pod wall biomass proportion was recorded by Tio canela (check), DSR11-13, DSR11-23, and DSR11-21. However, most genotypes and checks in this market class were comparable in their pod wall biomass proportion (Table 5.21). Biplot analysis showed that whereas some genotypes with high pod wall biomass proportion had low yield like Tio canela, MEX142 and SEN56, others such as DNB11-07 and DSR11-08 had high yield. Genotypes DMC11-10, DMC11-24, RCB231 and DSR11-12 had low pod wall biomass proportion but high rainfed grain yield (Figure 5.5)

Table 5.19: Pod wall biomass proportion (PWBP) of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PWBP (%)						
	Season 1		**Season 2**				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-12	36.3	37.3	35.7	43.0	36.0	40.2	38.1
DMC 11-01	34.0	43.0	32.5	42.5	33.3	42.8	38.0
DMC 11-13	32.6	40.8	34.0	43.1	33.3	42.0	37.6
SEN56*	37.7	34.0	35.0	43.7	36.4	38.9	37.6
DMC 11-03	30.7	40.8	33.5	44.3	32.1	42.6	37.3
DMC 11-08	29.3	40.2	33.0	44.5	31.2	42.4	36.8
DMC 11-07	34.3	38.1	30.5	42.4	32.4	40.3	36.3
DMC 11-23	37.7	39.0	25.4	35.0	31.6	37.0	34.3
DMC 11-14	29.1	31.2	34.5	38.8	31.8	35.0	33.4
DMC 11-11	31.1	36.7	26.5	34.4	28.8	35.6	32.2
DMC 11-19	29.4	34.5	26.0	37.5	27.7	36.0	31.9
DMC 11-05	29.7	30.4	30.7	36.0	30.2	33.2	31.7
DMC 11-02	28.5	36.0	25.5	36.5	27.0	36.3	31.6
DMC 11-20	31.1	35.5	23.5	34.0	27.3	34.8	31.0
DMC 11-17	25.8	35.5	29.7	31.5	27.8	33.5	30.6
DMC 11-15	31.3	35.5	21.5	34.0	26.4	34.8	30.6
KATB1*	27.0	33.3	24.4	37.0	25.7	35.2	30.4
SXB404*	28.4	31.4	20.0	40.0	24.2	35.7	30.0
NCB226*	28.0	37.0	23.5	31.0	25.8	34.0	29.9
GLPX92*	26.0	36.0	24.5	31.0	25.3	33.5	29.4
DMC 11-18	25.5	32.0	25.5	32.0	25.5	32.0	28.8
DMC 11-04	23.0	35.0	22.5	34.4	22.8	34.7	28.7
DMC 11-16	24.6	26.9	28.6	33.0	26.6	30.0	28.3
DMC 11-21	23.0	29.6	30.8	28.9	26.9	29.3	28.1
DMC 11-22	22.0	27.1	26.0	36.6	24.0	31.9	27.9
NCB280*	26.0	32.5	22.0	28.0	24.0	30.3	27.1
DMC 11-09	27.0	27.6	15.0	31.3	21.0	29.5	25.2
DMC 11-10	25.3	30.5	19.5	24.9	22.4	27.7	25.1
DMC 11-06	20.7	26.2	24.1	28.5	22.4	27.4	24.9
DMC 11-24	24.6	29.9	22.3	20.6	23.5	25.3	24.4
SEN53*	17.5	24.6	21.6	28.3	19.6	26.5	23.0
Mean of genotypes	**28.6**	**34.1**	**27.4**	**35.3**	**28.0**	**34.7**	**31.4**
Mean of checks	**27.2**	**32.7**	**24.4**	**34.1**	**25.8**	**33.4**	**29.6**
Overall mean	**27.9**	**33.4**	**25.9**	**34.7**	**26.9**	**34.1**	**30.5**
CV(%)		13					
LSD(P≤0.05)S	4.5NS	LSD(P≤0.05)SXG		5.4**			
LSD(P≤0.05)T	0.3**	LSD(P≤0.05)TXG		5.3**			
LSD(P≤0.05)G	3.8**	LSD(P≤0.05)SXTXG		7.6NS			
LSD(P≤0.05)SXT	3.7*						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.20: Pod wall biomass proportion (PWBP) of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PWBP (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-08	27.1	37.0	24.0	37.4	25.6	37.2	31.4
DNB 11-18	31.5	36.5	23.0	33.0	27.3	34.8	31.0
DNB 11-01	30.6	36.5	28.0	28.7	29.3	32.6	31.0
DNB 11-17	27.0	36.5	23.5	34.5	25.3	35.5	30.4
DNB 11-16	27.2	30.9	25.5	33.6	26.4	32.3	29.3
DNB 11-12	26.7	33.7	22.0	33.5	24.4	33.6	29.0
DNB 11-19	24.5	32.9	25.0	30.5	24.8	31.7	28.2
DNB 11-15	24.4	31.1	25.5	31.0	25.0	31.1	28.0
DNB 11-04	29.8	34.5	25.0	22.5	27.4	28.5	28.0
DNB 11-10	26.0	30.3	22.5	32.5	24.3	31.4	27.8
DNB 11-13	25.4	29.7	18.0	33.5	21.7	31.6	26.7
DNB 11-09	25.7	28.7	21.0	31.0	23.4	29.9	26.6
DNB 11-14	28.6	28.2	22.0	27.0	25.3	27.6	26.5
DNB 11-05	24.5	29.4	21.0	29.9	22.8	29.7	26.2
DNB 11-07	24.6	27.5	22.0	23.0	23.3	25.3	24.3
DNB 11-06	23.6	27.6	21.0	22.8	22.3	25.2	23.8
MEX142*	22.9	27.2	20.0	24.5	21.5	25.9	23.7
DNB 11-03	17.5	25.5	21.0	28.5	19.3	27.0	23.1
Mean of genotypes	**26.2**	**31.6**	**22.9**	**30.2**	**24.6**	**30.9**	**27.7**
Mean of checks	**22.9**	**27.2**	**20.0**	**24.5**	**21.5**	**25.9**	**23.7**
Overall mean	**24.6**	**29.4**	**21.5**	**27.4**	**23.0**	**28.4**	**25.7**
CV(%)		13					
LSD(P≤0.05)S	4.5NS	LSD(P≤0.05)SXG		5.4**			
LSD(P≤0.05)T	0.3**	LSD(P≤0.05)TXG		5.3**			
LSD(P≤0.05)G	3.8**	LSD(P≤0.05)SXTXG		7.6NS			
LSD(P≤0.05)SXT	3.7*						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.21: Pod wall biomass proportion (PWBP) of advanced small red bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	PWBP (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-09	34.2	56.9	29.1	54.5	31.7	55.7	43.7
DSR 11-05	31.6	42.5	22.5	45.9	27.1	44.2	35.6
RCB592*	35.0	38.5	24.4	39.5	29.7	39.0	34.4
DSR 11-06	35.1	41.5	26.7	32.3	30.9	36.9	33.9
KATB9*	33.5	36.0	26.1	38.4	29.8	37.2	33.5
RAB651*	32.6	44.5	22.0	33.0	27.3	38.8	33.0
DSR 11-24	30.7	35.8	28.0	34.5	29.4	35.2	32.3
SER155*	30.7	35.7	23.2	38.5	27.0	37.1	32.0
DSR 11-15	27.9	36.0	27.5	36.0	27.7	36.0	31.9
DSR 11-14	25.3	36.3	27.1	38.5	26.2	37.4	31.8
DSR 11-04	23.4	30.3	26.0	46.7	24.7	38.5	31.6
DSR 11-08	25.4	38.9	24.0	37.9	24.7	38.4	31.6
DSR 11-18	25.1	33.7	26.5	39.8	25.8	36.8	31.3
DSR 11-20	28.9	37.5	22.0	35.9	25.5	36.7	31.1
DSR 11-07	25.7	35.0	28.0	34.9	26.9	35.0	30.9
RCB270*	26.3	37.7	22.5	36.7	24.4	37.2	30.8
DSR 11-02	28.4	34.5	23.0	37.3	25.7	35.9	30.8
SER95*	25.6	36.5	22.5	36.5	24.1	36.5	30.3
DSR 11-22	25.8	36.5	24.0	34.5	24.9	35.5	30.2
DSR 11-16	24.0	32.1	24.0	35.9	24.0	34.0	29.0
SER16*	24.3	31.3	25.0	33.5	24.7	32.4	28.5
DSR 11-01	25.9	28.6	24.5	35.0	25.2	31.8	28.5
DSR 11-11	24.5	30.7	22.0	34.0	23.3	32.4	27.8
SER76*	24.3	29.8	23.0	33.5	23.7	31.7	27.7
DSR 11-12	23.0	28.5	23.0	35.3	23.0	31.9	27.5
DSR 11-10	24.0	32.6	16.5	35.5	20.3	34.1	27.2
RCB231*	20.5	25.1	25.0	37.1	22.8	31.1	26.9
DSR 11-19	23.4	28.0	24.5	28.9	24.0	28.5	26.2
SEA15*	24.0	29.9	21.5	28.0	22.8	29.0	25.9
GLP585*	21.3	28.4	21.3	28.3	21.3	28.4	24.8
DSR 11-03	24.9	27.2	15.0	26.3	20.0	26.8	23.4
TIO CANELA*	19.0	24.2	16.0	33.0	17.5	28.6	23.1
DSR 11-13	23.1	27.7	16.5	22.0	19.8	24.9	22.3
DSR 11-23	19.5	26.8	19.5	22.0	19.5	24.4	22.0
DSR 11-21	23.0	28.3	12.0	23.5	17.5	25.9	21.7
Mean of genotypes	**26.2**	**34.2**	**23.1**	**35.1**	**24.7**	**34.7**	**29.7**
Mean of checks	**26.4**	**33.1**	**22.7**	**34.7**	**24.6**	**33.9**	**29.2**
Overall mean	**26.3**	**33.7**	**22.9**	**34.9**	**24.6**	**34.3**	**29.4**
CV(%)		13					
LSD(P≤0.05)S	4.5NS	LSD(P≤0.05)SXG	5.4**				
LSD(P≤0.05)T	0.3**	LSD(P≤0.05)TXG	5.3**				
LSD(P≤0.05)G	3.8**	LSD(P≤0.05)SXTXG	7.6NS				
LSD(P≤0.05)SXT	3.7*						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

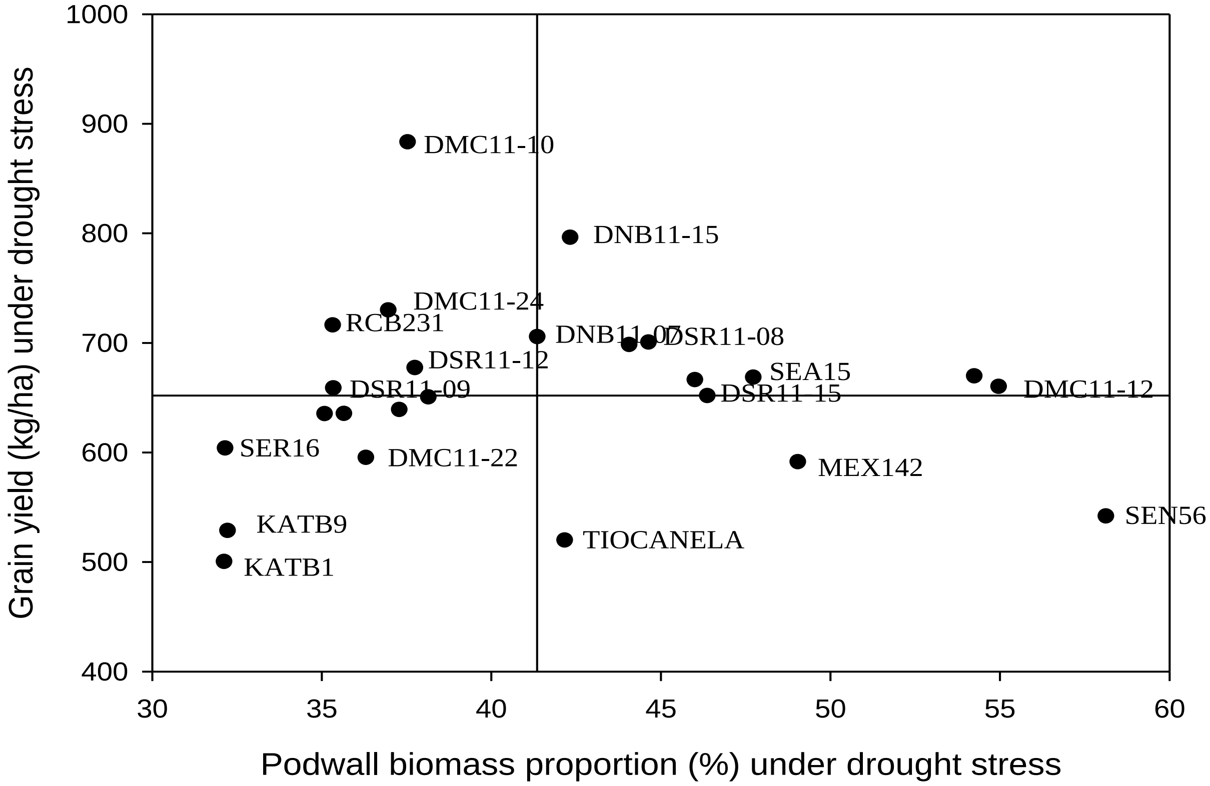


Figure 5.5: Correlation between grain yield and pod wall biomass proportion of 23 genotypes selected at random from the three market classes under rainfed conditions in Kabete.

5.4.8. Effect of drought on Stem biomass reduction (SBR)

The SBR of most genotypes was significantly different ($p \leq 0.05$) under drought stress and non drought stress conditions. Season on its own did not affect the stem reduction of all genotypes under drought stress and non stress treatments, but its interaction with genotype or stress level had significant ($p \leq 0.001$) effects on this parameter (Table 5.22). Of the three market classes, navy beans recorded the highest SBR under drought conditions followed by small reds and mixed colours. Genotypes such as DMC11-21, DMC11-15, DMC11-03, DMC11-17, DMC11-07, DMC11-19, DMC11-01 and DMC11-02 in the mixed colours market class recorded a positive SBR of up to 33% under drought stress. Other genotypes in this group under no stress had negative stem biomass reduction and included DMC11-24, DMC11-10, DMC11-05, DMC11-18, NCB280 (check), DMC11-16, GLPX92 (check) and KATB1 (check). In this market class most checks recorded a negative stem biomass reduction compared to the test genotypes (Table 5.22). Most navy beans including DNB11-07, DNB11-

01, DNB11-17, DNB11-03, DNB11-16, DNB11-18, DNB11-15 and DNB11-10 recorded a positive stem biomass reduction which was up to 30% under drought stress. The check MEX142 recorded a negative stem biomass reduction which was comparable with some genotypes including DNB11-04, DNB11-12 and DNB11-08 (Table 5.23). Among the small reds, most genotypes under drought stress had a positive stem biomass reduction which was up to 35%. These included DSR11-08, DSR11-23, DSR11-02, DSR11-03, DSR11-21, DSR11-13, DSR11-20 and DSR11-06. However, under no stress genotypes such as DSR11-24, DSR11-16, DSR11-14 and checks like RCB592, SER16, SER76, and RCB270 recorded negative stem biomass reduction over the two seasons (Table 5.24). Stem biomass reduction was negative under no stress and positive under drought stress in both seasons (Figure 5.6).

Table 5.22: Stem biomass reduction (SBR) of advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012

	SBR (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-21	82.0	-20.5	94.5	-23.0	88.3	-21.8	33.3
DMC 11-15	86.0	-34.5	95.5	-28.0	90.8	-31.3	29.8
DMC 11-03	46.0	-11.4	43.0	-21.0	44.5	-16.2	14.2
DMC 11-17	25.5	-14.6	34.0	-17.5	29.8	-16.1	6.9
DMC 11-07	30.0	-22.3	32.5	-23.5	31.3	-22.9	4.2
DMC 11-19	81.5	-83.3	97.0	-79.2	89.3	-81.3	4.0
DMC 11-01	25.0	-14.5	21.0	-18.5	23.0	-16.5	3.3
DMC 11-02	25.5	-15.5	17.0	-16.0	21.3	-15.8	2.8
DMC 11-08	76.5	-62.5	66.5	-69.5	71.5	-66.0	2.8
DMC 11-11	32.0	-21.2	21.0	-23.5	26.5	-22.4	2.1
DMC 11-06	77.0	-71.5	64.7	-62.0	70.9	-66.8	2.1
SXB404*	26.0	-23.7	23.5	-21.0	24.8	-22.4	1.2
DMC 11-23	24.5	-25.0	23.5	-21.0	24.0	-23.0	0.5
DMC 11-24	35.5	-38.5	35.5	-35.0	35.5	-36.8	-0.6
DMC 11-10	84.0	-94.1	96.0	-96.0	90.0	-95.1	-2.5
DMC 11-05	28.5	-28.0	14.5	-26.0	21.5	-27.0	-2.8
DMC 11-18	38.0	-44.3	36.5	-44.0	37.3	-44.2	-3.5
NCB280*	52.5	-63.5	56.5	-70.5	54.5	-67.0	-6.3
DMC 11-16	35.0	-49.9	35.5	-46.5	35.3	-48.2	-6.5
GLPX92*	23.5	-35.5	15.5	-33.5	19.5	-34.5	-7.5
KATB1*	79.5	-86.9	72.5	-95.5	76.0	-91.2	-7.6
DMC 11-14	41.5	-54.7	35.5	-53.0	38.5	-53.9	-7.7
DMC 11-04	29.0	-46.2	30.5	-45.5	29.8	-45.9	-8.1
DMC 11-09	40.5	-66.3	39.5	-63.5	40.0	-64.9	-12.5
DMC 11-13	63.0	-94.0	63.5	-95.5	63.3	-94.8	-15.8
SEN56*	27.0	-57.1	24.5	-60.5	25.8	-58.8	-16.5
NCB226*	25.0	-62.5	21.0	-64.0	23.0	-63.3	-20.1
DMC 11-12	68.5	-85.4	14.5	-83.0	41.5	-84.2	-21.4
DMC 11-22	22.5	-70.0	20.0	-83.5	21.3	-76.8	-27.8
DMC 11-20	26.5	-94.5	26.5	-93.0	26.5	-93.8	-33.6
SEN53*	16.5	-77.0	13.0	-93.5	14.8	-85.3	-35.3
Mean of genotypes	**44.3**	**-48.4**	**44.1**	**-48.6**	**44.2**	**-48.5**	**-2.2**
Mean of checks	**35.7**	**-58.0**	**32.4**	**-62.6**	**34.1**	**-60.3**	**-13.1**
Overall mean	**40.0**	**-53.2**	**38.3**	**-55.6**	**39.1**	**-54.4**	**-7.6**
CV(%)		7.5					
LSD(P≤0.05)S	2.2NS	LSD(P≤0.05)SXG		8.8**			
LSD(P≤0.05)T	3.0**	LSD(P≤0.05)TXG		8.9**			
LSD(P≤0.05)G	6.2**	LSD(P≤0.05)SXTXG		12.5**			
LSD(P≤0.05)SXT	2.8NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.23: Stem biomass reduction (SBR) of advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012

Line/market class	SBR (%)						
	Season 1		Season 2				
Navys	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-07	86.0	-33.5	94.0	-23.0	90.0	-28.3	30.9
DNB 11-01	84.5	-44.5	93.0	-45.5	88.8	-45.0	21.9
DNB 11-17	81.5	-46.6	86.5	-40.5	84.0	-43.6	20.2
DNB 11-03	67.0	-31.5	63.0	-23.0	65.0	-27.3	18.9
DNB 11-16	92.0	-60.4	83.5	-71.2	87.8	-65.8	11.0
DNB 11-18	74.0	-44.1	64.5	-53.0	69.3	-48.6	10.4
DNB 11-15	55.5	-42.5	53.5	-43.0	54.5	-42.8	5.9
DNB 11-10	24.5	-14.7	27.5	-15.5	26.0	-15.1	5.5
DNB 11-19	43.5	-34.2	42.5	-32.5	43.0	-33.4	4.8
DNB 11-06	26.5	-20.8	27.0	-16.0	26.8	-18.4	4.2
DNB 11-13	50.5	-61.2	48.0	-45.5	49.3	-53.4	-2.1
DNB 11-09	14.0	-34.0	15.5	-36.0	14.8	-35.0	-10.1
DNB 11-05	64.5	-96.0	70.5	-96.5	67.5	-96.3	-14.4
DNB 11-14	44.0	-68.5	43.0	-85.0	43.5	-76.8	-16.6
MEX142*	26.0	-67.2	23.5	-63.3	24.8	-65.3	-20.3
DNB 11-04	48.5	-81.8	46.0	-95.0	47.3	-88.4	-20.6
DNB 11-12	18.5	-59.4	14.0	-69.5	16.3	-64.5	-24.1
DNB 11-08	20.0	-95.5	24.0	-96.0	22.0	-95.8	-36.9
Mean of genotypes	**52.6**	**-51.1**	**52.7**	**-52.2**	52.7	-51.7	0.5
Mean of checks	**26.0**	**-67.2**	**23.5**	**-63.3**	24.8	-65.3	-20.3
Overall mean	39.3	-59.2	38.1	-57.8	**38.7**	**-58.5**	**-9.9**
CV(%)		7.5					
LSD(P≤0.05)S	2.2NS	LSD(P≤0.05)SXG	8.8**				
LSD(P≤0.05)T	3.0**	LSD(P≤0.05)TXG	8.9**				
LSD(P≤0.05)G	6.2**	LSD(P≤0.05)SXTXG	12.5**				
LSD(P≤0.05)SXT	2.8NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.24: Stem biomass reduction (SBR) of advanced small red bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	SBR (%)						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DSR 11-08	73.5	-15.2	95.5	-13.0	84.5	-14.1	35.2
DSR 11-23	82.5	-47.0	94.5	-49.5	88.5	-48.3	20.1
DSR 11-02	55.0	-22.9	52.5	-16.0	53.8	-19.5	17.2
DSR 11-03	58.0	-33.0	73.0	-36.0	65.5	-34.5	15.5
DSR 11-21	93.5	-49.8	96.0	-96.0	94.8	-72.9	10.9
DSR 11-13	47.0	-38.4	56.0	-36.0	51.5	-37.2	7.2
DSR 11-20	58.0	-43.5	52.0	-46.5	55.0	-45.0	5.0
DSR 11-06	67.5	-63.7	70.0	-55.0	68.8	-59.4	4.7
SER155*	35.5	-16.5	23.5	-24.5	29.5	-20.5	4.5
RAB651*	24.5	-15.5	29.5	-30.5	27.0	-23.0	2.0
DSR 11-22	95.5	-81.5	90.0	-97.0	92.8	-89.3	1.8
SER95*	23.5	-18.1	23.5	-26.5	23.5	-22.3	0.6
DSR 11-10	66.0	-61.7	64.0	-66.5	65.0	-64.1	0.5
RCB231*	84.0	-75.5	85.0	-96.0	84.5	-85.8	-0.6
DSR 11-18	33.5	-42.3	32.5	-28.0	33.0	-35.2	-1.1
DSR 11-19	23.0	-31.3	23.5	-25.5	23.3	-28.4	-2.6
DSR 11-04	62.0	-74.5	64.5	-64.3	63.3	-69.4	-3.1
KATB9*	28.5	-31.5	23.0	-32.5	25.8	-32.0	-3.1
DSR 11-09	86.0	-96.7	91.0	-96.0	88.5	-96.4	-3.9
DSR 11-01	22.5	-33.8	24.5	-34.5	23.5	-34.2	-5.3
DSR 11-07	21.5	-37.5	24.5	-35.5	23.0	-36.5	-6.8
SEA15*	27.5	-43.8	23.0	-40.5	25.3	-42.2	-8.5
DSR 11-15	21.0	-40.1	38.0	-54.8	29.5	-47.5	-9.0
DSR 11-05	16.5	-34.5	12.5	-30.5	14.5	-32.5	-9.0
DSR 11-11	41.0	-83.5	43.0	-48.0	42.0	-65.8	-11.9
GLP585*	24.5	-42.5	23.0	-55.8	23.8	-49.2	-12.7
TIO CANELA*	43.5	-71.0	42.5	-65.8	43.0	-68.4	-12.7
DSR 11-24	42.5	-63.5	44.5	-75.5	43.5	-69.5	-13.0
DSR 11-16	55.0	-94.3	52.5	-96.5	53.8	-95.4	-20.8
DSR 11-14	50.0	-83.2	38.0	-95.0	44.0	-89.1	-22.6
RCB592*	25.5	-74.2	23.5	-84.0	24.5	-79.1	-27.3
SER16*	23.0	-91.9	22.5	-82.5	22.8	-87.2	-32.2
SER76*	13.5	-80.6	15.0	-79.3	14.3	-80.0	-32.9
RCB270*	27.0	-91.0	23.5	-95.5	25.3	-93.3	-34.0
DSR 11-12	54.5	-82.4	-55.0	-93.5	-0.3	-88.0	-44.1
Mean of genotypes	**53.3**	**-54.5**	**51.2**	**-56.1**	**52.3**	**-55.3**	**-1.5**
Mean of checks	**31.7**	**-54.3**	**29.8**	**-59.5**	**30.8**	**-56.9**	**-13.1**
Overall mean	**42.5**	**-54.4**	**40.5**	**-57.8**	**41.5**	**-56.1**	**-7.3**
CV(%)		7.5					
LSD(P≤0.05)S	2.2NS	LSD(P≤0.05)SXG		8.8**			
LSD(P≤0.05)T	3.0**	LSD(P≤0.05)TXG		8.9**			
LSD(P≤0.05)G	6.2**	LSD(P≤0.05)SXTXG		12.5**			
LSD(P≤0.05)SXT	2.8NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

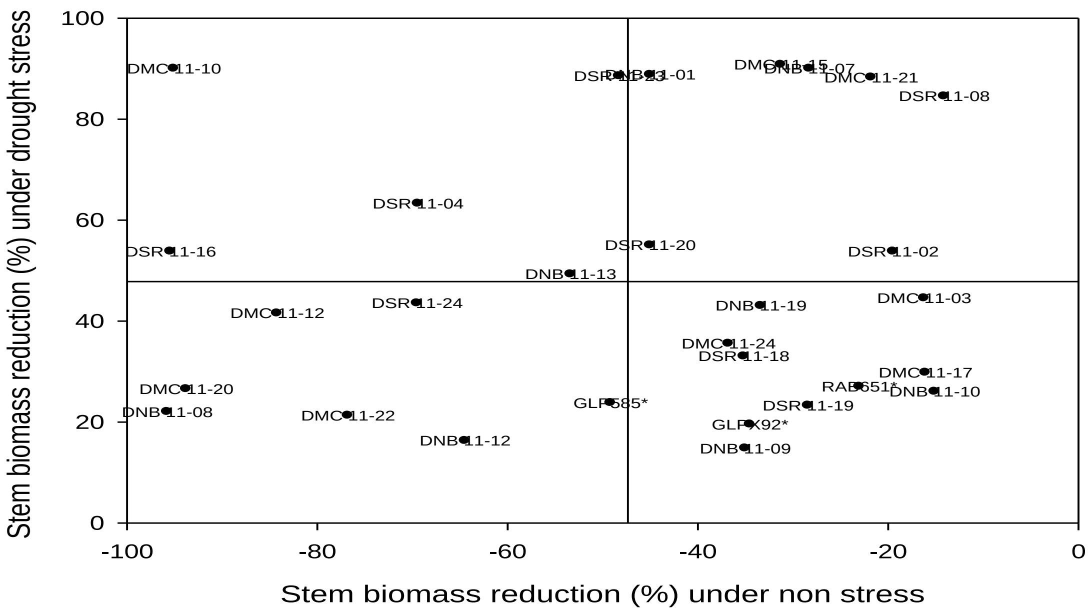


Figure 5.6. Comparison between stem biomass reductions of 29 genotypes selected at random from the three market classes under irrigated (NS) and rainfed (DS) conditions.

5.4.9. Effect of drought on canopy biomass accumulation

Accumulation of canopy biomass was significantly affected by genotype, water stress level and their interaction. Total canopy biomass among the three market classes ranged between a mean of 486 kgha^{-1} and 604 kgha^{-1} under drought stress and 752 kgha^{-1} and 1568 kgha^{-1} under no stress (Table 5.25, 5.26, 5.27). Season and its interaction with water stress treatment had significant effects ($p<0.05$) on the canopy biomass accumulation (Table 5.25, 5.26, 5.27). Navy beans recorded the highest canopy biomass followed by mixed colours and small reds. Within the mixed colours, DMC11-01, DMC11-16, DMC11-10, DMC11-12, NCB226 (check), DMC11-14, DMC11-18 and DMC11-07 recorded high canopy biomasses of over 1000 kgha^{-1} over the two seasons compared with other genotypes in the same market class and most checks. For example, as low as 407 kgha^{-1} of canopy biomass was recorded on checks namely KATB1 and SEN56. In this market class (mixed colours), most genotypes had high canopy biomass accumulation than the checks (Table 5.25). Navy beans such as DNB11-06, DNB11-09 recorded a high canopy biomass of over 1200 kgha^{-1} compared to other genotypes in the same market class and the check MEX142. All genotypes in this market class recorded over 600 kgha^{-1} of canopy biomass except DNB11-13 which had only 517 kgha^{-1} of canopy biomass in the two seasons. The check MEX142 was comparable to most genotypes in total canopy biomass accumulation (Table 5.26). Among the small reds, SEA15 (check), DSR11-12, DSR11-07 and DSR11-08 recorded over 1000 kgha^{-1} of canopy biomass, followed by DSR11-03, DSR11-01, DSR11-05, GLP585 and RCB270 which accumulated over 880 kgha^{-1} of canopy biomass over the two seasons. In this market class, as low as 394 kgha^{-1} of canopy biomass was recorded on checks such as RAB651. However, most genotypes in this market class were comparable to checks in canopy biomass accumulation under drought stress and no stress conditions (Table 5.27). High canopy biomass accumulation by beans was recorded under no stress than drought stress conditions. However, genotypes including DNB11-06, SEA15 (check), DMC11-16, DSR11-12 and DMC11-01 maintained high canopy biomass under both non stress and drought stress conditions (Figure 5.7)

Table 5.25: Canopy biomass accumulation (Kgha^{-1}) by advanced mixed colour bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	Canopy biomass						
	Season 1		**Season 2**				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DMC 11-01	830.2	987.6	1064.0	1928.4	947.1	1458.0	1202.6
DMC 11-16	713.8	1095.6	1227.8	1581.2	970.8	1338.4	1154.6
DMC 11-10	960.4	1018.0	838.0	1712.8	899.2	1365.4	1132.3
DMC 11-12	619.0	985.6	1224.8	1652.0	921.9	1318.8	1120.4
NCB226*	1032.0	1309.4	1043.4	1056.8	1037.7	1183.1	1110.4
DMC 11-14	1199.6	1259.6	686.6	1227.2	943.1	1243.4	1093.3
DMC 11-18	798.0	1435.0	818.2	1019.8	808.1	1227.4	1017.8
DMC 11-07	896.6	1539.2	685.6	910.4	791.1	1224.8	1008.0
DMC 11-19	603.0	1005.8	700.6	1449.8	651.8	1227.8	939.8
DMC 11-17	1019.4	1100.0	386.2	1093.2	702.8	1096.6	899.7
DMC 11-02	741.4	858.2	779.8	1152.8	760.6	1005.5	883.1
DMC 11-11	772.4	1326.4	674.6	737.2	723.5	1031.8	877.7
DMC 11-09	706.8	969.4	584.0	1203.6	645.4	1086.5	866.0
DMC 11-20	1114.8	1162.2	410.8	757.8	762.8	960.0	861.4
DMC 11-22	612.6	671.8	819.0	1290.4	715.8	981.1	848.5
SXB404*	1192.2	1345.4	327.6	467.8	759.9	906.6	833.3
DMC 11-13	808.8	965.6	706.4	749.6	757.6	857.6	807.6
DMC 11-21	420.2	965.4	581.4	1191.0	500.8	1078.2	789.5
SEN53*	636.6	722.4	844.8	953.8	740.7	838.1	789.4
DMC 11-24	571.4	786.4	746.8	968.2	659.1	877.3	768.2
NCB280*	709.2	945.8	581.8	797.8	645.5	871.8	758.7
GLPX92*	959.8	1002.4	313.2	737.6	636.5	870.0	753.3
DMC 11-04	638.0	769.4	454.4	978.4	546.2	873.9	710.1
DMC 11-15	705.4	937.0	512.8	675.4	609.1	806.2	707.7
DMC 11-06	563.8	1272.0	173.8	545.6	368.8	908.8	638.8
DMC 11-05	447.8	644.4	536.0	712.2	491.9	678.3	585.1
DMC 11-23	356.0	511.6	626.8	731.8	491.4	621.7	556.6
DMC 11-08	487.2	487.0	471.4	698.8	479.3	592.9	536.1
DMC 11-03	539.8	540.6	489.8	501.6	514.8	521.1	518.0
KATB1*	389.0	506.8	325.2	607.0	357.1	556.9	457.0
SEN56*	223.6	281.2	482.4	643.8	353.0	462.5	407.8
Mean of genotypes	**713.6**	**970.6**	**675.0**	**1061.2**	694.3	1015.9	855.1
Mean of checks	**734.6**	**873.3**	**559.8**	**752.1**	647.2	812.7	730.0
Overall mean	724.1	922.0	617.4	906.7	670.8	914.3	792.5
CV(%)			13.2				
LSD(P≤0.05)S	99NS	LSD(P≤0.05)SXG		311.3NS			
LSD(P≤0.05)T	150.8*	LSD(P≤0.05)TXG		318.8*			
LSD(P≤0.05)G	221.2*	LSD(P≤0.05)SXTXG		445.4NS			
LSD(P≤0.05)SXT	142.1NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.26: Canopy biomass accumulation (Kgha^{-1}) by advanced navy bean lines grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	Canopy biomass						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
DNB 11-06	1340.0	1590.6	861.4	1820.4	1100.7	1705.5	1403.1
DNB 11-09	1054.2	2050.2	546.2	1262.4	800.2	1656.3	1228.3
DNB 11-15	857.8	1049.4	679.4	1341.8	768.6	1195.6	982.1
DNB 11-08	995.6	1652.2	274.0	927.8	634.8	1290.0	962.4
DNB 11-16	977.4	1138.6	274.2	1452.6	625.8	1295.6	960.7
DNB 11-07	931.2	1346.8	267.2	1200.8	599.2	1273.8	936.5
DNB 11-12	642.0	935.4	952.8	1160.4	797.4	1047.9	922.7
DNB 11-03	829.2	1210.2	469.6	1039.0	649.4	1124.6	887.0
DNB 11-18	432.8	1332.6	852.2	930.4	642.5	1131.5	887.0
DNB 11-04	854.0	917.0	538.2	1156.4	696.1	1036.7	866.4
MEX142*	460.8	864.4	486.2	1568.6	473.5	1216.5	845.0
DNB 11-17	808.0	1030.8	570.2	941.8	689.1	986.3	837.7
DNB 11-14	578.2	931.4	393.4	1362.0	485.8	1146.7	816.3
DNB 11-10	663.0	924.6	542.2	1057.2	602.6	990.9	796.8
DNB 11-05	822.4	1082.2	370.6	723.4	596.5	902.8	749.7
DNB 11-01	861.8	891.0	521.0	617.4	691.4	754.2	722.8
DNB 11-19	624.0	1063.0	369.6	423.2	496.8	743.1	620.0
DNB 11-13	563.2	625.0	355.4	527.0	459.3	576.0	517.7
Mean of genotypes	**813.8**	**1163.0**	**519.9**	**1055.5**	**666.9**	**1109.3**	**888.1**
Mean of checks	**460.8**	**864.4**	**486.2**	**1568.6**	**473.5**	**1216.5**	**845.0**
Overall mean	**637.3**	**1013.7**	**503.1**	**1312.1**	**570.2**	**1162.9**	**866.5**
CV(%)			13.2				
LSD(P≤0.05)S		99.8NS		LSD(P≤0.05)SXG			311.3NS
LSD(P≤0.05)T		150.8*		LSD(P≤0.05)TXG			318.8*
LSD(P≤0.05)G		221.2*		LSD(P≤0.05)SXTXG			445.4NS
LSD(P≤0.05)SXT		142.1NS					

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.27: Canopy biomass accumulation (Kgha^{-1}) by small reds grown under drought stress (DS) and non stress (NS) conditions over two seasons in Kabete, Kenya, 2011/2012.

	Canopy biomass						
	Season 1		Season 2				
Genotype	DS	NS	DS	NS	Mean DS	Mean NS	Overall mean
SEA15*	1088.0	1293.8	1075.6	1169.4	1081.8	1231.6	1156.7
DSR 11-12	1196.8	1518.2	723.6	1077.0	960.2	1297.6	1128.9
DSR 11-07	951.4	1084.8	708.4	1360.8	829.9	1222.8	1026.4
DSR 11-08	780.0	1139.4	966.4	1119.4	873.2	1129.4	1001.3
DSR 11-03	928.6	1371.4	690.8	774.0	809.7	1072.7	941.2
DSR 11-01	818.2	1214.8	694.8	1011.6	756.5	1113.2	934.9
DSR 11-05	1160.6	1240.6	575.2	670.0	867.9	955.3	911.6
GLP585*	407.8	564.4	1055.2	1533.8	731.5	1049.1	890.3
RCB270*	910.0	970.0	624.4	1026.4	767.2	998.2	882.7
RCB592*	682.2	759.4	968.6	1028.6	825.4	894.0	859.7
DSR 11-21	760.4	1088.2	495.4	1044.0	627.9	1066.1	847.0
DSR 11-14	784.0	1406.0	457.8	722.4	620.9	1064.2	842.6
DSR 11-18	794.6	908.2	423.8	1172.8	609.2	1040.5	824.9
DSR 11-10	890.0	898.0	730.0	762.0	810.0	830.0	820.0
DSR 11-09	648.0	1024.6	568.8	1032.8	608.4	1028.7	818.6
DSR 11-13	662.6	1126.8	642.4	836.8	652.5	981.8	817.2
DSR 11-11	538.8	865.6	253.4	1596.2	396.1	1230.9	813.5
TIO CANELA*	754.2	1294.6	273.0	838.2	513.6	1066.4	790.0
DSR 11-20	803.4	1062.6	290.6	834.0	547.0	948.3	747.7
DSR 11-19	842.8	924.8	455.6	664.4	649.2	794.6	721.9
SER16*	602.8	922.2	565.6	794.0	584.2	858.1	721.2
SER76*	490.8	943.2	608.8	801.8	549.8	872.5	711.2
DSR 11-04	742.0	1017.6	266.4	797.8	504.2	907.7	706.0
RCB231*	633.8	636.0	714.4	836.2	674.1	736.1	705.1
DSR 11-06	730.6	854.6	338.2	817.8	534.4	836.2	685.3
DSR 11-23	368.8	757.6	518.6	1083.0	443.7	920.3	682.0
DSR 11-24	651.4	973.6	518.0	535.2	584.7	754.4	669.6
DSR 11-22	627.6	993.0	453.8	581.2	540.7	787.1	663.9
SER95*	384.4	937.0	519.2	716.0	451.8	826.5	639.2
DSR 11-02	474.2	882.8	303.8	820.4	389.0	851.6	620.3
DSR 11-15	546.4	849.0	474.4	559.0	510.4	704.0	607.2
KATB9*	418.6	739.8	351.4	673.6	385.0	706.7	545.9
DSR 11-16	559.8	571.6	394.8	627.8	477.3	599.7	538.5
SER155*	322.4	515.8	353.0	791.0	337.7	653.4	495.6
RAB651*	301.6	341.8	144.8	789.2	223.2	565.5	394.4
Mean of genotypes	**750.5**	**1033.6**	**519.3**	**891.3**	634.9	962.5	798.7
Mean of checks	**583.1**	**826.5**	**604.5**	**916.5**	593.8	871.5	732.7
Overall mean	666.8	930.1	561.9	903.9	614.4	917.0	765.7
CV(%)			13.2				
LSD(P≤0.05)S	99NS	LSD(P≤0.05)SXG		311.3NS			
LSD(P≤0.05)T	150.8*	LSD(P≤0.05)TXG		318.8*			
LSD(P≤0.05)G	221.2*	LSD(P≤0.05)SXTXG		445.4NS			
LSD(P≤0.05)SXT	142.1NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

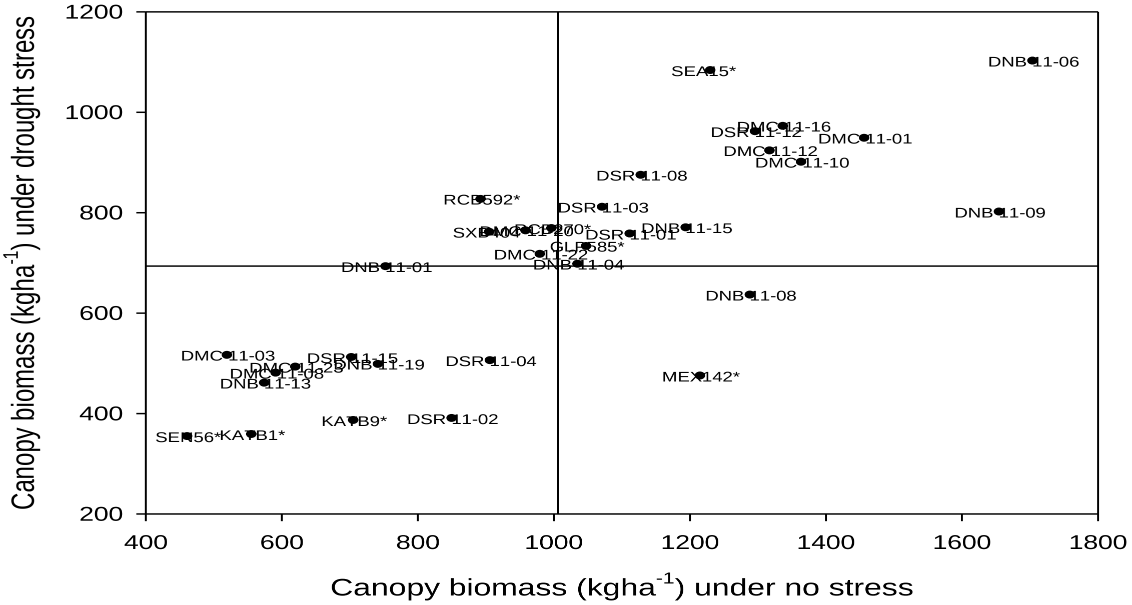


Figure 5.7. Comparison of canopy biomass accumulation of 33 genotypes selected at random from the three market classes under irrigated (NS) and rainfed (DS) conditions

5.4.10. Stomatal conductance at flowering

Stomatal conductance was significantly higher under non drought stress conditions than drought stress conditions (Table 5.28, 5.29, 5.30). It ranged between 37.7 and 209.0 m moles/m^2/s under drought stress and between 73.0 and 336.0 m moles/m^2/s under no stress for most genotypes. The interaction between genotype and drought stress level or site significantly affected stomatal conductance. Of the three market classes, navy beans recorded a higher stomatal conductance than mixed colours and small reds. Within the mixed colours, genotypes such as DMC11-14, SEN56 (check), NCB226 (check), DMC11-13, DMC11-20, DMC11-10, DMC11-21, DMC11-17 and DMC11-03 recorded high stomatal conductance at flowering which was over 183 m moles/m^2/s compared to the other genotypes in the same market class and most checks. Most genotypes and checks in this market class recorded over 140 m moles/m^2/s of stomatal conductance in the two locations except GLPX92 (check), DMC11-05 and DMC11-18 (Table 5.28). Navy beans maintained a high stomatal conductance compared to the other market classes with genotypes including DNB11-04, DNB11-03, DNB11-10, DNB11-16 and DNB11-06 recording high stomatal conductance of over 200 m moles/m^2/s. Other genotypes in this market class and the check MEX142 ranged between 129 m moles/m^2/s and 196 m moles/m^2/s (Table 5.29). Among the small reds, most genotypes were comparable to checks in stomatal conductance. In this market class, test genotypes that recorded over 150 m moles/m^2/s stomatal conductance included DSR11-13, DSR11-22, SER76 (check), GLP585 (check) SEA15 (check), DSR11-23, DSR11-19, Tio canela (check) and DSR11-11. All small red genotypes recorded over 100 m moles/m^2/s of stomatal conductance across the two locations (Table 5.30). For most genotypes, stomatal conductance was high under non stress than drought stress conditions (Figure 5.8). However, most navy bean genotypes including DNB11-04, DNB11-13, DNB11-19, DNB11-07 and DNB11-03 maintained high stomatal conductance under both non stress and drought stress conditions (Figure 5.8).

Table 5.28: Stomatal conductance of advanced mixed colour bean lines recorded at flowering on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012

	Stomatal conductance (milli moles/m^2/s) at flowering						
	Kabete		Mwea				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DMC 11-14	189.3	215.8	96.2	322.3	142.7	269.1	205.9
SEN56*	183.2	223.4	60.8	336.2	122.0	279.8	200.9
NCB226*	172.1	245.1	68.0	300.6	120.1	272.9	196.5
DMC 11-13	182.7	199.3	54.0	324.0	118.4	261.6	190.0
DMC 11-20	158.4	193.7	83.7	319.8	121.1	256.8	189.0
DMC 11-10	173.9	206.4	82.9	284.7	128.4	245.6	187.0
DMC 11-21	206.3	212.9	61.6	262.8	133.9	237.8	185.9
DMC 11-17	169.9	201.5	96.1	266.2	133.0	233.9	183.5
DMC 11-03	162.6	207.0	96.3	266.1	129.4	236.6	183.0
KATB1*	144.7	221.1	96.8	254.5	120.7	237.8	179.3
DMC 11-15	175.2	207.2	52.7	278.2	114.0	242.7	178.4
DMC 11-19	181.1	188.4	62.4	274.9	121.8	231.6	176.7
DMC 11-02	193.3	211.4	44.7	246.6	119.0	229.0	174.0
DMC 11-23	123.2	225.8	45.6	277.6	84.4	251.7	168.1
DMC 11-07	155.8	231.3	54.2	216.5	105.0	223.9	164.5
DMC 11-12	177.9	181.0	73.5	222.3	125.7	201.6	163.7
DMC 11-06	160.5	185.5	77.9	228.4	119.2	207.0	163.1
DMC 11-08	150.9	202.2	46.5	248.2	98.7	225.2	162.0
DMC 11-16	128.5	184.7	90.5	240.1	109.5	212.4	161.0
SXB404*	164.5	183.9	58.3	235.2	111.4	209.6	160.5
DMC 11-11	166.9	189.2	36.6	249.1	101.7	219.2	160.5
DMC 11-22	158.7	194.8	42.6	240.3	100.7	217.6	159.2
SEN53*	136.5	176.7	46.5	273.4	91.5	225.0	158.3
DMC 11-24	183.3	194.7	74.4	176.4	128.9	185.5	157.2
DMC 11-01	161.0	173.2	63.7	214.7	112.4	194.0	153.2
DMC 11-04	160.7	173.0	80.6	183.5	120.6	178.3	149.5
NCB280*	96.1	178.8	70.1	239.6	83.1	209.2	146.2
DMC 11-09	93.0	202.2	37.7	237.1	65.4	219.6	142.5
GLPX92*	146.1	198.7	98.3	100.5	122.2	149.6	135.9
DMC 11-05	82.6	150.1	51.3	152.8	67.0	151.4	109.2
DMC 11-18	124.7	132.2	42.6	77.1	83.7	104.7	94.2
Mean of genotypes	**158.1**	**194.3**	**64.5**	**242.1**	**111.3**	**218.2**	**164.8**
Mean of checks	**149.5**	**204.8**	**71.3**	**248.6**	**110.4**	**226.7**	**168.6**
Overall mean	**153.8**	**199.6**	**67.9**	**245.4**	**110.9**	**222.5**	**166.7**
CV(%)			**19.1**				
LSD(P≤0.05)L	13.1*	LSD(P≤0.05)TXG		13.5*			
LSD(P≤0.05)T	11.3*	LSD(P≤0.05)LXTXG		23.1*			
LSD(P≤0.05)G	9.4**						
LSD(P≤0.05)LXT	6.9NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.29: Stomatal conductance of advanced navy bean lines recorded at flowering on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012.

	Stomatal conductance (milli moles/m^2/s) at flowering						
	Kabete		Mwea				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DNB 11-04	198.8	227.9	241.6	283.8	220.2	255.9	238.1
DNB 11-03	202.1	209.0	142.3	321.5	172.2	265.2	218.7
DNB 11-10	209.5	231.2	156.1	259.7	182.8	245.5	214.2
DNB 11-16	188.8	222.9	195.3	218.8	192.1	220.9	206.5
DNB 11-06	182.0	207.7	154.0	263.8	168.0	235.7	201.9
DNB 11-08	163.5	228.6	173.9	218.9	168.7	223.8	196.3
DNB 11-13	154.1	210.9	186.6	225.9	170.4	218.4	194.4
DNB 11-14	162.4	222.8	143.1	238.5	152.8	230.6	191.7
DNB 11-18	203.5	203.8	127.2	231.9	165.4	217.9	191.7
DNB 11-05	160.3	229.2	177.8	195.0	169.1	212.1	190.6
MEX142*	166.2	237.5	109.7	221.3	137.9	229.4	183.7
DNB 11-17	140.3	234.5	168.6	181.9	154.5	208.2	181.4
DNB 11-07	180.9	188.3	142.2	213.9	161.5	201.1	181.3
DNB 11-19	181.8	194.3	151.6	189.8	166.7	192.1	179.4
DNB 11-12	170.8	207.3	145.1	167.6	158.0	187.5	172.8
DNB 11-09	135.8	221.9	140.8	154.4	138.3	188.2	163.3
DNB 11-15	147.8	204.3	124.3	162.4	136.1	183.4	159.8
DNB 11-01	121.1	188.7	82.3	124.1	101.7	156.4	129.1
Mean of genotypes	**172.7**	**214.7**	**156.0**	**214.8**	**164.4**	**214.8**	**189.6**
Mean of checks	**166.2**	**237.5**	**109.7**	**221.3**	**137.9**	**229.4**	**183.7**
Overall mean	**169.5**	**226.1**	**132.9**	**218.1**	**151.2**	**222.1**	**186.6**
CV(%)			**19.1**				
LSD(P≤0.05)L	13.1*	LSD(P≤0.05)TXG		13.5*			
LSD(P≤0.05)T	11.3*	LSD(P≤0.05)LXTXG		23.1*			
LSD(P≤0.05)G	9.4**						
LSD(P≤0.05)LXT	6.9NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.30: Stomatal conductance of advanced small red bean lines recorded at flowering on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012.

	Stomatal conductance(milli moles/m^2/s) at flowering						
	Kabete		Mwea				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DSR 11-13	193.2	200.5	112.5	161.8	152.8	181.1	167.0
DSR 11-22	153.5	206.8	143.7	157.1	148.6	181.9	165.3
SER76*	156.5	211.1	127.8	159.2	142.1	185.2	163.7
GLP585*	148.3	199.7	133.5	170.0	140.9	184.8	162.9
SEA15*	154.5	181.4	144.9	167.1	149.7	174.3	162.0
DSR 11-23	194.3	211.2	70.1	168.3	132.2	189.8	161.0
DSR 11-19	166.9	197.6	108.5	156.3	137.7	176.9	157.3
TIO CANELA*	148.2	211.7	103.7	157.5	126.0	184.6	155.3
DSR 11-11	161.3	210.2	109.3	134.8	135.3	172.5	153.9
DSR 11-12	191.2	194.9	87.0	128.5	139.1	161.7	150.4
SER155*	142.0	183.3	129.5	144.6	135.8	163.9	149.9
RCB592*	160.3	187.4	117.9	132.7	139.1	160.0	149.6
RCB231*	150.3	200.6	122.1	120.9	136.2	160.7	148.5
RAB651*	159.1	182.6	106.8	130.0	133.0	156.3	144.7
RCB270*	157.0	168.4	121.0	130.7	139.0	149.6	144.3
DSR 11-15	178.3	187.8	82.8	119.9	130.5	153.9	142.2
KATB9*	139.0	162.5	113.7	140.1	126.4	151.3	138.9
DSR 11-14	138.2	164.6	101.7	147.2	119.9	155.9	137.9
DSR 11-05	155.3	177.3	79.8	137.7	117.6	157.5	137.6
SER95*	143.5	177.0	79.2	134.0	111.4	155.5	133.5
DSR 11-04	150.8	171.3	103.9	106.1	127.4	138.7	133.1
DSR 11-08	166.9	175.8	83.5	100.4	125.2	138.1	131.7
DSR 11-02	144.0	183.4	80.4	118.3	112.2	150.9	131.6
DSR 11-21	166.7	187.8	70.3	89.9	118.5	138.9	128.7
DSR 11-07	137.8	172.5	89.4	106.6	113.6	139.5	126.6
DSR 11-20	142.8	190.2	58.2	114.2	100.5	152.2	126.4
DSR 11-24	151.7	182.7	71.5	95.8	111.6	139.3	125.5
DSR 11-09	151.7	189.2	60.4	88.2	106.0	138.7	122.4
DSR 11-10	128.6	172.7	85.3	96.8	107.0	134.8	120.9
DSR 11-06	145.9	151.1	66.8	108.0	106.3	129.6	118.0
DSR 11-16	111.5	162.8	70.8	116.2	91.2	139.5	115.4
SER16*	106.9	162.2	64.4	104.2	85.6	133.2	109.4
DSR 11-18	123.8	189.4	50.8	73.0	87.3	131.2	109.3
DSR 11-01	118.7	159.1	44.9	110.3	81.8	134.7	108.3
DSR 11-03	113.4	150.6	62.3	92.0	87.9	121.3	104.6
Mean of genotypes	**151.6**	**182.2**	**82.3**	**118.6**	**117.0**	**150.4**	**133.7**
Mean of checks	**147.1**	**185.6**	**113.7**	**140.9**	**130.4**	**163.3**	**146.9**
Overall mean	**149.4**	**183.9**	**98.0**	**129.8**	**123.7**	**156.9**	**140.3**
CV(%)			**19.1**				
LSD(P≤0.05)L	13.1*	LSD(P≤0.05)TXG		13.5*			
LSD(P≤0.05)T	11.3*	LSD(P≤0.05)LXTXG		23.1*			
LSD(P≤0.05)G	9.4**						
LSD(P≤0.05)LXT	6.9NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

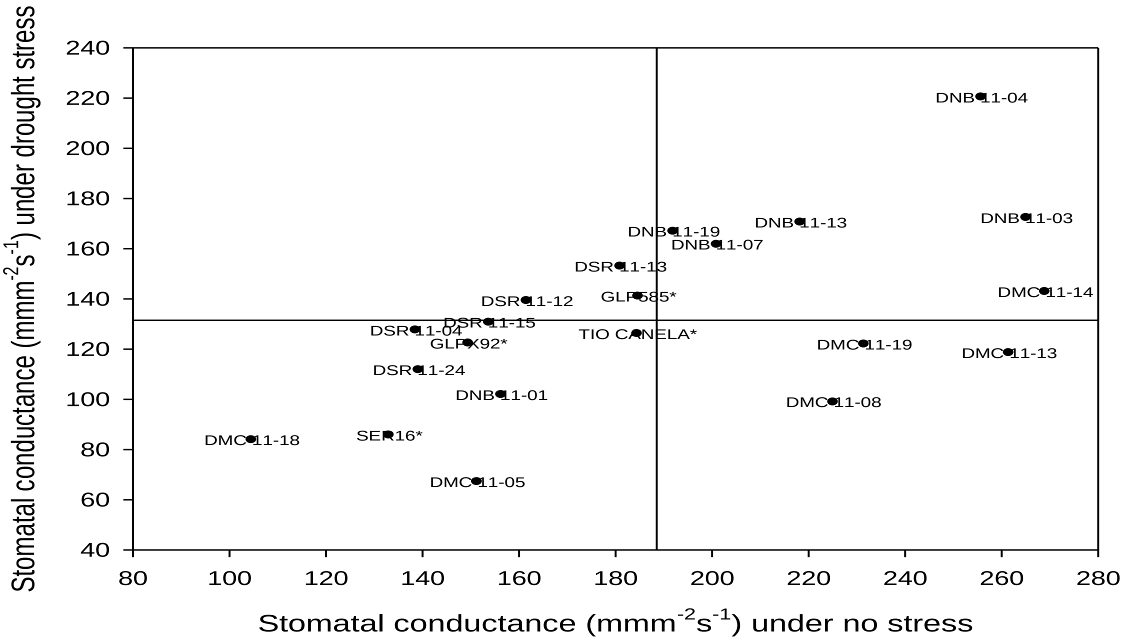


Figure 5.8. Correlation between stomatal conductance at flowering of 21 genotypes under non stress (NS) and drought stress (DS) conditions

5.4.11. Stomatal conductance at mid pod filling

At mid pod filling, stomatal conductance was significantly higher under non drought stress than under drought stress conditions and increased by over 40% from flowering (Table 5.31, 5.32, 5.33). It ranged between 20.0 m moles/m^2/s and 198.0 m moles/m^2/s under drought stress and 65.0 m moles/m^2/s and 363.0 m moles/m^2/s under no stress for most genotypes. Stomatal conductance of dry bean was significantly affected by the genotype, drought stress level and their interaction (Table 5.31). Of the three market classes, navy beans maintained high stomatal conductance at this growth stage compared to mixed colours and small reds. Within the mixed colours over 300 m moles/m^2/s of stomatal conductance was recorded by genotypes including DMC11-22, DMC11-16, DMC11-11, DMC11-19, NCB226 (check), DMC11-08 and DMC11-18. In this market class, most genotypes were comparable to checks in stomatal conductance (Table 5.31). Navy beans also maintained high stomatal conductance of up to 368 m moles/m^2/s in genotypes such as DNB11-03, DNB11-05, DNB11-17, DNB11-04 and the check MEX142. The lowest stomatal conductance was recorded on DNB11-13. All genotypes in this market class maintained high stomatal conductance of over 230 m moles/m^2/s compared to that recorded at flowering (Table 5.32). Among the small reds GLP585 (check) recorded higher stomatal conductance of 323 m moles/m^2/s than the other genotypes and checks. This was followed by other genotypes including DSR11-11, DSR11-

22, DSR11-20, DSR11-05, DSR11-08, DSR11-02 and DSR11-01, which had over 250 m moles/m^2/s stomatal conductance. Most genotypes were comparable to checks in stomatal conductance at this growth stage (Table 5.33). Genotypes in all the market classes recorded high stomatal conductance under non stress than drought stress conditions (Figure 5.9). However, DNB11-03, DMC11-19, DMC11-10 and GLP585 maintained high stomatal conductance under both drought stress and non stress conditions (Figure 5.9).

Table 5.31: Stomatal conductance of advanced mixed colour bean lines recorded at mid pod filling on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012.

	Stomatal conductance (milli moles/m^2/s) at mid pod						
	Kabete		Mwea				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DMC 11-22	280.8	734.3	211.9	329.6	246.4	532.0	389.2
DMC 11-16	405.4	523.6	198.8	347.7	302.1	435.7	368.9
DMC 11-11	459.1	471.5	231.7	284.8	345.4	378.2	361.8
DMC 11-19	411.9	458.7	178.2	328.6	295.1	393.7	344.4
NCB226*	382.3	609.2	154.8	220.7	268.6	415.0	341.8
DMC 11-08	139.0	598.9	225.6	309.0	182.3	454.0	318.2
DMC 11-18	258.0	618.9	177.5	215.2	217.8	417.1	317.5
DMC 11-15	455.2	487.5	95.2	200.4	275.2	344.0	309.6
DMC 11-04	236.3	379.9	227.3	390.0	231.8	385.0	308.4
DMC 11-17	388.2	412.5	151.4	276.3	269.8	344.4	307.1
DMC 11-03	390.0	401.8	174.1	238.6	282.1	320.2	301.2
SEN53*	346.6	395.9	181.3	271.3	264.0	333.6	298.8
DMC 11-24	299.5	368.7	177.5	329.4	238.5	349.1	293.8
DMC 11-10	450.6	472.8	45.3	161.6	248.0	317.2	282.6
DMC 11-09	336.4	571.4	20.9	193.5	178.7	382.5	280.6
DMC 11-21	285.6	472.1	77.7	279.7	181.7	375.9	278.8
DMC 11-14	255.9	446.0	101.7	273.3	178.8	359.7	269.3
RCB231*	277.8	552.8	33.5	211.4	155.7	382.1	268.9
SXB404*	271.5	345.5	201.4	213.8	236.5	279.7	258.1
DMC 11-05	188.5	507.0	119.8	216.4	154.2	361.7	258.0
DMC 11-23	291.0	333.5	179.5	219.6	235.3	276.6	256.0
DMC 11-12	173.5	441.1	36.9	363.4	105.2	402.3	253.8
RCB270*	318.5	346.6	100.1	243.9	209.3	295.3	252.3
RAB651*	306.7	365.2	58.6	271.6	182.7	318.4	250.6
RCB592*	270.8	381.9	146.8	188.7	208.8	285.3	247.1
DMC 11-20	298.5	360.9	150.8	175.5	224.7	268.2	246.5
DMC 11-13	330.1	373.1	70.7	187.4	200.4	280.3	240.4
DMC 11-07	143.0	320.9	169.9	248.9	156.5	284.9	220.7
NCB280*	226.2	320.0	135.1	192.3	180.7	256.2	218.5
DMC 11-01	181.3	329.6	151.9	192.4	166.6	261.0	213.8
KATB1*	239.0	313.3	85.1	200.1	162.1	256.7	209.4
SEN56*	223.1	301.9	89.8	217.9	156.5	259.9	208.2
DMC 11-06	150.0	343.0	88.0	242.4	119.0	292.7	205.9
SEA15*	198.3	251.0	161.3	174.3	179.8	212.7	196.3
GLPX92*	169.3	274.8	78.5	208.2	123.9	241.5	182.7
DMC 11-02	194.0	318.5	31.9	144.3	113.0	231.4	172.2
Mean of genotypes	**291.7**	**447.8**	**137.3**	**256.2**	**214.5**	**352.0**	**283.3**
Mean of checks	**269.2**	**371.5**	**118.9**	**217.9**	**194.0**	**294.7**	**244.4**
Overall mean	**280.5**	**409.7**	**128.1**	**237.1**	**204.3**	**323.4**	**263.8**
CV(%)			**11.8**				
LSD(P≤0.05)L	**13.5***	LSD(P≤0.05)TXG		13.5*	15.3*		
LSD(P≤0.05)T	**10.3***	LSD(P≤0.05)LXTXG		23.1*	19.9NS		
LSD(P≤0.05)G	**9.7****						
LSD(P≤0.05)LXT	11.0NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.32: Stomatal conductance of advanced navy bean lines recorded at mid pod filling on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012.

	Stomatal conductance (milli moles/m^2/s) at mid pod						
	Kabete		**Mwea**				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
DNB 11-03	441.2	500.0	263.4	269.4	352.3	384.7	368.5
DNB 11-05	325.9	408.5	221.3	331.1	273.6	369.8	321.7
DNB 11-17	299.1	663.6	59.2	258.5	179.2	461.1	320.2
DNB 11-04	338.0	537.9	153.9	231.9	246.0	384.9	315.5
MEX142*	200.3	575.2	213.4	252.1	206.9	413.7	310.3
DNB 11-12	247.7	498.0	173.4	270.0	210.6	384.0	297.3
DNB 11-01	276.0	346.7	216.4	336.6	246.2	341.7	294.0
DNB 11-07	180.8	394.2	238.4	346.7	209.6	370.5	290.1
DNB 11-09	332.4	469.1	125.9	231.3	229.2	350.2	289.7
DNB 11-15	426.9	276.5	201.8	241.3	314.4	258.9	286.7
DNB 11-19	332.9	363.8	135.2	290.7	234.1	327.3	280.7
DNB 11-08	309.1	369.4	107.9	285.4	208.5	327.4	268.0
DNB 11-14	240.4	334.3	201.5	282.0	221.0	308.2	264.6
DNB 11-16	215.3	469.2	65.7	258.2	140.5	363.7	252.1
DNB 11-18	258.2	366.4	151.1	200.4	204.7	283.4	244.1
DNB 11-10	217.8	320.1	148.5	239.4	183.2	279.8	231.5
DNB 11-06	158.5	334.9	184.0	242.3	171.3	288.6	230.0
DNB 11-13	167.4	400.3	55.8	74.5	111.6	237.4	174.5
Mean of genotypes	**280.4**	**414.9**	**159.0**	**258.2**	**219.7**	**336.5**	**278.1**
Mean of checks	**200.3**	**575.2**	**213.4**	**252.1**	**206.9**	**413.7**	**310.3**
Overall mean	**240.4**	**495.1**	**186.2**	**255.2**	**213.3**	**375.1**	**294.2**
CV(%)			**11.8**				
LSD(P≤0.05)L	**13.5***	LSD(P≤0.05)TXG		13.5*	15.3*		
LSD(P≤0.05)T	**10.3***	LSD(P≤0.05)LXTXG		23.1*	19.9NS		
LSD(P≤0.05)G	**9.7****						
LSD(P≤0.05)LXT	11.0NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

Table 5.33: Stomatal conductance of advanced small red bean lines recorded at mid pod filling on genotypes grown under drought stress (DS) and non stress (NS) conditions in Kabete and Mwea, Kenya, 2011/2012.

	Stomatal conductance (milli moles/m^2/s) at mid pod						
	Kabete		Mwea				
Genotype	**DS**	**NS**	**DS**	**NS**	**Mean DS**	**Mean NS**	**Overall mean**
GLP585*	389.7	515.5	161.5	225.2	275.6	370.4	323.0
DSR 11-11	374.3	442.6	150.5	210.1	262.4	326.4	294.4
DSR 11-22	347.9	435.9	160.1	223.5	254.0	329.7	291.9
DSR 11-20	382.1	442.4	130.2	202.6	256.2	322.5	289.3
DSR 11-05	420.6	503.0	41.9	179.9	231.3	341.5	286.4
DSR 11-08	288.0	393.5	157.7	214.2	222.9	303.9	263.4
DSR 11-02	280.3	477.8	124.3	169.2	202.3	323.5	262.9
DSR 11-01	237.5	366.6	173.4	223.8	205.5	295.2	250.3
DSR 11-21	262.7	315.4	172.6	234.4	217.7	274.9	246.3
DSR 11-16	244.5	271.9	219.4	228.1	232.0	250.0	241.0
DSR 11-07	259.0	508.3	50.0	136.3	154.5	322.3	238.4
DSR 11-09	173.8	424.5	150.3	203.1	162.1	313.8	237.9
DSR 11-03	265.4	322.5	122.5	214.4	194.0	268.5	231.2
DSR 11-19	264.1	298.6	161.3	194.6	212.7	246.6	229.7
TIO CANELA*	231.8	273.8	161.6	197.9	196.7	235.9	216.3
SER76*	267.5	298.1	123.5	157.3	195.5	227.7	211.6
DSR 11-04	257.8	267.0	114.2	198.1	186.0	232.6	209.3
DSR 11-14	273.3	340.0	78.7	127.2	176.0	233.6	204.8
DSR 11-15	225.1	277.7	152.4	161.3	188.8	219.5	204.1
DSR 11-24	242.6	381.7	48.9	130.1	145.8	255.9	200.8
KATB9*	292.4	326.4	77.7	106.6	185.1	216.5	200.8
DSR 11-06	234.1	336.9	101.5	129.2	167.8	233.1	200.5
DSR 11-23	316.0	340.9	31.7	110.1	173.9	225.5	199.7
SER155*	319.5	355.7	50.7	59.3	185.1	207.5	196.3
SER16*	153.2	371.1	109.1	148.3	131.2	259.7	195.5
DSR 11-13	197.3	263.0	130.3	180.2	163.8	221.6	192.7
DSR 11-10	197.7	293.9	52.9	220.1	125.3	257.0	191.2
DSR 11-18	226.6	242.4	117.0	167.5	171.8	205.0	188.4
DSR 11-12	208.7	274.3	101.2	163.9	155.0	219.1	187.0
SER95*	213.2	306.0	65.3	92.0	139.3	199.0	169.2
Mean of genotypes	**268.7**	**357.4**	**119.3**	**183.6**	**194.0**	**270.5**	**232.3**
Mean of checks	**266.8**	**349.5**	**107.1**	**140.9**	**186.9**	**245.2**	**216.1**
Overall mean	**267.8**	**353.5**	**113.2**	**162.3**	**190.5**	**257.9**	**224.2**
CV(%)			**11.8**				
LSD(P≤0.05)L	**13.5***	LSD(P≤0.05)TXG		13.5*	15.3*		
LSD(P≤0.05)T	**10.3***	LSD(P≤0.05)LXTXG		23.1*	19.9NS		
LSD(P≤0.05)G	**9.7****						
LSD(P≤0.05)LXT	11.0NS						

*,**, NS, Significant at 0.05 and 0.001 and not significant respectively. S (season), L (location), T (irrigation treatment), G (genotype). Lines/varieties marked with * denote checks.

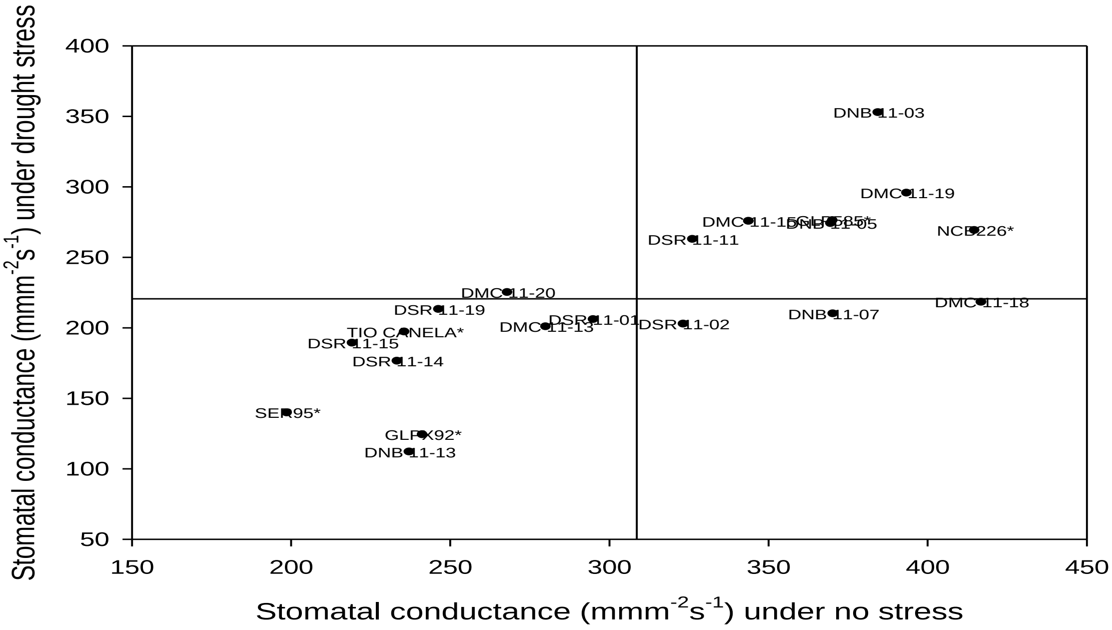


Figure 5.9. Correlation between non stress (NS) and drought stress (DS) stomatal conductance of 20 genotypes at mid pod filling selected at random from the three market classes

5.4.12. Correlation coefficients (r) between grain yield and other plant traits

Positive correlation was observed between grain yield under drought stress conditions and attributes such as pod harvest index (0.40***), pod partitioning index (0.89***), stem biomass reduction (0.32**) and grain harvest index (0.39***) (Table 5.34). Stem biomass reduction was negatively correlated with grain yield under non drought stress conditions (-0.18*). Canopy biomass accumulation was strongly associated with grain yield under no drought stress conditions (0.64***) compared to drought stress conditions (0.25**). Also, grain yield was highly related with pod harvest index and grain harvest index under both drought stress (0.40*** and 0.39*** respectively) and non drought stress conditions (0.62*** and 0.50*** respectively). Pod partitioning index was strongly associated with grain yield under drought stress conditions (0.89***) compared to non drought stress conditions. Stomatal conductance was positively correlated with grain yield under both drought stress and non stress conditions (Table 5.34).

Table 5.34: Correlation coefficients (r) between grain yield and other plant traits of 84 genotypes under irrigated and rainfed conditions.

Plant traits	**Irrigated**	**Rainfed**
Canopy biomass (kg/ha)	0.64***	0.25**
Pod harvest index (%)	0.62***	0.40***
Grain harvest index (%)	0.50***	0.39***
Pod partitioning index (%)	0.57***	0.89***
Pod wall biomass proportion (%)	0.26**	0.19*
Stem biomass reduction (%)	-0.18*	0.32**
Total chlorophyll content (SPAD)	0.24**	0.18**
Stomatal conductance (mm/m^2/s)	297.0**	109.3**

*, **, *** Significant at p<0.05, p<0.01 and p<0.001 probability levels respectively.

5.5. Discussion

High average canopy temperatures of up to 25ºC were recorded under drought stress conditions compared with an average of 19ºC under non stress conditions especially in Mwea. Genotypes with low canopy temperatures such as DMC11-10, DMC11-02, DNB11-07 and DSR11-12 recorded high yield especially under drought stress while genotypes with high canopy temperature such as DMC11-19, DMC11-14, DMC11-20, KATB1 and DNB11-13 had lower yields. High canopy temperatures may have resulted from stomatal closure by plants in an effort to reduce moisture loss due to limited moisture availability (Flexas et al., 2004; Lawlor and Cornic, 2002). A canopy temperature range of 20°C to 26°C under drought stress for beans has been reported (Flexas et al., 2004) thus confirming the results of the current study.

Drought stress reduced the leaf chlorophyll content of most genotypes. Studies carried out by Farooq et al., (2009) showed that most bean varieties have leaf chlorophyll content of between 33 and 45 units under normal circumstances but under drought stress, chlorophyll content can be as low as 28 units. In this study, chlorophyll content of beans under drought stress may have been affected by the differential drying of the soils within these two locations making it difficult for bean nodules to have maximum nitrogen fixation activity (Farooq et al., 2009). However, some genotypes such as DMC11-14 maintained their chlorophyll content and stay green characteristic across varying environments though this did not translate to higher yield. Thus stay green characteristic may be genetic (Havaux, 1998; Kiani et al., 2008).

Variations in dry matter partitioning were observed among genotypes in the three market classes with genotypes within the navy beans market class such as DNB11-07, DNB11-15 and DNB11-19 showing increased partitioning especially under drought stress. This resulted in high grain yields from these genotypes. Differences in partitioning of dry matter among genotypes can be attributed to genetic differences and the different mechanisms adopted by bean plants under drought stress (Beebe et al., 2008). Pod partitioning and stem biomass reduction were high under drought stress. This could be attributed to partitioning of dry matter towards grain production and remobilization of photosynthates from various plant parts to the developing grain resulting in improved yield under drought stress (Beebe et al., 2008; Rao et al., 2007). Correlation between these attributes and grain yield showed that, grain yield especially under drought stress was dependent on the ability of plants to adopt a combination of mechanisms such as dry matter accumulation and efficient partitioning in favour of grain production.

Pod harvest index (PHI) is one of the main partitioning indices that measure the remobilization of photosynthates to seeds (Beebe et al., 2009). Pod harvest index was reduced under drought stress compared to non stress conditions. This may have resulted from severe flower and pod abortion by the plants in an effort to reduce demand for the already limited resources such as moisture and nutrients and enable the plant to survive (Beebe et al., 2009; Porch et al., 2008). According to Beebe et al. (2009), PHI reflects plant efficiency in partitioning of photosynthates from vegetative shoot structures to pods and from pod wall to grain, which varies with the genotypes and is also affected by drought. These research results support the conclusion that a strong association exists between PHI and the grain yield of genotypes grown under drought stress conditions (CIAT, 2008; Rao et al., 2009).

Under drought stress, most genotypes had low canopy biomass but genotypes such as DMC11-01, DMC11-02, DMC11-21, DNB11-07, DNB11-09, DNB11-14, DSR11-09, DSR11-12 and TIO CANELA recorded higher canopy biomass which may have led to high yield. This may be attributed to increased plant size under no stress due to availability of growth requirements such as adequate moisture (Munoz-Perea et al., 2006; Padilla Ramirez et al., 2005, Ramirez-Vallejo and Kelly, 1998) and ability of the plant roots to proliferate within the soil under drought stress and mine lower soil profiles for nutrients such as N and P which are highly essential for plant growth. Drought stress reduces the ability of bean plants to access these nutrients thus interfering with fixation, partitioning and utilization by the plants (Ramos et al., 1999; Serraj and Sinclair, 1998). However, drought tolerant genotypes are known to overcome these challenges and yield well under drought stress through improved partitioning of shoot dry matter and efficient remobilization of the assimilates to the developing grain (Rao et al., 2007; Rao, 2001; Ishitani et al., 2004; Beebe et al., 2007). Genotypes such as DMC11-01, DNB11-07, DNB11-14, DNB11-15, DSR11-02, DSR11-21 and DNB11-03 from the three market classes were high yielding under drought stress in both seasons and locations. However, some genotypes such as DMC11-14, DMC11-20 and checks like GLPX92 had high canopy biomass and low yield. This shows that these genotypes are poor partitioners of accumulated dry matter especially under drought stress.

Stomatal conductance was higher under no stress than under drought stress conditions at both flowering and mid pod filling growth stages. This may have resulted from stomatal closure which may have reduced carbon dioxide assimilation and overall gaseous exchange by the plants (Rao et al., 2009; Flexas et al., 2004). This in turn may have slowed down the rate and efficiency of photosynthesis by the plants thus causing a reduction in growth, assimilate production, translocation and subsequent grain production (Amede and Schubert, 2003b; Scartazza et al., 2001).

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1. General Discussion

This study showed that though farmers' selection criteria did not entirely agree with scientific procedures, some of their criteria were scientifically sound. Besides, the importance of their participation cannot be underestimated. It was noted that farmers' have a good understanding of their crops due to their ability to select the best dry bean genotypes using a set of criteria. This was realized during the participatory variety selection (PVS) where some of their information could scientifically be related. Hence, involving farmers in PVS should be adopted in order to develop demand driven products. Also, farmers' perception of some dry bean properties by visual examination should be validated through scientific research since not all their observations may be right. This will equip them with real information. It was also observed that most genotypes that were selected were good performers under drought stress and were new lines. This shows that farmers in semi-arid areas are looking for varieties that can sustain good yields under diminished rainfall conditions particularly in the face of climate change challenge. Rejection of the local checks underscores the importance of PVS in ensuring acceptability of newly developed varieties. Participation by both gender in the selection process was highly important as it clearly brought out gender differences and diversity of perceptions about different dry bean lines. This showed that for successful adoption of new varieties, both men and women should be involved in research work.

Drought tolerant bean lines were observed to be high yielding especially under drought stress and most employed drought escaping properties such as accelerated phenological development and high harvest indices. This shows that these varieties have high water use efficiency and can be able to utilize the little moisture available in the soil to produce grain. Under the current climate change and variability, these are the most preferred varieties as they will be able to sustain crop production under predicted drought conditions that are likely to persist. Therefore, it is highly important to identify these lines, develop them and make them available to dry bean farmers in order to avoid future problems like malnutrition and subsequent food insecurity as bean is the most important grain legume worldwide.

It was also observed that genotypes adapted certain mechanisms including shoot biomass accumulation, partitioning towards the developing grain and stomatal control to produce high yield especially under drought stress. For most genotypes, a combination of these mechanisms rather than a single one was used to deal with drought effects. This was reflected by all the market classes especially navy beans which were high yielding even under severe drought. It was also evident from the correlations that yield result from an interaction of many factors and is highly influenced by slight changes in these factors. Understanding the mechanisms of adaptation to drought stress in common bean is a vital step towards developing drought tolerant varieties hence the validity of this research. It will also be the best proactive approach of dealing with drought effects in the future due the projected climate change and variability. Therefore, this knowledge should be applied in a wide range of crops for future food security. Other detailed studies involving root studies and nutrient use efficiency especially under drought stress conditions for the best adapted varieties should also be done in order to produce varieties tolerant to more than one abiotic stress. Based on the results obtained, all the hypotheses stated in this research are not true because farmers' selection criteria did not entirely agree with scientific criteria, performance of small seeded genotypes differed in non stress and drought stress environments especially in terms of grain yield, drought tolerance differed between local varieties and the test genotypes and shoot traits such as dry matter partitioning played an important role in yield performance of many genotypes especially under drought stress.

6.2. Conclusions

New dry bean lines were more preferred by farmers and were selected in different sites and seasons while the most common local varieties available to farmers were given less preference. Also, farmers have some knowledge about good dry bean varieties which enabled them to have a pre identified selection criteria that were successfully used to identify the best varieties out of the many dry bean lines that were used. Therefore, it is highly important to involve different stakeholders in research work.

Yield was found to be a constituent of many factors including various yield components as well as drought escaping mechanisms. In addition, farmers used yield as the most important qualifier of a good variety. Therefore, high yielding varieties even under drought stress are most preferred and will sustain bean yields even under the current climate change and variability.

Shoot traits played a major role in enhancing productivity of most small seeded beans in the three diverse market classes under drought stress. This was shown by the ability of these bean types to accumulate and efficiently partition shoot dry matter in favour of grain production hence high yield was obtained even under drought stress. Furthermore, yield performance of most genotypes under drought stress differed with that under no stress with most genotypes performing better under no stress than drought stress conditions. This shows a clear relationship between performance of genotypes and the environment under which they are grown as well as the importance of adaptive mechanisms to drought stress in common bean.

6.3. Recommendations

It is recommended that the experiment on physiological mechanisms enhancing drought tolerance be repeated over many variable environments and include root sampling in the field. This will help determine if the genotypes change their mechanisms depending on location and soil condition. Also, distinct drought lines with uniformity of performance under different soil conditions in variable environments will be identified. Most importantly, farmers should be allowed to participate in screening and identifying good varieties as this will increase familiarity and enhance adoption of new varieties which will ensure food security by improving productivity of dry bean despite the climate change challenge. In this regard, I suggest that genotypes DMC11-02, DMC11-10, DMC11-12, DMC11-24, DNB11-03, DNB11-07, DNB11-10, DNB11-14, DNB11-15, DNB11-19, DSR11-02, DSR11-04, DSR11-08, DSR11-12, DSR11-13, DSR11-22 and checks SEN53, NCB280, NCB226, Tio canela, SER16, SER76, RCB231 and SEA15 be further evaluated with farmers. Moreover, familiarization of small seeded beans should be done especially to farmers in Kenya who prefer large seeded varieties which may not be as high yielding and drought tolerant as the Mesoamerican dry bean types. This will help sustain dry bean productivity under the highly variable weather conditions. Finally, detailed root studies of the best drought tolerant genotypes should be done under controlled conditions in order to establish the contribution of the roots towards enhancing drought adaptability in small seeded beans.

7.0. REFERENCES

Abebe, A.S. and M.A. Brick (2003). Traits associated with dry edible beans *(Phaseolus vulgaris L.*) productivity under diverse soil moisture environments. Euphytica 133:339-347

Acosta-Gallegos, J.A., E. Acosta, S. Padilla, M.A. Goytia, R. Rosales, and E. López (1999). Mejoramiento de la resistencia a la sequía del frijol común en México. Agronomy journal 10:83-90.

Allen, G. R., S. L. Pereira, D. Raes, and M. Smith (1998). Crop evapotranspiration: guidelines for computing crop water requirements. Food and Agricultural Organization of the United Nations (FAO), Publication No. 56, Rome, Italy.

Amede, T. and S.Schubert (2003). Mechanisms of drought resistance in grain legumes II: stomatal regulation and root growth. SINET: Ethiopia Journal of Science 26(2), 137-144

Amede, T. (1998). Analysis of drought resistance in grain legumes. The case of *Vicia faba, Pisum sativum, Phaseolus vulgaris* and *Cicer arietinum.* Ulrich E. Grauer Publishing, Stuttgart, Germany.

Ampofo, J.K.O. and S.M. Massomo (1998). Some cultural strategies for the management of bean stem maggot (Diptera: *Agromyzidae*) on beans in Tanzania. African Crop Science Journal 6:351-356.

Battistelli, A. (2001). Effect of water shortage on photosynthesis, growth and storage carbohydrate accumulation in walnut *(Juglans regia* L.*).* Acta Horticulture 544: 227-232

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

Beebe, S., I. Rao, H. Terán, and C. Cajiao (2007). Breeding concepts and approaches in food legumes: The example of common bean. Crop science journal 23–29.

Beebe, S., I. Rao, M.W. Blair and L. Butare (2009). Breeding for abiotic stress tolerance in common bean: present and future challenges. Available at http://193.43.36.176/gipbtest/images/pdf_files/LiteratureViews/Beebe_DOC_apb09.pdf [accessed 15 February 2011]

Beebe, S., J. Rengifo, E. Gaitan, M.C. Duque and J. Tohme (2001). Diversity and origin of Andean landraces of common bean. Crop science 41:854-862.

Beebe, S., P.W. Skroch, J. Tohme, M.C. Duque, F. Pedraza and J. Nienhuis (2000). Structure of genetic diversity among common bean landraces of Middle American origin based on correspondence analysis of RAPD. Crop Science 40:264–273

Blair, M.W., G. Iriarte and S. Beebe (2006). QTL analysis of yield traits in an advanced backcross population derived from a cultivated Andean x wild common bean (*Phaseolus vulgaris* L.) cross. Theory Applied Genetics 112:1149–1163

Bouhmouch I, B. Souad-Mouhsine, F. Brhada and J. Aurag (2005). Influence of host cultivars and Rhizobium species on the growth and symbiotic performance of *Phaseolus vulgaris* under salt stress. Journal of Plant Physiology 162(10):1103–1113

Boutraa, T., and F.E. Sanders (2001). Influence of water stress on grain yield and vegetative growth of two cultivars of bean (*Phaseolus vulgaris*, L.). Journal of Agronomy Crop Science. 187:251-257.

Broughton, W.J., G. Hernandez, M.W. Blair, S. Beebe, P. Gepts and J. Vanderleyden (2003). Beans (*Phaseolus vulgaris*) Model food legumes. Plant and Soil 252:55-128

Buruchara, R. (2007). Background information on Common Beans (*Phaseolus vulgaris L.*) in Biotechnology, Breeding & Seed Systems for African Crops. http://www.africancrops.net/rockefeller/crops/beans/index.htm.

Cardona, C. (2004). Common beans: Latin America. In: Hodges R, Farrell, editors. Crop post-harvest: science and technology. Durables. Oxford: Blackwell;. pp. 145–150.

Ceccarelli, S. and S. Grando (2007). Decentralized participatory plant breeding: an example of demand driven research. Euphytica 155:349-360.

Chaco´n, S.M.I., B. Pickersgill and D.G. Debouck (2005). Domestication patterns in common bean (*Phaseolus vulgaris L.*) and the origin of the Mesoamerican and Andean cultivated races. Theory of Applied Genetics 110:432–444

Chaves, M.M., J.S. Pereira, J.P. Maroco, M.L. Rodrigues, C.P.P. Ricardo, M.L. Osório, I. Carvalho, T. Faria and C. Piheiro (2002). How plants cope with water stress in the field: photosynthesis and growth. Annual Botany 89:907-916

Christinck, A., K. Vom Brocke, K.G. Kshirsagar, E. Weltzien and P.J. Bramel-Cox, (2000b). Participatory methods for collecting germplasm: Experiences with farmers in Rajasthan, India. Plant Genetic Resources Newsletter121:1-9

CIAT (Centro Internacional de Agricultura Tropical) **1987**. Standard system for the evaluation of bean germplasm. Van Schoonhoven, A. and M.A. Pastor-Corrales (compilers). Cali, Colombia. 54 p.

CIAT, (2007). Annual report 2007. Improved beans for the developing world. P.120

CIAT, (2008). Annual report 2008. Improved beans for the developing world. P.39-65

Cotty, D., M. Garcia, I. Estrada, and E. Anchundia (2001). Indicadores basicos el decempeno agropecuario 1971-2000.In J.Moya(Ed). Proyecto de informacion agricola y analisis de politicas instituto Nacional de Estadistica pp. 34-88

Costa Franca, M. G., A.T. Pham Thi, C. Pimentel, R.O. Pereyra Rossiello, Y. Zuily-Fodil, and D. Laffray (2000). Differences in growth and water relations among *Phaseolus vulgaris* cultivars in response to induced drought stress. Environmental and Experimental Botany 43:227-237.

David, S., R. Kirkby, and S. Kasozi (2000). Assessing the Impact of Bush Bean Varieties on Poverty Reduction in Sub-Saharan Africa: Evidence from Uganda Network on Bean Research in Africa, Occassional Publication series N0.31, CIAT, Kampala, Uganda.

Diaz, L.M., and M.W.Blair (2006). Race structure within the Mesoamerican gene pool of common bean (*Phaseolus vulgaris)* as determined by microsatellite markers. Theory of Applied Genetics 114:143–154

FAOSTAT (2002). FAO statistical data base for Agriculture.

FAOSTAT (2003). FAO statistical data base for Agriculture.

FAOSTAT (Food and Agriculture Organisation of the United Nations) **(2007)**. Statistics Division 2007. [Online] Available at http://faostat. fao.org/site/339/default.aspx (accessed 26th June, 2010)

FAOSTAT (Food and Agriculture Organization at www.fao.org.), **Ferris, S. and Kaganzi, E. (2008)**. Evaluating marketing opportunities for haricot beans in Ethiopia. Rural agro-enterprise development project report

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra (2009). Plant drought stress effects, mechanisms and management. Agronomy for Sustainable Development 29: 185–212

Fisher and Maurer (1978). Australian Journal of Agricultural Research 29:897–912

Flexas, J., J. Bota, J. Cifre, J.M. Escalona, J. Galmés, J. Gulías, E. Lefi, S.F. Martínez-Cañellas, M.T. Moreno, M. Ribas-Carbó, D. Riera, B. Sampol, H. Medrano (2004). Understanding down-regulation of photosynthesis under water stress: future prospects and searching for physiological tools for irrigation management. Annual Applied Biology 144:273-283

Frahm, M.A., E.F. Foster and J.D. Kelly (2003). Indirect screening techniques for drought resistance in dry beans. Annual Report. Bean Improvement 46: 87–88.

Frahm, M.A., J.C. Rosas, N. Mayek-perez, E. Lopez –Salinas, J.A. Acosta- Gallegos and J.D. Kelly (2004). Breeding beans for resistance to terminal drought in the lowland tropics. Euphytica 136:223-232

Freyre, R., R. Rı´os, L. Guzma´n, D. Debouck and P. Gepts (1996). Ecogeographic distribution of *Phaseolus vulgaris* (Fabaceae) in Bolivia. Economic Botany 50:195–215

George, C. Kuo (2001). Growth, development, and Physiological aspect of Mung bean Yield. Asian vegetable research and development center, Taiwan

German, C., H. Teran, R.G. Allen, J.L. Wright, D.T. Westermann and S.H.P. Singh (2006). Selection for drought resistance in dry bean landraces and cultivars. Crop Science 46:2111-212

Google (2010). Google earth. http://earth.google.co.uk/intl/en_uk/submit.html

Graham, P.H., and P. Ranalli (1997). Common bean (*Phaseolus vulgaris*), Field Crops Research 53:131-146.

Griffiths, H., A.H. Price, J.E. Cairns, P. Horton and H.G. Jones (2002). Linking drought-resistance mechanisms to drought avoidance in upland rice using a QTL approach: progress and new opportunities to integrate stomatal and mesophyll responses. Journal of Experimental Botany 53:989-1004

Guida dos Santos, M., R. Vasconcelos, R. Ferraz and C. Pimentel (2004). Gas exchange and yield response to foliar phosphorus application in *Phaseolus vulgaris* under drought. Plant Physiology 16:171-179

Habtu, A., D. Daniel, M. Tariku, S. Gebeyehu, A. Asfaw, B. Tesso, and P. Kimani (2006). Participatory plant breeding with women and small scale farmers: A case study in haricot bean in Ethiopia. Pp 30-41 *In* Food and forage legumes of Ethiopia: Progress and prospects. Proceedings of the workshop on food and forage legumes. Addis Ababa, Ethiopia

Havaux, M. (1998). Carotenoids as membrane stabilizers in chloroplasts. Plant Science 3: 147–151

Haywood, J., and M. Schulz (2007). Causes of the reduction in uncertainty in the anthropogenic radiative forcing of climate between IPCC (2001) and IPCC (2007), Geophysical Research 34, L20701: 10.1029/2007GL030749.

Hieng, B., K. Vgrinovic, J. Sustan-Vozlic and M. Kidric (2004). Different classes of proteases are involved in the response of drought of *Phaseolus vulgaris* cultivars differing in sensitivity. Plant Physiology 161:519-530

Hosfield, G.L., M.A. Uebersax and L.G. Occena, (2000). Technological and genetic improvements in dry bean quality and utilization. Proceedings of the Idaho Bean Workshop, August 3-4, 2000, University of Idaho, Moscow pp: 135-152.

IPCC (2007). http://www.ipcc-data.org.

Ishitani, M., I. Rao, P. Wenzi, S. Beebe and J. Tohme (2004). Integration of genomic approach with traditional breeding towards improving abiotic stress adaptation: drought and aluminium toxicity as case studies. Field Crops 90:35-45

Jarvis, A. (2009). Andy Jarvis models on the effect of climate change on world's top 50 crops. http://www.earthsky.org/interviewpost/agriculture/andy-jarvis-models-the-effect-of-climate-change-on-worlds-top-50-crops. Accessed on 5th November 2009.

Kambewa, S. P. (1997). The Bean Sub-sector in Malawi: historical developments, current status and policy issues. A Master of Science Thesis, Department of Agricultural Economics, Michigan State University, USA.

Karanja, D. Kenya national bean program annual report **(2006).**

Kelly, J.D., P. Gepts, P.N. Miklas and D.P. Coyne (2003). Tagging and mapping of genes and QTL and molecular marker-assisted selection for traits of economic importance in bean and cowpea. Field Crop Research 82:135–154

Kiani, S.P., P. Maury, A. Sarrafi and P. Grieu (2008). QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus* L.) under well-watered and water-stressed conditions. Plant Science 175: 565–573

Kimani, P.M., R. Buruchara, K. Ampofo., M. Pyndji, R. Chirwa and R. Kirkby (2005). Breeding bean for smallholder farmers in Eastern, Central and Southern Africa: Constraints, Achievements and Potential. Cali, Colombia, CIAT

Kimani, P.M., R. Chirwa and R. Kirkby (2000). Bean breeding for Africa: strategy and plan. Pan African Bean Research Alliance Millennium Symposium, Arusha, Tanzania 28 May-1 June 2001. International Center for Tropical Agriculture (CIAT), Cali, Colombia.

Kimani, S.K., A.O. Esilaba, M.M. Odera, L. Kimenye, B. Vanlauwe and A. Bationo (2007). Effects of organic and mineral sources of nutrients on maize yields in three districts of central Kenya. . In: Bationo A, Waswa B, Kihara J, Kimetu J (eds). Advances in integrated soil fertility management in Sub-Saharan Africa: Challenges and opportunities, Springer, The Netherlands pp. 353-357. Lal R, Reigner E, Edwards WM, Hammond R (1991)

Laffray, D. and P. Louguet (1990). Stomatal responses and drought resistance. Actual Botany 1:47-60

Lawlor, D.W. and G. Cornic (2002). Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant Cell Environment 25:275-294

Leterme, P. and C. Munoz (2002). Factors influencing pulse consumption in Latin America. British Journal of Nutrition Supplements 3:251-254.

Letourneau, D.K. (1994). Bean fly management practices and biological control in the Malawian subsistence agriculture. Agriculture Ecosystem Environment 50:103-111.

Lizana, C.M., J. Wentworth, P. Martinez, D. Villegas and R. Meneses (2006). Differential adaptation of two varieties of common bean to abiotic stress. Crop Science 57:685-697

Lunze, L. P.M. Kimani, R. Ngatoluwa, B. Rabary, G.O. Rachier, M.M. Ugen, V. Ruganza, and E.E. Awad Elkarim (2007). Bean improvement for low soil adaptation in eastern and central Africa. In: Bationo A, Waswa B, Kihara J, Kimetu J (eds). Advances in integrated soil fertility management in Sub-Saharan Africa: Challenges and opportunities, Springer, The Netherlands pp. 324-332.

Lynch, J.P. and K.M. Brown (2008). Root strategies for phosphorus acquisition. In White PJ, Hammond JP, eds, The Ecophysiology of Plant-Phosphorus Interactions. Springer, Dordrecht, The Netherlands pp 83–116

Lynch, J.P. (2007). Roots of the second Green Revolution. Australian Journal of Botany 55: 493–512.

Mead, R., R.N. Curnow and A.M. Hasted (2003). Statistical Methods in Agriculture and Experimental Biology, 3rd edn. Boca Raton: Chapman & Hall/CRC Press.

Medrano, H., J.M. Escalona, J. Bota, J. Gulías and J. Flexas (2002). Regulation of photosynthesis of C3 plants in response to progressive drought: the interest of stomatal conductance as a reference parameter. Annual Botany 89:895-905

Michieka D.O. (1977). Soils of the valley bottoms of Kabete Faculty Farm. National Agricultural Laboratories, Ministry of Agriculture, Nairobi, Kenya.

Maciel, F.L., L.T.S. Gerald and S. Echeverrigaray (2001). Random amplified polymorphic DNA (RAPD) markers variability among cultivars and land races of common beans (*Phaseolus vulgaris*) of South-Brazil. Crop Science 51: 257-263.

Manene, S. K. (2010). Kirinyaga South district briefs. Ministry of Agriculture. MoA. Kenya.

Miller, P.R., B.G. McConkey, G.W. Clayton, S.A. Brandt, J.A. Staricka, A.M. Johnston, G.P. Lafond, B.G. Schatz, D.D. Baltensperger and K.E. Neill (2002). Pulse crop adaptation in the Northern great plains. Agronomy Journal 94:261-272

Miyashita, K., S. Tanakamaru, T. Maitani and K. Kimura (2004). Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. Environment Experimental Botany 53:187-198.

Miyashita, K., S. Tanakamaru, T. Maitani and K. Kimura (2005). Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. Environment Experimental Botany 53:205-214

Morris, M.L. and M.R. Bellon (2004). Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. Euphytica 136:21–35.

Muasya, R.M. (2001). Crop Physiological Analysis of Seed Quality Variation in Common Beans (*Phaseolus vulgaris* L.). Ph.D. Thesis, Wageningen University. The Netherlands.

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

Munoz-Perea, C.G., H. Teran, R.G. Allen, J.L. Wright, D.T. Westermann and S.P. Singh (2007). Water use efficiency among dry bean landraces and cultivars in drought stressed and non stressed environments. Euphytica 155:393-402

Nchimbi-Msolla, S. and R.N. Misangu (2002). Seasonal distribution of common bean (*Phaseolus vulgaris* L.) bruchid species in selected areas in Tanzania. Proceedings of the Bean Seed Workshop, Jan. 12-14, Arusha, Tanzania, pp: 1-1.

Nielsen, D.C., and N.O. Nelson (1998). Black bean sensitivity to water stress at various growth stages. Crop Science 38:422–427.

Nkunika, P.O.Y. (2002). Smallholder farmers integration of indigineous technical knowledge (ITK) in maize IPM: a case study in Zambia. Insect Science 22:235-240.

Norman, M.J.T., C.J. Pearson and P.G.E. Searle (1995). The ecology of tropical food crops. Cambridge University Press, Cambridge 208-224

North, G.B., and P.S. Nobel (1997). Root soil contact for the desert succulent *Agave desertii* in wet and dry soil. New phytology 135:21-22

Nunez-Barrios, A., G. Hoogenboom and D.S. Nesmith (2005). Drought stress and the redistribution of vegetative and reproductive traits of a bean cultivar. Crop Science 62:18-22

Nyombaire, G., M. Siddiq and K. Dolan (2007). Effect of soaking and cooking on the oligosaccharides and lectins of red kidney beans (*Phaseolus vulgaris*). Bean improvement Cooperation Annual Report 50:31-32

Otsyula, R.M., J.H. Nderitu and R.M. Buruchara (1998). Interaction between bean stem maggot, bean root rot and soil fertility. *In* G. Farrell and G.N. Kibata (Eds), Crop protection research in Kenya, Proceedings of the Second Biennial Crop Protection Conference, 16-17 September 1998. Kenya Agricultural Research Institute (KARI). Department of International Development (DFID), Nairobi, Kenya.

Padilla-Ramirez, J.S., J.A. Acosta-Gallegos, E. Acosta-Diaz, N. Mayek-Perez and J.D. Kelly, (2005). Partitioning and partitioning rate to seed yield in drought stressed and non stressed dry bean genotypes. Crop Science 48:152-153

Passioura, J.B. (1996). Drought and drought tolerance. Plant Growth Regulation 20:79-83.

Pastor-Corrales, M.A., C. Jara, and S.P. Singh (1998). Pathogenic variation on, sources of, and breeding for resistance to *Phaeoisariopsis griseola* causing angular leaf spot in common bean. Euphytica 103:161-171.

Pimentel, C., G. Hebert and J. Silva (1999). Effects of drought on O_2 evolution and stomatal conductance of beans at the pollination stage. Environmental Experimental Botany 42: 155-162.

Porch, T. G., R. Bernsten, J.C. Rosas and M. Jahn (2008). Climate change and the potential economic benefits of heat tolerant bean varieties for farmers in Atlantida, Honduras. Journal of Agriculture 91:133–148.

Ramírez M., M.A. Graham, L. Blanco-López, S. Silvente, A. Medrano-Soto, M.W. Blair, G. Hernández, C.P. Vance and M. Lara (2005). Sequencing and analysis of common bean ESTs. Building a foundation for functional genomics. Plant Physiology 137: 1211–1227

Ramirez-vallejo, P., and J.D. Kelly (1998). Traits related to drought resistance in common bean. Euphytica 99:127-136

Ramos, M.L.G., A.J. Gordon, F.R. Minchin, J.I. Sprent and R. Parsons (1999). Effect of water stress on nodule physiology and biochemistry of a drought tolerant cultivar of common bean (*Phaseolus vulgaris L.*). Crop Science 83:57-63

Rao, I.M. (2001). Role of physiology in improving crop adaptation to abiotic stresses in the tropics: the case of common bean and tropical forages. In: Pessarakli M (ed) Handbook of plant and crop physiology. Marcel Dekker, Inc., New York, USA, pp 583–613

Rao, I. M., S.E. Beebe, J. Polanía, M. Grajales, C. Cajiao, R. García, J. Ricaurte and M. Rivera (2009). Physiological basis of improved drought resistance in common bean: the contribution of photosynthate mobilization to grain. Paper presented at Interdrought III: The 3rd International Conference on Integrated Approaches to Improve Crop Production under Drought-Prone Environments, October 11-16, 2009, Shanghai, China.

Rao, I. M., S. Beebe, J. Ricaurte, C. Cajiao, J. Polania and R. Garcia (2007). Phenotypic evaluation of drought resistance in advanced lines of common bean (*Phaseolus vulgaris* L.). Paper presented at ASA-CSSA-SSSA International Annual Meeting, new Orleans, LA, USA. 4-8 November, 2

Rosales-Serna, R., J. Kohashi-Shibata, J.A. Acosta-Gallegos, C. Trejo-Lopez, J. Ortizcereceres and J. Kelly (2004). Biomass distribution, maturity acceleration and yield in Drought- stressed Common bean Cultivars. Field Crops Research 85: 203-211

Rosales-Serna, R., J. Kohashi-Shibata, J.A. Acosta-Gallegos, C. Trejo-López J. Ortiz-Cereceres and J.D. Kelly (2002): Yield and phenological adjustment in four drought-stressed common bean cultivars. Annual Report Bean Improvement Cooperation 45, 198- 199

Rubio, G., H. Liao, X, Yan, and L.P. Lynch (2003). Indirect screening techniques for drought resistance in common bean. Crop Science 43:598-607

Saxena, C.M., S.N. Silim and B.K. Singh (1990). Effect of supplementary irrigation during reproductive growth on winter and spring chickpea (*Cicer arietinum*) in a Mediterranean environment. Journal of Agricultural Science 114, 285-293

Scartazza, A., S. Proietti, S. Moscatello, A. Augusti, M.C. Monteverdi, E. Brugnoli and A. Battistelli (2001). Effect of water shortage on photosynthesis, growth and storage carbohydrate accumulation in walnut *(Juglans regia* L.*)*. Acta Horticulture 544, 227-232

Schneider, K.A., R. Rosales-Serna, F. Ibarra-Perez, B. Cazares-Enriquez, J.A. Acosta-Gallegos, P. Ramirez-Vallejo, N. Wassimi and J.D. Kelly (1997). Improving common bean performance under drought stress. Crop Science 37:43-50

Serraj, R. and T.R. Sinclair (1998). Nitrogen fixation responses to drought in common bean (*Phaseolus vulgaris L.*). Crop Science 82:229-234

Shenkut, A. A. and M.A. Brick (2003). Traits associated with dry edible bean (*Phaseolus vulgaris* L.) productivity under diverse soil moisture environments. Euphytica 133 (3), 339-347

Siddique, K.H.M., L.K. Regan, D. Tennant and B.D. Thompson (2001). Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean type environments. European Journal of Agronomy 15: 267-280

Simmonds, L.P., M.W.K. Mburu and C.J. Pilbeam (1999). Bean growth and yield response to irrigation, nitrogen fertilizer and planting density under temperate and tropical conditions. East Africa Agriculture and Forestry Journal 65:21-36.

Singh B.B. (2005). Cowpea *[Vigna unguiculata* (L.) Walp. In: R.J. Singh. and P.P. Jauhar (Eds.), Genetic Resources, Chromosome Engineering and Crop Improvement. Volume 1, CRC Press, Boca Raton, FL, USA, pp. 117-162

Singh, D.P., V.S. Tomar, R.K. Behl, S.D. Upadhyaya, M.S. Bhale and D. Khare (2007). Crop production in stress environment: Genetic and management options. Jodhpur Agrobios International 30:1-656

Singh, S.P. (2001). Broadening the genetic bases of common bean cultivars. Crop Science 41:1659-1675

Socías, F.X., M.J. Correia, M.M. Chaves and H. Medrano (1997). The role of abscisic acid and water relations in drought responses of subterranean clover. Journal of Experimental Botany 48, 1281-1288

Songa, J.M. and T.K. Ampofo (1999). Ecology of the bean stem maggot attacking dry bean (*Phaseolus vulgaris* L.) in the semi arid areas of Eastern Kenya. International Journal of Pest management 45:35-40

Sthapit, B. and R. Rao (2007). “Grassroots breeding”: A way to optimise the use of local crop diversity for the well-being of people. Paper presented at the Tropengtag Conference, 9–11 October 2007, Witzenhausen, Germany.

Tardieu F. (1996). Drought perception by plants: do cells of droughted plants experience water stress? Plant Growth Regulation 20, 93–104.

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

Thung, M. and I.M. Rao (1999). Integrated management of abiotic stresses. In: S. P. Singh (ed.), Common Bean Improvement in the Twenty-First Century. Kluwer. Academic Publishers, Dordrecht, The Netherlands, pp. 331-370.

Timothy, G., S. Reeves, M.V. Rayaram, R. Ginkel, H. Trethowan, J. Braum and K. Cassady (2000). New wheat for a secure sustainable future. Agronomy Journal 41,141-143

Trutmann, P., J. Voss and J. Fairhead (1996). Local knowledge and farmer perceptions in bean diseases in the Central African highlands. Agriculture and Human Values 13:64-67.

UNFCCC, (2007). Climate change: Impacts, vulnerabilities and adaptation in developing countries. Bonn. Germany. Climate change secretariat (UNFCCC)

Van Schoonhoven, A. and M.A. Pastor-Corrales (1987). System for evaluation of bean germplasm. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Wahid, A., S. Gelani, M. Ashraf and M.R. Foolad (2007). Heat tolerance in plants: an overview. Environment Experimental Botany 61: 199–223

White, J.W., J.A. Castillo, J.R. Ehleringer, J.A. Garcia-c and S.P. Singh (1994a). Relations of carbon isotope discrimination and other physiological traits to yield in common bean (*Phaseolus vulgaris L.*) under rainfed conditions. Agricultural Science 122:275-284

White, J.W. (1994a). Relations of carbon isotope discrimination and other physiological traits to yield in common bean (*Phaseolus vulgaris*) under rainfed conditions. Journal of Agricultural Science 122:275–284

White, J.W., R. Ochoa, F. Ibarra and S.P. Singh (1994b). Inheritance of seed yield, maturity and seed weight of common bean (*Phaseolus vulgaris*) under semi-arid rainfed conditions. Journal of Agricultural Science 122:265–273

Witcombe, J.R. (2005). Participatory Varietal Selection and Participatory Plant Breeding: The last 10 Years. In: Gonsalves J., Becker T., Braun A., Campilan D., de Chavez H., Fajber E., Kapiriri M., Rivaca-Caminade J. and Vernooy R., editors. Participatory research and development for sustainable agriculture and natural resource management: A sourcebook. Volume 1: understanding participatory research and development. CIP-

Upward/ IDRC. Available online at http://www.idrc.ca/en/ ev-73443-201-1-DO_TOPIC.html.

Woolley, J., R.L. Ildefonso, T.A.P. Castro, and J. Voss (1991). Bean cropping systems in the tropics and subtopics and their determinants. Pages 679-706 *in* A. Van Schoonhoven and O. Voysest (eds), Common beans: Research for crop improvement. CAB International, Wallingford, UK.

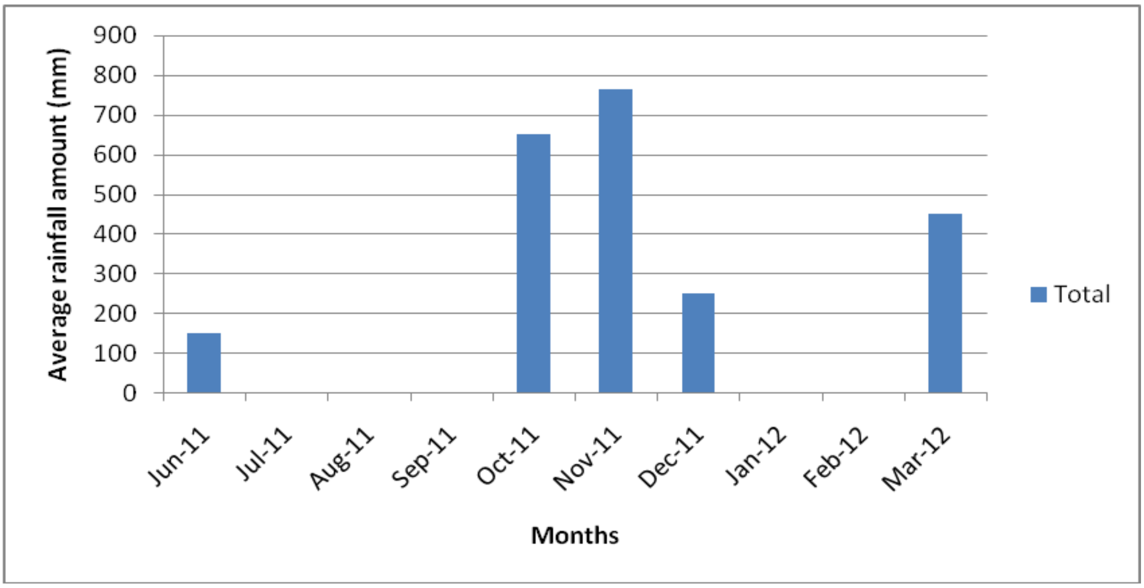
Wortmann, C.S., C.A. Eledu, and S. David (1999). Beans as a cash earner in Sub-Saharan Africa. Pages 103–104 *in* Annual Report of the Bean Improvement Cooperative, Vol. 42. Bean Improvement Cooperative, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI, USA.

Wortmann, C.S., R.A. Kirkby, C.A. Eledu and D.J. Allen (1998). Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. CIAT, Cali, Colombia.

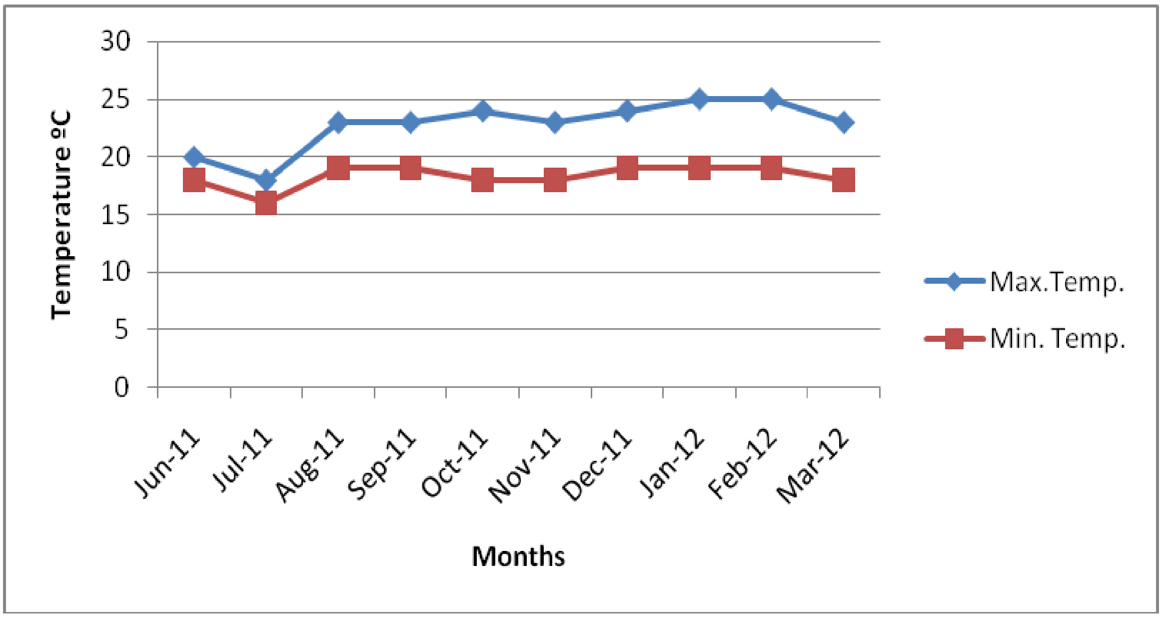
Xavery, P., R. Kalyebara, C. Kasambala and F. Ngulu (2005). The impact of improved bean varieties in Northern Tanzania. Selian Agricultural Research Institute (SARI) Tanzania in collaboration with the Pan-African Bean Research alliance (PABRA) and the International Centre for Tropical Agriculture (CIAT) (Unpublished Report)

8.0. APPENDICES

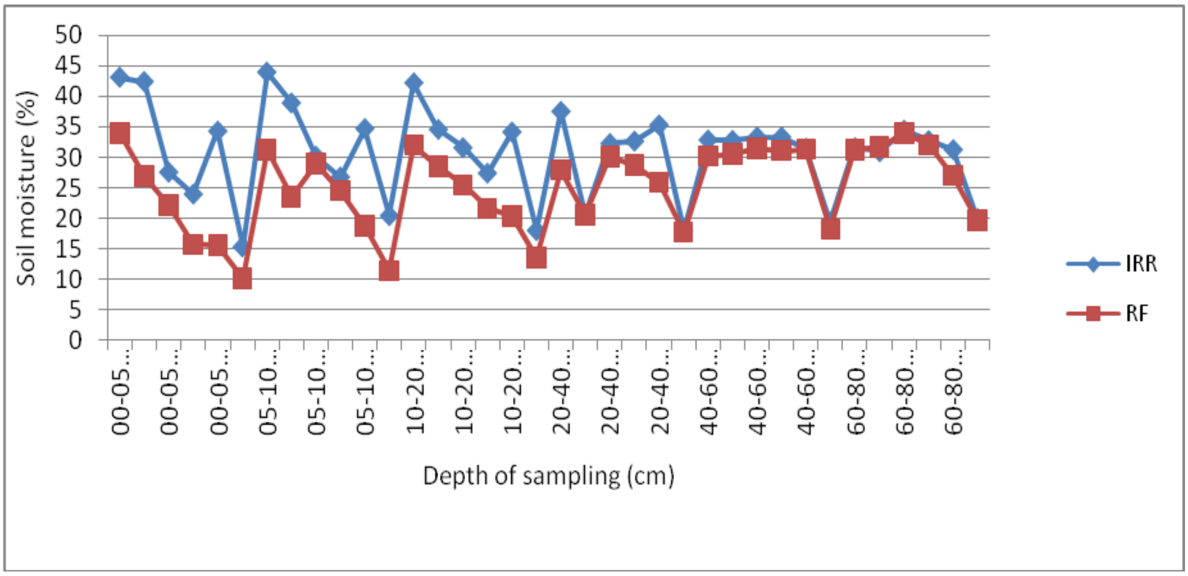
Appendix 1. Rainfall distribution during the two seasons over which the experiment was conducted at Kabete



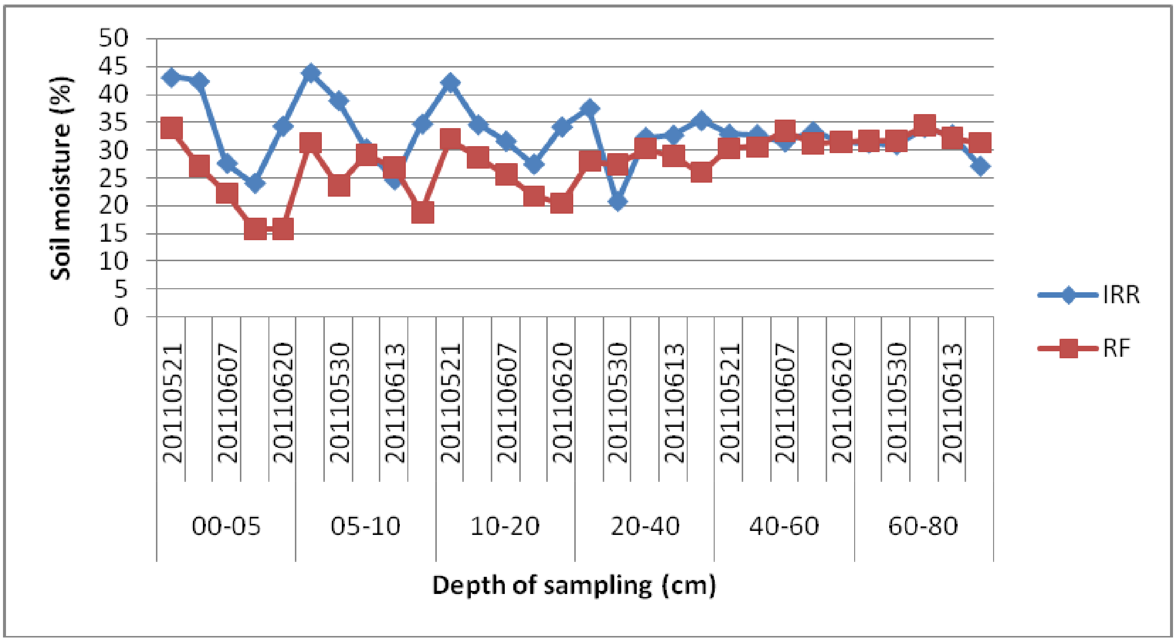
Appendix 2. Minimum and maximum temperature recorded during the two seasons over which the experiment was conducted at Kabete



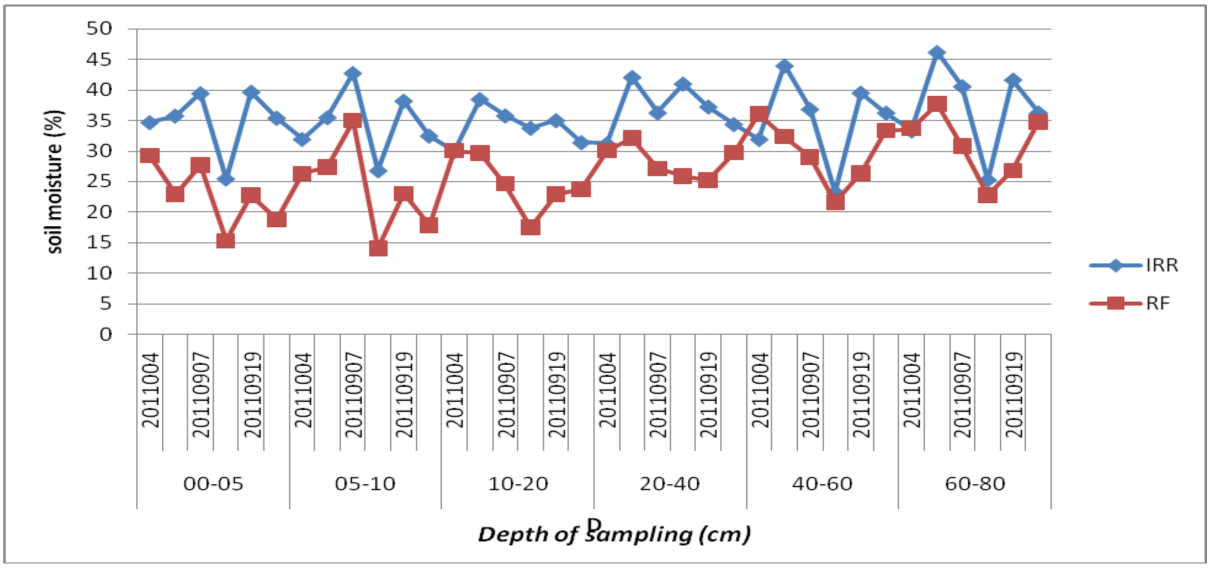
Appendix 3: Soil moisture status for non stress (IRR) and drought stress (RF) treatments during the first season trial at Mwea.



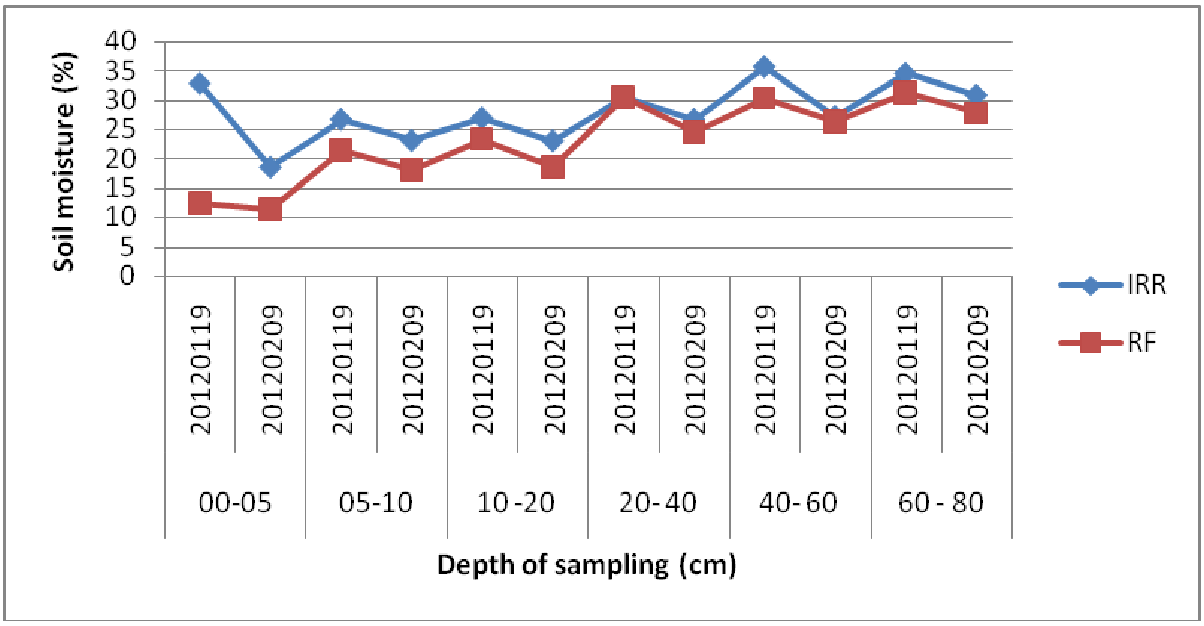
Appendix 4: Soil moisture status for non stress (IRR) and drought stress (RF) treatments during the second season trial at Mwea.



Appendix 5: Soil moisture status for non stress (IRR) and drought stress (RF) treatments during the first season trial at Kabete.



Appendix 6: Soil moisture status for non stress (IRR) and drought stress (RF) treatments during the second season trial at Kabete.



Appendix 7: Mean squares for days to 50% flowering, 90% days to physiological maturity and yield (kgha-1) of 84 Mesoamerican dry bean genotypes under irrigated and non irrigated treatments in Kabete and Mwea

Source	**Df**	**50%DF (Days)**	**90%DM (Days)**	**Yield ($Kgha^{-1}$)**
Replicates	1	77.6	257.3	159098
Season	1	4239.4*	16632.4*	11136214
Error (a)	1	17.4	114.3	232550
Location	1	68500.0*	64907.4***	11865245***
Season x Location	1	16012.1*	6448.8*	4858173*
Error (b)	2	136.5	15.9	9378
Treatments	1	0.3	4400.8*	7048516***
Season x Treatments	1	25.5*	68.8	73128
Location x Treatments	1	40.4**	2754.3**	274364
Season x Location x Treatments	1	1.3	168.6	346932
Error(c)	4	2.7	118.5	70394
Genotype	83	102.7***	92.1***	187464***
Season x Genotype	83	28.7***	139.3***	52047***
Location x Genotype	83	78.4***	129.7***	102135***
Treatments x Genotype	83	5.6	68.0	21397
Season x Location x Genotype	83	40.6***	104.0***	36391***
Season x Treatments x Genotype	83	5.8	69.2*	13384
Location x Treatments x Genotype	83	4.0	42.6	16624
Season x Location x Treatments x Genotype	83	4.5	74.0**	19502

*,**,***, significant at 0.05, 0.01 and 0.001 respectively.

Appendix 8: Mean squares for number of pods per plant, number of seeds per pod and 100 seed weight of 84 Mesoamerican dry bean genotypes under irrigated and non irrigated treatments in Kabete and Mwea

Source	Df	Pods per plant	Seeds per pod	100 seed weight (g)
Replicates	1	14.62	9.9635	585.4
Season	1	400.479*	240.7501*	33093.6**
Error (a)	1	1.504	1.1589	7.79
Location	1	416.71	331.477**	13274.39**
Season x Location	1	173.807	0.7888	1221.6
Error (b)	2	56.533	1.5308	118.92
Treatments	1	447.857**	15.2344*	996.1**
Season x Treatments	1	65.418	22.379*	199.56
Location x Treatments	1	42.56	1.1027	276.4
Season x Location x Treatments	1	48.439	1.5773	347.8*
Error(c)	4	24.058	0.4021	50.83
Genotype	83	31.559***	1.8427***	285.92***
Season x Genotype	83	10.213	0.8901**	88.86***
Location x Genotype	83	19.296***	1.3853***	59.34***
Treatments x Genotype	83	14.146***	0.5746	27.12
Season x Location x Genotype	83	10.399	0.8603**	51.55**
Season x Treatments x Genotype	83	8.025	0.5696	33.22
Location x Treatments x Genotype	83	10.406	0.7169	43.59
Season x Location x Treatments x Genotype	83	6.743	0.5278	35.26

*,**,***, significant at 0.05, 0.01 and 0.001 respectively.

Appendix 9: Mean squares for canopy temperature and leaf chlorophyll at flowering and mid pod filling growth stages of 84 Mesoamerican dry bean genotypes under irrigated and non irrigated treatments in Kabete and Mwea

Source	**Df**	**Canopy temp. at flowering (°C)**	**Canopy temp. at mid pod fill (°C)**	**SPAD at flowering**	**SPAD at mid pod fill**
Replicates	1	43.6	402.0	1.2	22.0
Season	1	3302.8*	347.3	42.8	37.0
Error (a)	1	6.3	22.6	47.0	236.7
Location	1	2595.2*	114.0	3161.4**	2.5
Season X Location	1	2714.6*	4372.6	262.6	4416.7**
Error (b)	2	90.2	519.8	30.8	27.0
Treatments	1	99.7	4808.6**	94.9*	6.1
Season X Treatments	1	70.1	165.1	0.8	37.6
Location X Treatments	1	18.5	66.6	129.6*	17.8
Season X Location X Treatments	1	25.5	326.9	70.4	159.5
Error(c)	4	30.4	166.1	11.5	178.1
Genotype	83	5.6***	16.6**	72.4***	63.1***
Season X Genotype	83	3.7*	12.5	9.1	23.8***
Location X Genotype	83	4.3***	16.8*	9.5*	24.7***
Treatments X Genotype	83	2.2	12.3	8.9	15.4
Season X Location X Genotype	83	2.8	12.3	10.7*	20.6**
Season X Treatments X Genotype	83	3.1	8.4	6.0	12.9
Location X Treatments X Genotype	83	2.8	10.8	9.1	15.6
Season X Location X Treatments X Genotype	83	2.1	10.8	6.6	12.7

*,**,***, significant at 0.05, 0.01 and 0.001 respectively.

Appendix 10: Mean squares for pod harvest index (PHI), harvest index (HI), pod wall biomass proportion (PWBP), pod partitioning index (PPI) and stem biomass reduction (SBR) of 84 Mesoamerican dry bean genotypes under irrigated and non irrigated treatments in Kabete

Source	**Df**	**PHI**	**HI**	**PWBP**	**SBR**	**PPI**
Replications	1	487.86	149.1	103.8	32.8	73.9
Season	1	24653.45	4857.1	196.8	368.0	22.9
Error (a)	1	544.98	179.0	20.9	4.8	107.5
Treatments	1	7364.79**	3415.1*	11250.1***	1630375.8***	22856.0*
Season x Treatments	1	99.13	0.4	421.1**	12.1	0.2
Error (b)	2	41.19	13.0	1.0	82.5	39.4
Genotype	83	96.81***	81.8***	149.4***	2213.8***	1725.7***
Season x Genotype	83	54.92***	28.6***	28.5***	160.6***	111.3*
Treatments x Genotype	83	31.34**	11.9	28.2***	3131.6***	160.2***
Season x Treatments x Genotype	83	24.16	12.0	12.5	125.3***	47.7

*,**,***, significant at 0.05, 0.01 and 0.001 respectively.

Appendix 11. Drought susceptibility indices of genotypes in the three market classes under drought stress and non stress conditions in Kabete and Mwea during the 2011 and 2012 growing seasons

	Drought susceptibility index (DSI)				
	Kabete		**Mwea**		
Genotype	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Mean DSI**
DMC 11-01	0.43	0.31	0.79	0.89	0.6
DMC 11-02	0.21	0.19	0.42	0.87	0.4
DMC 11-03	0.08	0.16	0.05	0.91	0.3
DMC 11-04	0.23	0.18	0.35	0.83	0.4
DMC 11-05	0.42	0.28	0.14	0.32	0.3
DMC 11-06	0.27	0.21	0.42	0.29	0.3
DMC 11-07	0.21	0.14	-0.01	0.68	0.3
DMC 11-08	0.08	0.18	-0.14	0.43	0.1
DMC 11-09	0.14	0.28	0.12	0.13	0.2
DMC 11-10	0.03	0.22	0.24	1.14	0.4
DMC 11-11	0.17	0.11	0.47	0.18	0.2
DMC 11-12	-0.55	0.21	0.22	0.64	0.1
DMC 11-13	0.37	0.35	0.17	1.17	0.5
DMC 11-14	-0.64	0.10	0.21	0.62	0.1
DMC 11-15	-0.05	0.26	0.09	0.82	0.3

DMC 11-16	0.48	0.23	0.33	0.61	0.4
DMC 11-17	0.15	0.48	0.33	-0.03	0.2
DMC 11-18	0.20	0.29	0.49	0.65	0.4
DMC 11-19	0.15	0.25	0.21	0.92	0.4
DMC 11-20	0.12	0.39	0.21	1.03	0.4
DMC 11-21	0.38	0.23	-0.14	1.06	0.4
DMC 11-22	0.44	0.52	0.17	1.46	0.6
DMC 11-23	0.39	0.32	-0.10	0.91	0.4
DMC 11-24	-0.12	0.10	0.26	0.25	0.1
DNB 11-01	0.32	0.25	0.52	0.69	0.4
DNB 11-03	0.53	0.11	0.03	0.18	0.2
DNB 11-04	0.59	0.22	0.36	0.44	0.4
DNB 11-05	0.28	0.21	0.56	0.12	0.3
DNB 11-06	0.53	0.19	0.60	0.47	0.4
DNB 11-07	0.19	0.27	0.25	0.52	0.3
DNB 11-08	0.34	0.24	0.25	0.70	0.4
DNB 11-09	0.12	0.27	0.29	0.26	0.2
DNB 11-10	0.49	0.07	0.22	0.32	0.3
DNB 11-12	0.15	0.13	0.23	1.12	0.4
DNB 11-13	0.07	0.32	0.10	0.82	0.3
DNB 11-14	0.08	0.18	0.03	0.29	0.1
DNB 11-15	0.46	0.32	0.18	0.22	0.3
DNB 11-16	0.32	0.28	0.27	0.70	0.4
DNB 11-17	0.42	0.32	0.40	0.85	0.5
DNB 11-18	0.01	0.32	0.10	0.49	0.2
DNB 11-19	-0.03	0.20	0.43	0.22	0.2
DSR 11-01	-0.48	0.10	0.43	0.58	0.2
DSR 11-02	0.23	0.20	-0.70	0.83	0.1
DSR 11-03	0.26	0.47	0.25	0.54	0.4
DSR 11-04	0.59	0.25	0.36	0.73	0.5
DSR 11-05	0.48	0.36	0.01	-0.35	0.1
DSR 11-06	0.36	-0.29	-0.11	0.38	0.1
DSR 11-07	0.52	0.01	0.44	0.75	0.4
DSR 11-08	-0.08	0.27	-0.44	0.64	0.1
DSR 11-09	0.43	0.11	0.14	0.33	0.3
DSR 11-10	0.47	0.32	0.80	0.30	0.5
DSR 11-11	0.28	0.13	0.46	0.58	0.4
DSR 11-12	0.34	0.25	0.87	0.55	0.5
DSR 11-13	0.48	0.08	0.42	0.44	0.4
DSR 11-14	0.42	0.18	0.17	0.56	0.3
DSR 11-15	0.04	0.23	0.73	0.51	0.4
DSR 11-16	-0.04	0.08	-0.35	0.33	0.0
DSR 11-18	0.17	-0.02	0.60	0.91	0.4
DSR 11-19	0.45	-0.21	0.40	0.01	0.2
DSR 11-20	0.13	0.16	-0.28	0.06	0.0

DSR 11-21	0.34	0.10	0.70	0.49	0.4
DSR 11-22	0.21	0.14	0.00	0.68	0.3
DSR 11-23	0.20	0.17	0.08	0.12	0.1
DSR 11-24	0.00	0.03	0.48	0.49	0.3
GLP585*	0.02	-0.31	0.65	0.32	0.2
GLPX92*	-0.02	0.28	-0.57	1.28	0.2
KATB1*	0.28	0.36	0.51	0.34	0.4
KATB9*	0.11	0.31	0.06	0.20	0.2
MEX142*	0.57	0.16	0.16	0.82	0.4
NCB226*	0.22	0.29	0.07	0.12	0.2
NCB280*	0.30	0.13	0.00	0.16	0.1
RAB651*	0.26	0.27	0.51	0.26	0.3
RCB231*	0.13	0.00	-0.11	0.35	0.1
RCB270*	0.32	0.08	0.06	0.80	0.3
RCB592*	0.20	0.14	0.32	0.54	0.3
SEA15*	0.20	-0.21	0.08	0.28	0.1
SEN53*	0.12	0.52	0.33	0.37	0.3
SEN56*	-0.16	0.35	0.40	0.56	0.3
SER155*	0.11	0.43	0.85	0.21	0.4
SER16*	0.00	0.31	0.46	0.09	0.2
SER76*	0.15	0.23	0.30	0.30	0.2
SER95*	0.18	0.42	0.06	0.07	0.2
SXB404*	-0.03	0.30	0.33	0.11	0.2
TIO CANELA*	0.27	0.24	0.08	0.20	0.2
Mean of genotypes	**0.22**	**0.20**	**0.24**	**0.56**	**0.3**
Mean of checks	**0.16**	**0.21**	**0.23**	**0.37**	**0.2**
Overall	**0.19**	**0.21**	**0.25**	**0.46**	**0.3**