MAKERERE UNIVERSITY

EVALUATION OF MALAWI PIGEON PEA (*CAJANUS CAJAN L*) ACCESSIONS FOR TOLERANCE TO MOISTURE STRESS AND SUPERIOR AGRONOMIC TRAITS IN UGANDA

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DECLARATION

I declare that the work presented in this Thesis is original and has not been submitted to any other university for the award of a degree.

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DEDICATION

To my son Favour Mponya, husband Chimwemwe Mponya, mother, Besta Khaki, sister, Ida Khaki and brother Zyxme Khaki.

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ABSTRACT

Narrow genetic diversity among Ugandan local germplasm has greatly slowed down pigeon pea breeding progress in Uganda. Low yielding and drought susceptible cultivars are under cultivation by farmers due to unavailability of improved varieties with farmers' preferred traits. This has contributed to the decline in area under pigeon pea cultivation with farmers' shifting interest to other competitive crops. However, the crop is still popular with farmers as is evidenced by its backyard cultivation. It is therefore believed that, the crop can regain its productivity after improvement on drought and other traits of economic importance.

In this study, 52 pigeon pea accessions from Malawi, two local check varieties (20L and 22L) from Uganda were evaluated under field conditions for agronomic traits of economical importance at Makerere University Agricultural Research Institute-Kabanyolo (MUARIK) in Wakiso district for two rain seasons (2010a and 2011b) and at Ngetta Zonal Agricultural Research and Development Institute (NgeZARDI) in Lira district in Uganda for (2010a) season . The experiment was set up in a partially balanced lattice and replicated twice. Data on days to 50 % flowering and days to 75 % maturity, plant height, yield and yield components were recorded. Pest damage levels due to pod suckers *Clavigralla tomentosicollis* Stal., pod borers *Helicoverpa armigera* Hubner and pod fly *Melanagromyza chalcosoma* Spencer were recorded on the accessions at flowering, podding and pod maturity. Results showed no significant differences ($P > 0.05$) for all tested lines in their response to pest damage across locations. However, significant differences ($P \leq .0.01$) to pest damage were expressed across seasons at MUARIK. Across locations results showed that 90% of the lines were highly resistant at flowering, 19% during podding and 21% at pod maturity while 78% were highly resistant to pest damage at all stages. Significant differences at ($P \leq 0.05$) were observed for days to 50 % flowering and 75 % maturity, plant height, yield and yield components among genotypes. About 22 % expressed short maturity duration, 77% were

medium duration while only 1% exhibited long duration maturity period. Sixty nine percent of the accessions were medium seeded and about 22% of these accessions including local check 20L gave yield of > 500kg/ha for both across locations and seasons. Accessions in this include; KB05-2, KB06, KB14, AP02, AP04, AP29, 2246, 2256, 2306, 2321 and 2328. Grain yield showed high and positive association with 100 seed weight (r=0.603**) and number of pods per plant (r=0.888***).

Based on the above traits, 14 lines; 2311, 2302, 2047, 2300, 2263, KB05-2, KB03, KB06, KB08, AP10, AP10 (2), AP10 (3), AP01 and 20L were selected and screened for post flowering drought tolerance alongside checks KAT 60/8 and ICEAP00068 using a two factorial (watering regimes and genotype) split plot experimental design. The experiment involved the accessions being subjected to four watering regimes; i) 1000mm, ii) 500mm, ii) 250mm and iv) 0 mm applied every seven days starting at 50% flowering (approximately 97 days after planting) until harvest and the experiment was repeated twice. Data was collected on relative leaf water content, chlorophyll content, leaf defoliation and flower fall, leaf wilting, root biomass and grain yield. Results showed that post flowering drought significantly ($P < 0.05$) reduced grain yield by 50%. Accessions KB06, KB08 and KB05-2 recorded higher significant ($P < 0.001$) drought tolerance efficiency (DTE ≥ 80%), lower drought susceptibility index (≤ 1) and high grain yield compared to KAT 60/8, ICEAP00068 and 20L. Accession AP10 gave zero yield under 500mm, 250mm and 0mm water treatment and was therefore regarded the most susceptible to post flowering drought.

These results demonstrate that Malawian pigeon pea accessions have exploitable amount of genetic diversity useful to improve yield and drought tolerance traits in current Uganda local germplasm. However, multi-location evaluation, inclusion of farmers' preferences and understanding the physiological relationship of drought parameters and yield should be considered in follow up studies.

CHAPTER ONE

INTRODUCTION

1.1 Economic Importance of Pigeon pea

Pigeon pea (*Cajanus cajan L.*) is an important grain legume crop in Eastern and Southern Africa (ESA), Asia and Central America (Hillocks *et al*, 2000). In Africa, it is mainly grown by subsistence farmers in the semi-arid areas due to its drought tolerance (Odeny, 2007). Globally, the crop ranks fifth in importance among legumes after common beans, soy bean, cowpeas and chick peas (Egbe and Idoko, 2012). In 2008, annual world production of pigeon peas was estimated at 3.65 million metric tons (MT) cultivated on an approximated area of 4.92 million hectares. Yield is estimated at 898 kg/ha (Saxena, 2008 and FAOSTAT, 2010). The global annual production of pigeon pea is valued at approximately US$ 1, 600 million (FAOSTAT, 2011). In Asia, ESA, Caribbean regions and Latin America, pigeon pea is currently being cultivated on 5.2 million ha of land (ICRISAT, 2012). India has the largest area (3.38 million ha) and its production is estimated at around 3 million tonnes per annum (ICRISAT, 2012) accounting close to 70 % of world's pigeon pea production.

In ESA, pigeon pea is cultivated on an approximated area of 0.82 million ha with production of 0.53 million tonnes. This is much below the current demand for food and feed (ICRISAT, 2012, FAOSTAT, 2011). The main pigeon pea growing countries in the region with their annual production include; Kenya (≈89.0 metric tons produced on 196, 261ha of land) (Simtowe *et al*., 2012), Malawi (79.3 metric tons produced from 123,000ha of land) (Simtowe *et al*., 2008), Uganda (77.3 metric tons produced from 86,000ha of land), Tanzania (46.0 metric tons produced from 68,000ha of land) and Mozambique (40.0 metric tons produced from 85,000ha of land) (Monaco, 2006).

In Uganda, pigeon pea production currently stands at 13,000 metric tons from 29,800 ha (the reported cultivation area) (UCA, 2010). The crop is mainly grown in dry areas of the northern and north-eastern regions in the districts of Apac, Lira, Gulu, Kitgum, Arua, Moyo, Nebbi and Soroti (Manyansa *et al.*, 2009; UCA, 2010). In all these districts, pigeon pea is commonly grown as a secondary backyard crop or in a mixed cropping system with sorghum (*Sorghum bicolor*) and millet (*Eleucine coracana*) (UCA, 2010). The small holder farmers in the northern region contribute 97.4 % of the total production in Uganda. The average pigeon pea productivity in Uganda ranges from 0.5-0.7t h^{-1} compared to on-stationyield o

About 90 % of the pigeon pea growers use local varieties such as Apio Elina, Agali, Adyang and Adong. These varieties are late maturing (6-9 months) and produce low yields (250 - 450 kg/ha) (Silim *et al.*, 2006). Adong is the most widely cultivated variety and has maturity duration of over 8 months (FAOSTAT, 2010; NaSARRI, 2003). Farmers prefer these late maturing and low yielding varieties because of large seed size, taste and colour (Manyansa *et al.*, 2009).

An important feature of pigeon pea is its contribution to soil fertility improvement. The crop is often grown on poor soils with few or no inputs due to its ability to fix atmospheric nitrogen of up to 40kg/ha N (Saxena, 2008) and to solubilise and utilise fixed phosphorus and make it available to subsequent crops and thus contributing to soil fertility amelioration and increased productivity (Mallikarjuna *et al.*, 2011). Its deep extensive root system and fallen leaves to the soil enhances the soil-biomass and fertility (Mallikarjuna *et al.*, 2011).

Pigeon pea grain is also an important source of protein (29%), essential amino acids (1%), minerals such as calcium (Ca) of about 16.3mg/100g, phosphorus (P), magnesium (Mg) 78.9mg/100g, iron (Fe) 2.9mg/100g, Copper (Cu) 1.3mg/100g and Zinc (Zn) 3.0mg/100 and soluble vitamins such as riboflavin, thiamine and niacin and these are important to both human and animal nutrition (Singh *et al.*, 1990). The grains provide a cheap source of carbohydrates (51–59 %), (Saxena *et al.*, 2002). This makes pigeon pea a good source of both macro and micro nutrients for rural people who largely depend on starchy foods (FAOSTAT, 2010). Cases of malnutrition are especially more pronounced among children of below five years of age and reproductive mothers (MAAIF and MoH, 2005). Therefore, promoting pigeon pea production in countries like Uganda could substantially contribute to reduction in the cost of vitamin A supplementation and food fortification (MAAIF and MoH, 2005). Because of its high nutritional values, the crop has a potential to offset low supply of bone meal and high cost prices associated with fish meal in the animal feed industry (Safalaoh, 2009).

Grain of pigeon pea can be eaten whole, dehulled or grounded and used as flour (Mallikarjuna *et al*., 2011). The green immature seeds are also often eaten as a vegetable (Snapp *et al*., 2003) and dry peas are often processed into "dahl," decorticated split seeds (Mallikarjuna *et al*., 2011). In India, pigeon pea is a highly tradable commodity and offers employment to a number of people in both small and large scale agro based industries (Saxena, 2008). This always keeps its demand very high even during off seasons. During periods of scarcity of pigeon pea, supplies are frequently met through imports from as far as African farms (Odeny, 2007). However the challenge is always stability of production in Africa that normally fails to meet sustained and dependable export demand (FAOSTAT, 2010). In Kenya, pigeon pea is regularly exported to Europe with more than 5 % entering the European market in 2006 (Odeny, 2007; USAID, 2010).

In addition to being a food and income source, pigeon pea has several other uses. In Nigeria, for instance, the leaves and roots are used as medicine to treat malaria and other ailments (Aiyeloja and Bello, 2006). Pigeon pea leaves also make a good fodder for livestock, while, the plant's woody stems are valuable firewood, thatch and fencing (Mallikarjuna *et al*., 2011). The slow growth of the crop above ground during its early phase offers very little competition to other crops allowing productive inter-cropping with crops such as maize, sorghum, pearl millet, groundnut, soybean, cowpea under a wide range of climatic conditions thereby fitting well in cropping system in uganda (Okware, 2001). Pigeon pea cultivation is not labour intensive and can, therefore, be cultivated by both gender groups. This makes it fit well in a peasant agricultural system as is the current practice of most pigeon pea growers (FAOSTAT, 2010).

1.2 Production constraints of pigeon pea

A number of biotic, abiotic and social economic factors contribute to low yields and marketability of pigeon peas (Rusike and Dimes, 2006; Simtowe *et al*., 2008). The main pigeon pea production challenges in Uganda include, pests and diseases, extended droughts and in availability of improved pigeon pea varieties with farmers preferred traits (Manyas *et al*., 2009; Areke *et al*., 1995).

1.2.1 Biotic constraints

Pests and diseases are some of the biotic constraints to pigeon pea production in Uganda. The common pests of pigeon pea include *Aphis craccivora* Koch, pod sucking like *Clavigralla tomentosicollis* Stal., pod borers *Helicoverpa armigera* Hubner and pod fly *Melanagromyza chalcosoma* Spencer (Kokorom, 2001, Night and Latigo, 1994). The most serious and damaging pests are those that occur during flowering and podding stage (Night and Latigo, 1994). These include Lepidopteran pod and flower feeders and pod sucking Hemiptera (Hillocks *et al*., 2000). In severe cases, these pests significantly reduce nutritive quality of pigeon pea grains which is the ultimate benefit of farmers (Minja, 2000). Increased pest pressure is a challenge to resource constrained farmers since this means more cost are incurred on insecticides for spraying the crop (Hillocks *et al*., 2000). Consequently many farmers in Uganda have reduced acreage and now grow pigeon pea as a backyard crop despite its high nutritional status (Manyasa *et al.,* 2009).

Among the diseases affecting pigeon pea include Fusarium wilt (*Fusarium udum* Butler), Cercospora leaf spot (*Mycovellosiella cajan* Range ex. Trotter) and powdery mildew (*Leveillula taurica* (Lev.) Salmon) (Ngugi and Omanga, 1992, Hillocks *et al*., 2000). The severity and incidence of these pests and diseases is greatly influenced by the period the crop stays in the field (Minja, 2000). Breeding for tolerance or resistance has been the strategy to manage these stresses (Kokorom, 2001).

1.2.2 Abiotic constraints

Adequate soil moisture is critical during flower bud initiation, podding and grain filling in pigeon peas (Nam *et al*., 2001). Deficiency of soil water at reproductive stage alone accounts for 100% loss of grain yield (Farooq *et al*., 2009, Kumar *et al*., 2011, FAOSTAT, 2010). The rains have become increasingly unpredictable due to possible effects of climate change and posing a threat to rain fed cropping systems (FEWSNET Uganda, 2010). This problem is further aggravated by the lack of appropriate drought tolerant varieties that fit into the ever changing weather conditions (Farooq *et al*., 2009, Blum, 2005). Compounded to this is the problem caused by soil salinity which has also been reported to cause some yield loss in pigeon peas (Mallikarjuna *et al*., 2011). The severity of soil salinity is dependent on soil water deficit (Saxena, 2008). Pigeon pea is also affected by water logging conditions which substantially reduces pigeon pea biomass. However, successful management strategies for water logging have been developed (Saxena, 2008).

1.2.3 Marketing, institutional and policy challenges

Since 1970s, seed inaccessibility has been a widespread problem in the Southern and Eastern Africa region (Jones *et al*., 2000, Simtowe *et al*., 2008). It has been frequently reported that inaccessibility of improved seeds is the greatest challenge to most rural farmers because of transportation problems as rural roads are muddy and impassable during rainy season (Jones *et al*., 2000, Simtowe *et al*., 2008). Another challenge to seed supply is the lack of well established seed multiplication and delivery systems for the crop and as such the supply for pigeon pea seed to farmers is always low (Shiferaw, *et al*., 2005, FAOSTAT, 2010,).

1.3 The status of pigeon pea improvement programs and future prospects in Africa

Traditionally, farmers have employed their own criteria for selecting varieties of their interest (Jones *et al*., 2000, Manyansa *et al*., 2009). Production systems and expected use of the crop commonly dictated the traits to be selected (Songok *et al*., 2010, Odeny, 2007). These selections are based on the physical appearance of the crop. This informal selection by farmers, however, needs to be complimented with more formal breeding schemes since farmers' criteria do not include other factors such as changes in climatic conditions (Songok *et al*., 2010, IRIN news, 2010).

Concerted efforts to strengthen pigeon pea first commenced in ICRISAT in 1972 (Silim *et al*., 2006). Working together with a selected National Agricultural Research Systems (NARS) in Africa, an agenda for pigeon pea improvement was set, that resulted in the development and release of more than 15 improved pigeon pea varieties with distinct maturity periods in a period of more than 10 years (from early 1980s to 2003) (ICRISAT, 2006, Odeny, 2007). However, much of the improvements were on disease resistance (Fusarium wilt) and earliness (Areke *et al*., 1995, Gwata *et al*., 2006). Additionally, farmers' preferences were not taken into consideration while developing the new improved varieties since most pigeon pea enhancement programmes focused much on breeding for pest resistance (Areke *et al*., 1995; Naluwairo, 2011). Introductions of early maturing and high yielding improved varieties were not widely adopted in Kenya partly because most farmers preferred white and large seeded varieties over small and dark coloured seeds varieties, and most of the new improved varieties tended to harbour the latter traits (Jones *et al*., 2000)

Unfortunately, low appeal and several other social economic factors have prevented wide adoption of these varieties (Simtowe *et al*., 2012, Simtowe *et al*., 2008). Moreover these varieties were released in major pigeon pea producing countries in ESA (Manyansa *et al*., 2009). Consequently several local landraces have been retained and are still widely grown (Simtowe *et al*., 2012). These landrace are late maturing, low yielding and susceptible to pests and diseases (Okware, 2001, Manyansa *et al*., 2009).

To address the seed challenge, a collaborative pigeon pea improvement project was established in the early 1990's by ICRISAT and was funded by African Development Bank (Silim *et al*, 1992). Partners included National Agricultural Systems (NARS) from ESA and selected agro based nongovernmental organizations in each country. This project aimed to strengthen the harmonization of pigeon pea breeding in ESA (Silim *et al*., 1995). Since then, ICRISAT has continued to place major emphasis on pigeon pea improvement for ESA and is currently working directly with many national agricultural research systems on legumes. However, ineffective seed distribution channels hamper deployment of new improved seeds

(Jones *et al.*, 2000, Simtowe *et al*., 2012). For instance, a recent study on the adoption of improvement varieties in Malawi indicates that the demand for seed is higher than supply (Simtowe *et al*., 2008). This means that, the deficit could be met by improving both formal and informal seed sectors. Rusike and Dimes (2006) and Simtowe *et al*. (2008) also indicate that marketing, institutional and policy failures as the major constraints to expanded production of African pigeon pea. Farmers are unaware of what is happening on the market as a result they end up being price takers in a highly unstable market which consequently, results in getting the least share of the final consumer prices. This has directly influenced farmers' choice and prioritization of this crop. To ensure high variety adoption rates, farmers are now involved in the selection and improvement of local varieties, as well as in promoting local seed production enterprises (Shiferaw *et al*., 2005). Markets are being strengthened by involving both the formal and informal seed sectors and creating a good information flow and product development (Simtowe *et al*., 2008, Odeny, 2007). Currently, most pigeon pea research in ESA makes use of classical breeding and use of molecular markers technology in the development of superior genotypes (Wasike *et al*, 2005).

1.4 Statement of the problem

Pigeon pea yields under farmers' conditions in Uganda is < 0.450t ha^{-1} compared to potential yield (1.5- 2.5t ha^{-1}) Mergeai *et al*., 2001 in Odeny, (2007) achieved on on-station experiments (FAOSTAT, 2010; NaSARRI, 2012). A number of factors attributed to low yields and among these include; drought (low soil moisture), pests and diseases, and use of unimproved late maturing varieties (Silim *et al*., 2006, Minja, 2000). Of the pigeon pea pests, the most damaging ones in Uganda are especially those that occur at flowering and podding ie. pod sucking like *Clavigralla tomentosicollis* Stal., pod borers *Helicoverpa* *armigera* Hubner and pod fly *Melanagromyza chalcosoma* Spencer (Kokorom, 2001, Night and Latigo, 1994). For instance, pod suckers and feeders have been reported to significantly reduce nutritive quality of pigeon pea grains by 45% - 75% (Odeny, 2007) which is the ultimate benefit of farmers (Minja, 2000).

Increased pest pressure is specifically a challenge to resource constrained farmers who grow this crop since this means more cost is incurred on insecticides for spraying the crop (Hillocks *et al*., 2000). A number of studies on pest management have been conducted in Uganda with main focus on integrated pest control measures with no attention to breeding for inherent pest resistance (Kokorom, 2001). Breeding for pest resistance varieties in pigeon peas is expected to offer an alternative and best complementary pest control measures to integrated pest management (Okware, 2001). Improved varieties which were introduced in Uganda for the past 20 years suffered low appeal and adoption because they lacked farmers preferred traits such as large seed size, storability, good taste and cookability (Okware, 2001). New pigeon pea improvement programs ought to look at a more diverse and holistic way in order to address all the challenges linked to both production and adoption of improved pigeon pea varieties.

Further to this, is the issue of extended drought occurrences in pigeon pea growing area of Uganda (Hepworth and Goulden, 2008). In Uganda, extended droughts reduce pigeon pea grain yield of up to 77% especially when it occurs at reproductive stage (FEWSNET, 2010). Breeding for early maturing varieties through introgression or selecting for drought escape mechanism has been used by ICRISAT as an approach to breeding for drought tolerance in pigeon pea (ICRISAT, 2006). However, this approach has been challenged with unpredictable and extended droughts at reproductive stage which were reported to reduce grain yield by 45-75% in extra short duration pigeon pea varieties (Odeny, 2007). With an average rainfall of 1200mm received in pigeon pea growing district of Lira, pigeon pea production is possible but under extended drought conditions and un equal distribution of rainfall, reduction farmers produce is expected to continue (FAOSTAT, 2007). Increasingly, most pigeon pea growing areas in Uganda received unpredictable rainfall further destabilising farmers produce (Hepworth and Goulden, 2008). Thus developing pigeon pea drought tolerant varieties with pest resistance and farmers preferred traits is expected to improve pigeon pea yields. However, the narrow genetic diversity among pigeon pea germplasm in Uganda has slowed down improvement of such traits (Manyansa *et al*., 2009).

1.5. Justification

Strengthening national breeding programmes is one recommended approach to improve pigeon pea in ESA (Odeny, 2007). The starting point of this is the selection and identification of unique genotypes for different agronomic traits that would serve as parental stocks (Manyansa *et al*., 2009). Relatively low diversity in traits of economic importance in Uganda pigeon pea germplasm necessitated introductions to broaden the genetic base of Uganda pigeon pea germplasm (Wasike *et al*., 2005). Recently, the Department of Agricultural Production of Makerere University with funding from RUFORUM introduced some pigeon pea collections from Malawi with an aim of widening the genetic base of local germplasm to which this research is part of. Malawi has a considerable pigeon pea diversity that would help widen the narrow genetic base of Ugandan pigeon pea cultivars (Wasike *et al*., 2005). Multi-location evaluation of the introduced pigeon pea germplasm is specifically crucial to unlocking the genetic and phenotypic diversity harbored by the germplasm (Upadhyaya *et al*., 2008; Manyansa *et al*., 2009). The agronomic performance of any crop including pigeon pea is better judged when evaluations are done in the areas where the crop is adapted (Karim *et al*., 2006). For instance, expression of drought tolerance differs from genotype to genotype and is environmental specific (Blum, 2005). Drought tolerance in pigeon pea has been reported to result from a combination of mechanisms which include ability of genotypes to maintain turgor pressure (leaf relative water content), ability to extract water in drought conditions which is related to root proliferation and ability to maintain chlorophyll content (Saxena, 2008). Efforts have been made to screen for large root trait and ability to maintain turgor pressure (relative leaf water content) and chlorophyll content in order to establish the reliability of these traits in selecting for drought tolerance in pigeon pea (Saxena, 2008). However, no information is available on whether these traits were combined to develop drought tolerant varieties. There was a need therefore to screen some selected accessions from Malawi for drought tolerance. Information about the agronomic performance of Malawi pigeon pea accessions in Uganda was generated and accessions which performed well compared to local checks were identified.

1.6 Overall Objective

To develop improved pigeon pea varieties tolerant to drought and with farmer preferred traits in Uganda

1.6.1 Specific objectives

Specifically, the study was undertaken to:

1 To i identify pigeon pea lines with superior key agronomic traits among selected accessions from Malawi under Ugandan conditions

2 To i dentify genotypes with exploitable levels of drought tolerance as possible drought tolerant breeding parents.

1.7 Hypotheses

1. Malawian pigeon pea germplasm is diverse and unique with some superior agronomic traits that can perform well under Ugandan conditions.
2. There is exploitable post flowering moisture stress tolerance among the Malawian pigeon pea accessions.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, distribution and taxonomy of pigeon pea

The origin of pigeon pea *(Cajanus cajan L.*Millsp) is not clearly known. However, it is believed to have been introduced into East Africa from India by immigrants who came as railway workers and storekeepers in the 19^{th} century (Hillocks *et al.*, 2000). It is further believed that the crop thereafter was taken up to the Nile valley into West Africa and eventually to America (Mallikarjuna *et al*., 2011). East Africa was once thought to be a centre of origin of pigeon pea due to the presence of numerous pigeon pea wild relatives (van der Maesen, 1990). However, further evidence indicated that India is the centre of origin for pigeon pea in the world and that Eastern Africa is just the centre of its diversity (van der Maesen, 1990). Currently**,** the crop is mainly grown in Asia, East and Southern Africa, South, Central and Latin America and Caribbean region (FAOSTAT, 2010, ICRISAT, 2012).

Pigeon pea belongs to the genus *Cajanus*, sub tribe Cajaninae, tribe Phaseoleae, under the family fabaceae (Saxena *et al.*, 2002). It is the only cultivated species among the known 32 species under the sub tribe *Cajaninae* (Odeny, 2007). Most cultivars of pigeon pea are diploid (2n = 22) however, tetraploids and hexaploids also exist in other cultivars (van der Maesen 1990). The crop is dicotyledonous and is propagated by seed. Pigeon pea is predominantly self pollinated, with an out crossing rate of 1 to 40 percent (Hillocks *et al.*, 2000). However, the extent of out crossing depends on the prevailing populations of insect pollinators (Karim *et al.,* 2006). Pigeon peas have three flowering patterns and these include indeterminate, determinate and semi determinate (Singh, 2000). The majority of cultivars have indeterminate type of flowering pattern where the inflorescences develop as axillary racemes from all over the branches and flowering continue acropetally from base to apex on both branches and racemes (Gumber and Singh, 1997, Singh, 2000). Determinate pigeon pea cultivars have their flowers develop from the apical buds of the main shoot while in semi-determinate flowering pattern inflorescences form from the nodes and proceed acropetally and basepetally (Gumber and Singh, 1997). Finally, *Cajanus cajan* is a shrub pulse that grows up to four metres tall and has a tap root system which can grow up to two metres deep.

2.2 Growth conditions and growth patterns in pigeon pea

Pigeon pea grows well in an optimal temperature range of 18^{o}C-38^{o}C and its growth is moderately slow in the first three months (Saxena *et al*., 2002). The crop is a short day plant and is greatly affected by prolonged day lengths and frost (Mallikarjuna *et al*., 2011). Flowering is triggered by short days while long days trigger vegetative growth at the expense of flowering (Silim *et al*., 2006). Therefore, late maturing pigeon pea varieties are strongly affected with any slight increase in day length which in turn affects flower induction (Saxena, 2008). In addition, photoperiodism and temperature greatly influence number of days to flowering as well as production of biomass (Saxena, 2008; Silim *et al*., 2006). Thus delayed planting of late maturing varieties often leads to dwarfness and low crop biomass especially in areas with short day lengths and early planting will allow the crop to grow to its genetic potential (Saxena *et al*, 2000).

The crop grows well on a wide range of well drained soil types from sandy to clay soils (Odeny, 2007). It tolerates pH values of 4.5 to 8.0 and some varieties are sensitive to salinity (Mallikarjuna *et al*., 2011). In general, some pigeon pea varieties do not grow well under water logged conditions and high soil salinity (Ngugi and Omanga, 1992, Saxena, 2008). The crop requires an optimum rainfall range of 600-1000mm per annum (Silim *et al*., 2006) but flowers well even with rainfall of 1500mm to 2000mm per annum. In deep and well structured soils pigeon pea can still thrive with 250mm to 370mm of rainfall (Silim *et al.*, 2006).

2.3 Pigeon pea improvement in Uganda.

Uganda has a long history of pigeon pea cultivation and its production dates back to 1961^{s} (FAOSTAT, 2011). Organised research started in early 1970s at The National Semi-Arid Crops Resources and Research Institute (NaSARRI) located in the Eastern region of Uganda with Makerere University Agricultural Research Institute Kabanyolo (MUARIK) and Ngetta Zonal agricultural Research and Development Institute (NgeZARDI) as other experimental sites (NaSARRI, 2003). However, research was enhanced with the introduction of pigeon pea collaborative research programme led by ICRISAT in Eastern and Southern African funded by African Development Bank (Silim *et al*., 1995). During this period one of the objective was to enhance the genetic base of the local lines (Silim *et al*., 1995).

Introduction, collection and evaluation of germplasm from ICRISAT and various national programs with emphasis on identification and advancement of high yielding, earliness and good quality and development of suitable production technologies to suit target cropping systems was done (Silim *et al*., 1995). Through this, medium maturing and Fusarium wilt resistant varieties were introduced and few varieties adopted in Uganda included KAT 60/8, ICPL 87091, 87101 and 90029. Later, NaSARRI developed and released two improved pigeon pea varieties namely; SEPI1 which matures in 4.5 months and yields up to 1300 kgha^{-1}, and SEPI 2 which matures within 4.0 months and yields up to 1,500 kgha^{-1} in 2003 (NaSARRI, 2003) under research station conditions . This was a step ahead in pigeon improvement though the efforts were challenged by narrow genetic diversity in local germsplasm (Manyansa *et al*., 2009).

Unlike previous studies which concentrated much on promoting the adoption of improved varieties developed by ICRISAT, current studies focus more on improving the existing local varieties (Manyansa *et al*., 2009). Initial efforts are devoted on assessing the variability among local landraces as potential sources of traits for pigeon pea improvement. In 2005, genetic diversity analysis study was conducted at Makerere University using ALF molecular markers to determine the relatedness of local pigeon pea germplasm (Wasike *et al*., 2005). The results of this study were supplemented by a phenotypic diversity study on the same landraces (Manyansa *et al*., 2009). More focus was on conducting an *in situ* evaluation of pigeon pea cropping system and management in Uganda and agro-morphological traits to identify cropping systems applied in pigeon pea cultivation and evaluate the diversity of these landraces (Manyans *et al*., 2009). The overall results were that there were relatively marginal variations among the accessions suggesting a closer genetic relation between the Ugandan pigeon pea germplasm (Manyansa *et al*., 2009).

2.4 Approaches to breeding and screening for drought tolerance in pigeon pea

Mitra, (2001) suggests three approaches in breeding for drought resistance in crop plants. These include i) breeding for high yielding genotypes under optimum conditions. Since maximum genetic potential of any genotype is expressed under optimal conditions. It is expected that a higher yielding genotype will also yield relatively well under drought stress conditions (Blum, 2005). However, genotype by environment interactions (G x E) restricts the performance of high yielding genotype under stress (Saxena, 2008). The G x E approach also suffers from drastic changes in selection pressure from one generation to another because of variability in drought intensities (Akihiko *et al*., 2008). The consequence is that it delays breeding programmes. ii) An alternative method is that of improving drought resistance in already high yielding genotypes through introgression of physiological and morphological mechanisms for drought resistance (Kumar *e t al*., 2011).

However, lack of understanding of the physiological and genetic adaptation of drought tolerance limits this approach (Kumar *e t al*., 2011). iii) The third approach is improving yield in an already drought tolerant genotype and this has been considered the most promising approach (Mitra, 2001). This is the approach which this study has employed. Field screening during off rain season and use of rain out shelters have been used to screen pigeon pea for drought tolerance (Odeny, 2007; Ngugi and Omanga, 1992; Svejcar, *et al*., 1999). Pigeon pea has been subjected to different watering regimes in the field during off rain season. Kiboko (the driest place) with average rainfall of 40-200mm per annum has been used as a drought screening site (Ngugi and Omanga, 1992) in Kenya. But of these, rains out shelters are the commonly used drought tolerance screening tools.

Additionally, polyethylene glycol 6000 has also been used to identify pigeon pea lines with drought tolerant genes at seedling stage (Kumar *e t al*., 2011). However, rainout shelters are prohibitively expensive to erect (Chauhan *et al*., 2011). This study used potted experiments in the screen house due to limited resources as rain out shelters are associated with high costs (Svejcar *et al*., 1999). Depending on the objective of the study, different crops have been screened for different drought types (Nam *et al*., 2001). Severity and timing of drought in relation to the growth stage at which it occurs have been used to classify drought in many field crops (Akihiko *et al*., 2008).

Three types of drought are recognised, namely, vegetative, intermittent and terminal. Vegetative drought commonly occurs from seedling to the time prior to flower bud initiation (vegetative growth stage). This type of drought affects both early and late maturing pigeon pea varieties (Akihiko *et al*., 2008, Nam *et al*., 2001). Drought escape, dehydration avoidance and dehydration tolerance are known to be some of the plants' survival mechanisms to drought stress (IRRI, 2006). With these, it has been possible to develop varieties that mature earlier to escape post flowering drought in pigeon peas (Silim *et al*., 2006). But with increased occurrences of post flowering drought, the productivity of these varieties has been greatly affected (Nam *et al*., 2001).

In areas characterised by unimodal type of rainfall pattern, droughts may occur at any of the crop growth stages leaving the plants more vulnerable (MAAIF, 2005, FEWSNET, 2010). Drought severity is more aggravated by soil salinity since it affects the osmotic potential of the plant cells there by failing translocation of sugars and other photosynthates (Saxena, 2008). Therefore, combining different drought resistance mechanisms is a potential strategy for enhancing levels of drought resistance in pigeon pea as has been the case with other crops plants (Blum, 2005). To achieve this, a number of pigeon pea cultivars need to be screened at different growth stages in order to establish traits which are greatly affected by drought and are directly or indirectly associated with grain yield (Mallikarjuna, *et al*., 2011). Efforts have been made to screen for large root trait and ability to maintain turgor pressure (relative leaf water content) and chlorophyll content in order to establish the reliability of these traits in selecting for drought tolerance in pigeon pea (Saxena, 2008). However, no information is available on whether these traits were combined to develop drought tolerant varieties.

CHAPTER THREE

AGRONOMIC PERFORMANCE OF MALAWI PIGEON PEA LANDRACES UNDER LOCAL UGANDA CONDITIONS

3.1 Introduction

With an ever changing agro-environment, the extension of cultivation of pigeon pea into harsh drought prone environments is becoming increasingly important in order to overcome deficiencies in food. Stabilizing crop yields in such environment requires that optimum use of incident rainfall is made through use of appropriate agronomic practices and breeding for and selection of genotypes better adapted to environment (Odeny, 2007, Blum, 2005). The latter approach requires that a wide pool of genetic materials that offer variability in traits of interest is available to the breeding program (Atta *et al*., 2008).

As already mentioned, about 90 % of the pigeon pea growers grow majorly their local varieties such as Apio Elina, Agali, Adyang and Adong (Manyansa *et al*., 2009) due to the possession of preferred traits such as, large seed size, taste and colour. However, these varieties are late maturing (6-9 months) and produce low on farm yields of 250 - 450 kgha^{-1} and are highly susceptible to diseases and pests (Jones *et al*., 2000 in Manyansa *et al*., 2009). Improved varieties that are drought tolerant, pest and disease resistant or early maturing and possess the farmer preferred traits are largely unavailable (Manyansa *et al.*, 2009).

Unfortunately, pigeon pea receives very little attention in terms of research in Uganda as such the phenotypic and genetic diversity of the local pigeon pea germplasm that is necessary to make breeding progress is narrow (Wasike *et al*., 2005 and Manyansa *et al*., 2009). This requires that introductions of pigeon peas from somewhere else or hybridization be done in order to broaden the diversity. The availability of pigeon pea genotypes which are tolerant or resistant to insect pests would be of particular importance to the resource constrained farmers who grow the crop in Uganda and who could not afford rising costs of pesticides. The crop improvement programme at NaSARRI has been searching not only for resistance to pests and diseases but also for the ability of pigeon pea to compensate for early pod/seed losses and for high-yielding plants that will flower and mature when pest populations are low (Manyansa *et al*., 2009).

This Chapter describes the introduction and the evaluation of germplasm from Malawi. These accessions were assessed for agronomically important traits like yield, number of pods per plant, 100 seed weight, earliness (estimated by days to 50% flowering and days to 75% pod maturity) and pest resistance with a view of identifying elite accessions for eventual incorporation into pigeon pea germplasm enhancement program in Uganda.

3.2 Materials and methods

3.2.1 Sources and description of planting material

Malawi pigeon pea landraces were assembled from the Malawi Plant Genetic Resources Centre (gene bank), commercial markets of Blantyre, Mulanje and Chiradzulo, and from farmers in the pigeon pea growing areas of Thyolo, Chikwawa, Mwanza, Blantyre, Balaka, Mangochi, Machinga and Mulanje in the southern region of Malawi (Table 1). Chikwawa is a drought prone area which experience perennial droughts while Blantyre, Thyolo, Chiradzulo and Mulanje districts receive erratic and unequally distributed rains in some months of the year. The collection areas represent key pigeon pea growing areas in Malawi and have different day lengths. A total of 73 landraces were collected and subjected to an initial screening at Chitedze Agricultural Research Station (Malawi) for germination. Accessions which registered germination percentage of 80% and above were retained to make a final number of fifty-two representative pigeon pea accessions that were shipped to Makerere University for storage and subsequent studies in Uganda. Two local checks (20L and 22L) adapted to Lira district environmental conditions were included in the evaluations.

3.2.2 Study location

Field experiments were conducted at MUARIK for two growing seasons (2010a and 2011b) and at NgeZARDI in Lira district for one rainy season (2010a). MUARIK is located at an altitude of 1217 metres above sea level on coordinates 0.16° 24□ 16 N and 32.5°27□ 34 E, approximately 19 km in the northeast of Kampala at Kabanyolo in Lake Victoria Crescent. The area is a semi-humid zone which receives a bimodal type of rainfall. First rains are received between March and June while second rains come between September and December. The average amount of rain per annum for the area is 1000mm. Average temperature ranges between 25- 28°c while relative humidity ranges between 71-88%. MUARIK has deep ferrallitic soils with pH range of 5.2 to 6.0 (Wakiso district, 2010).

The area is regarded as a hot spot for pigeon pea pests (Night and Latigo, 1994) and was hence selected for this study. NgeZARDI is located on 02° 20□ N, 33° 06□ E at an altitude of 975 metres above sea level which is to the northeast of Lira town and is approximately 6 km from Lira trading centre. The place is located in Kyoga plains with high average temperatures of 28-30°C all year round. NgeZARDI experience a unimodal type of rainfall averaging around 1200mm per annum with the rains starting from July to September. NgeZARDI has sandy loam to sandy clay soils with pH of 5.7. Lira district is one of drought prone areas due to unpredictable rainfall pattern and main pigeon pea growing areas in the northern part of Uganda and was hence included as a second evaluation site for this study.

Table 1 : Description of pigeon pea accessions evaluated for agronomic performance at MUARIK for two seasons during 2010a and 2011b and at NgeZARDI during 2010a rain season in Uganda.

Accessions	Adaptation	Remarks	Accession	Adaptation	Remarks
MW2244	Nsanje/Southern	Drought prone area	MW2263	Mwanza/Southern	Drought prone area
MW2245	Nsanje/Southern	Drought prone area	MW2265	Mwanza/Southern	Drought prone area
MW2251	Nsanje/ Southern	Drought prone area	MW2287	Ntcheu/Central	High land area
MW2243	Nsanje/Southern	Drought prone area	MWKB14	Mchinji/Central	Plain area
MW2047	Chikwawa/Southern	Drought prone area	MW2323	Nkhatabay/Northern	Lake shore area
MW2238	Chikwawa/Southern	Drought prone area	MW2324	Nkhatabay/Northern	Lake shore area
MW2241	Chikwawa/Southern	Drought prone area	MW2325	Nkhatabay/Northern	Lake shore area
MW2256	Chikwawa/Southern	Drought prone area	MW2332	Karonga/Northern	Lake shore area
MW2258	Chikwawa/Southern	Drought prone area	MW2335	Karonga/Northern	Lake shore area
MW2266	Thyolo/Southern	High land area	MWAP29	Phalombe/Southern	Plain area
MW2267	Thyolo/ Southern	High land area	MWAP 02	Phalombe/Southern	Plain area
MW2268	Thyolo/ Southern	High land area	MWAP10	Chiradzulo/Southern	High land area
MW2282	Thyolo/Southern	High land area	MWAP04	Chiradzulo/Southern	High land area
MW2284	Thyolo/Southern	High land area	MWAP06	Zomba/ Southern	High land area
MW2279	Phalombe/Southern	Plain area	MW2306	Zomba/Southern	High land area
MW2276	Phalombe/Southern	Plain area	MW2302	Zomba/Southern	High land area
MW2281	Phalombe/Southern	Plain area	MW2300	Zomba/Southern	High land area
MW2311	Machinga/Southern	Drought prone area	MW2298	Balaka/Southern	Drought prone area
MW2328	Karonga/Northern	Lake shore area	MW2309	Machinga/Souhtern	Drought prone area
MW2097	Mangochi/Southern	Lake shore area	MW786	Machinga/Southern	Drought prone area
MW2321	Balaka/Southern	Drought prone area	MW2336	Karonga/ Northern	Lake shore area
MW2289	Balaka/Southern	Drought prone area	MW2303	Zomba/Southern	High land area
MWKB08	Blantyre/Southern	High land area	MW2287	Ntcheu/Southern	High land area
MWKB05(2)	Blantyre/Southern	High land area	UG20 L	Lira/Northern	Drought prone area (local check)
MWKB06	Blantyre/Southern	High land area	UG22L	Lira/Northern	Drought prone area (local check)
MWKB05(1)	Blantyre/Southern	High land area	KAT60/08	ICRISAT	Screened for drought (drought tolerant Check)
MWKB02	Blantyre/southern	High land area	ICEAP00068	ICRISAT	Screened for drought (drought tolerant check)
MWKB03	Blantyre/Southern	High land area			
MW2264	Mwanza/ Southern	Drought prone area			

3.2.3 Experimental design

3.2.3.1 Evaluation of agronomic performance

The experiments were set up in a partial balanced lattice design (Cochran and Cox, 1992) with two replicates. Two Ugandan landraces from Lira district (Table 1) were included as checks. Each entry (accession) was represented by 2 rows of 5m with planting spacing of 0.75m x 0.60m. Three seeds were planted per hill but were later thinned to one when the plants attained a height of 15 cm. Weeding was done once a month to check competition from weeds.

3.2.3.2 Data Collection

Five representative plants per plot were randomly sampled and tagged for phenological data including days to 50% flowering, days to 75% maturity (when three quarters of the pods on the plant turned brown) and phenotypic data including plant height (measured at harvesting/maturity time), grain yield and its components which include 100 seed weight and number of pods per plant. Characteristics and procedures of key heritable characters followed those stipulated in the pigeon pea descriptor handbook developed by ICRISAT and International Board for Plant Genetic Resources (IBPGR and ICRISAT, 1993). A measuring ruler was used to record the plant height in cm. Data obtained from each plot was averaged to give the mean plant height of the landrace in each plot. At maturity, plants in the middle rows (border plants were excluded) were harvested manually (by hand), sun dried to 12% moisture content (MC), threshed and seeds weighed at 12 % MC determined by oven dry method. Yield per plot was calculated and extrapolated to yield per hectare. Response of entries to pests attack was scored at both sites on a scale of 1 to 9 adopted from pigeon pea descriptor hand book prepared by ICRISAT and IBPGR, (1993) –where 1 means very low pest attack and 9 high pest attack. Visual pest scoring was done at flowering, podding and at pod physiological maturity stages on five tagged plants. The mode of pest scores was obtained from the five plants at each scoring stage. Finally rainfall data over the growing seasons were recorded.

3.2.3.3 Data analysis

Data on the measured parameters were subjected to analysis of variance (ANOVA) using 12th Edition of Genstat Statistical computer Package (GenStat, 2010) in two different ways. I) Data from MUARIK 2010a and NgeZARDI 2010a was analysed on multiple environment bases to evaluate the accessions performance across these two locations in one season (2010a) in which these experiments were conducted. II) Data for MUARIK 2010a and 2011b was analysed on multiple season basis to evaluate the performance of the accessions across two seasons. Means of the measured parameters were separated using Fisher's protected least significant difference (LSD). However, due to high Genotype by Environmental interactions (GXE) for both experiments, means of parameters for both across locations and seasons were compared with those for individual locations and season respectively. Standard error of the difference between means (SED) and Coefficient of Variation (CV) were calculated from the Error mean Square (EMS) of an ANOVA that included all accessions. Due to large variations in grain yield, 100 seed weight and pods per plant among lines, for NgeZARDI 2010a and MUARIK 2011b experiments, CVs of these parameters were slightly higher than usual. A number of genotypes did not do well (20% of the genotypes had grain yield $\leq$ 10kg/ha) at NgeZARDI during 2010a season while at MUARIK the lowest yield was 43kg/ha during the same season. Correlations were done to determine the relationship between traits.

The effective lattice error was not significant for all the parameters and therefore the data was analysed using as randomised complete design and therefore the experiment assumed the following linear model;

$$\mathbf{Yijk = Y... + E_i + R_j/E_i + G_k + GE_{ik} + eijk}$$

Where; **Y** = an overall mean for grain yield

$\mathbf{E_i}$ = environment i,

$\mathbf{R_j/E_i}$= j^{th}replication within i^{th} environment

Gk = genotype in an environment

$\mathbf{GE_{ik}}$ = interaction of genotype by environment

eijk = error term.

3.2.4 Results

Results of evaluation of Malawi accessions in Uganda across two locations in one season (2010a) and across two seasons (2010a-2011b) in one location are presented in the Tables2-10.

3.2.4.1 Performance of agronomic traits of pigeon pea accessions across two locations over one season

Results of evaluation of Malawi accessions across two locations showed statistical differences between locations and that the effects of genotypes by environment interactions (GXL) were highly significant ($P \leq 0.001$) on grain yield, 100 seed weight, pods per plant, days to 50% flowering and 75% pod maturity and plant height (Table 2). Genotypes showed high significant differences ($P \leq 0.001$,) on grain yield, pods per plant ($P \leq 0.01$) and plant height ($P \leq 0.01$) only (Table 2) when compared to each other across locations. However, genotypes showed no significant differences ($P > 0.05$) relative to each other in their performance in 100 seed weight, days to 50% flowering and 75% pod maturity across locations. High GXL interactions across MUARIK and NgeZARDI could have masked the performance of these genotypes to their full genetic potential as such the data was further looked at on across season's basis to get an overview of genotype performance in a specific location and season. The means and mean squares of the agronomic performance of pigeon pea lines across two locations in one season are presented in Tables 2 - 4.

Table 2: Mean squares of yield, seed weight, pods per plant, days to 50% flowering and 75% maturity and plant height of pigeon pea accessions evaluated across two locations MUARIK and NgeZARDI in 2010a season.

			Mean squares					
Source of Variation	d.f	F-test	Yield (kg/ha)	100 seed wt (g)	Pods/ plant	Days to 50% flowering	Days to 75% maturity	Plant height (cm)
Location	1	Loc./Loc./Reps	18513016.8***	1580.0352***	224800.2**	188410.31***	33037.11***	160562.3**
Location/Reps	2	Loc./Reps/Error	1088.2ns	0.0036ns	352.1ns	7.03ns	1.57ns	304.7ns
Genotype	53	Genotype/GXL	143467.6***	26.0099ns	8964.8**	953.72ns	825.15ns	3641.5***
GX L	53	GXL./Error	140347.1***	38.7251***	4060***	644.85***	819.31***	940.1***
Pooled Error	106		553.5	0.9809	301	11.64	13	104.9

*, **, and *** represent significance level at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively, ns= non-significant, G is genotype, L is location, df is degrees of freedom
Only two experiments conducted during the same season at different locations were included in the analysis.

Table 3 : Means of yield, seed weight and number of pods per plant of selected pigeon pea accessions evaluated across two locations in during 2010a.

Entries	Yield (kg/ha)			100 seed weight (g)			No. pods per plant		
	MUARIK	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**
2047*	267.33	44.67	156.00	14.11	10.60	12.36	54.00	45.50	49.75
2097*	164.67	6.67	85.67	13.60	5.00	9.30	71.00	24.00	47.50
20L[b]	1145.33	168.00	656.67	9.61	9.99	9.80	231.00	358.00	294.50
2238*	245.33	6.67	126.00	15.32	5.00	10.16	62.00	9.00	35.50
2241*	130.67	94.00	112.33	13.08	15.39	14.23	128.00	124.00	126.00
2243[c]	83.33	4.40	43.87	12.05	4.09	8.07	53.50	2.35	27.93
2244*	486.67	19.07	252.87	13.17	14.21	13.69	148.50	50.50	99.50
2245*	300.67	30.00	165.33	13.12	10.12	11.62	57.50	53.50	55.50
2246[a]	1273.33	9.33	641.33	10.94	7.00	8.97	240.00	16.50	128.25
2251*	906.00	88.00	497.00	14.22	14.49	14.35	174.50	111.00	142.75
2256[a]	1326.67	24.71	675.69	12.67	12.15	12.41	175.50	53.00	114.25
AP10*	682.00	40.00	361.00	15.39	8.73	12.06	94.00	56.00	75.00
AP29[d]	944.67	94.67	519.67	16.10	14.93	15.51	137.50	144.50	141.00
KB05-2[a]	1219.33	0.58	609.96	15.38	0.44	7.91	120.00	2.50	61.25
KB06[a d]	1165.33	4.60	584.97	19.88	3.15	11.52	85.50	6.50	46.00
KB08[d]	478.67	2.00	240.33	18.51	1.50	10.00	118.00	7.00	62.50
KB14[d]	995.33	41.33	518.33	14.04	12.95	13.49	72.00	59.50	65.75
Mean	617.40	31.88	324.64	14.21	8.88	11.55	113.79	49.27	81.53
SED (P=0.05)	**375.11**	**16.74**	**264.9**	**2.48**	**1.35**	**4.40**	**57.78**	**17.05**	**45.06**
CV%	**4.6**	**52.5**	**81.6**	**3.7**	**15.1**	**38**	**15.5**	**34.6**	**55.3**

SED is standard error of the difference of means and CV is coefficient of variation. .CV was calculated from means for genotype by location interaction for across location.

a = **entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison**

Table 4: Means of days to 50% flowering, days to 75% maturity and plant height of selected pigeon pea accessions evaluated across two locations during 2010a

Entries	Days to 75% maturity			Days to 50% flowering			Plant height (cm)		
	MUARIK	NgeZARDI	Mean	MUARIK	NgeZARDI	Mean	MUARIK	NgeZARDI	Mean
2047*	157.50	189.00	173.25	103.50	169.00	136.25	213.30	233.80	223.55
2097*	170.00	202.00	186.00	88.00	176.00	132.00	179.90	253.08	216.49
20L[b]	162.00	140.00	151.00	103.50	125.00	114.25	174.40	184.65	179.53
2238*	166.50	213.00	189.75	120.50	192.50	156.50	220.60	242.88	231.74
2241*	177.00	134.00	155.50	116.00	118.00	117.00	169.30	222.63	195.96
2243[c]	178.00	211.17	194.58	102.50	176.70	139.60	187.10	241.56	214.33
2244*	173.00	203.50	188.25	144.00	190.00	167.00	176.80	260.23	218.51
2245*	172.50	181.50	177.00	103.50	162.50	133.00	181.90	251.33	216.61
2246[a]	176.50	190.50	183.50	107.00	171.00	139.00	199.90	243.05	221.48
2251*	150.00	159.00	154.50	90.50	140.00	115.25	161.30	257.90	209.60
2256[a]	176.50	142.00	159.25	104.00	124.00	114.00	185.20	224.00	204.60
AP10*	162.00	142.00	152.00	103.00	124.00	113.50	162.45	235.80	199.13
AP29[d]	146.50	170.00	158.25	91.00	151.00	121.00	124.10	191.50	157.80
KB05-2[a]	119.00	216.50	167.75	103.00	201.50	152.25	115.50	235.38	175.44
KB06[a d]	124.00	203.00	163.50	102.00	186.00	144.00	102.30	139.00	120.65
KB08[d]	156.00	193.00	174.50	77.50	177.00	127.25	121.20	155.00	138.10
KB14[d]	124.00	135.00	129.50	80.00	188.00	134.00	134.90	179.25	157.08
Mean	160.41	185.14	172.77	109.36	168.43	138.9	176.96	231.49	204.22
SED(P=0.05)	**17.62**	**23.06**	**20.24**	**18.15**	**21.70**	**17.96**	**25.33**	**37.98**	**21.68**
CV%	**7.7**	**2.3**	**11.7**	**2.8**	**2.2**	**12.9**	**13.5**	**5.3**	**10.6**

SED is standard error of the difference of means and CV is coefficient of variation. .CV was calculated from means for genotype by location interaction for across location.

a = **entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison**

Large variations were recorded among entries for yield, pods per plant and 100 seed weight. Grain yield at MUARIK during 2010a ranged from 83.30 kg/ha to 1326.67 kg/ha (Appendix 1) while at NgeZARDI during the same season yield ranged from 0 kg/ha to 168.00 kg/ha (Appendix 1). In general, yields were higher at MUARIK than at NgeZARDI. About 18.5% of the accessions including local check 20L gave yield above 1000kg/ha at MUARIK while all genotypes including the local checks had yield below 200kg/ha at NgeZARDI 2010a (Appendix 1). Accessions in the latter proportion at MUARIK include; 2256 (1,326.67 kg/ha), 2246 (1,273.33 kg/ha), 2306 (1,246.67 kg/ha), KB05-2 (1,219.33 kg/ha) and 2321 (1,184.00kg/ha) and local check (20L) (1,145.33 kg/ha) while at NgeZARDI higher yield were given by local check 20L (168.0 kg/ha), AP01 (123.20 kg/ha) and 2321 (122.50 kg/ha) (Appendix 1).

About 29% of the accessions gave yield of > 600kg/ha while 20% gave yield similar to those under farmers conditions (400-550kg/ha) at MUARIK (Appendices 1 and 3). The lowest mean yield were recorded on accession, 2241 (130.67 kg/ha), 2311 (119.33 kg/ha), 2267 (94. 00 kg/ha) and 2243 (83.3 kg/ha). At NgeZARDI, zero yields were recorded from accessions 2281, KB05-2, 2325 and 2328. However, the mean yield of genotypes across locations ranged from 675.67 to 43.87kg/ha and it was observed that about 24% of the genotypes including local check gave higher mean yield (≥ 500kg/ha) compared to current farmers yield (≤ 450kg/ha). Genotypes in this category include accessions 2256 (675kg/ha), 20L (656.67kg/ha), 2306 (629.10kg/ha), 2321 (628.23kg/ha), KB05-2 (609.96kg/ha), KB06 (584.97kg/ha), 2328 (567.47kg/ha), AP04 (534.33kg/ha), AP29 (519.67kg/ha) and KB14 which gave yield of 518.33 kg/ha. These showed more stability across two locations. Accessions which gave low yields included 2243 (43.87kg/ha), 2267 (60.33 kg/ha), 2311

(73.07 kg/ha), 2336 (84.67kg/ha), 2097 (85.67kg/ha) and accession 2281 which had yield of 85.99kg/ha.

The mean seed weight at MUARIK (2010a) ranged from 9.1 to 19.9g per 100 seeds while at NgeZARDI the weights ranged from 1 to 16.40g. Accessions with the largest seed weights (≥ 17.0g) at MUARIK included, KB06, KB08, KB05-1, KB03, 2336, 2268 and 2302. Lowest 100 seed weight of ≤9.0g was recorded for the local checks 20L and 22L and accessions 2264 and 2267. The rest (79.6%) had medium seed size ranging from 11.0g to 16.9g. However, seed weight performance across locations revealed that, about 69% of the accessions had medium seed weights ranging from 11.00-15.60g/ 100 seeds. Accessions with the highest 100 seed weight include; 2284 (15.63g), AP29 (15.51g), 2321 (15.09g), 2251 (14.35g), 2282 (14.25g) and 2241 (14.23g). Local check 20L gave low seed yield (9.80g) across locations. Accessions with high seed weights across locations also registered slightly higher seed weights at MUARIK and those with low seed weights also recorded small seed sizes. The lowest seed weight (6.67g) was recorded in accession 2265 (Table 3 and appendix 1).

Performance in number of pods per plant was highly variable for both individual and across locations. The number of pods per plant at MUARIK (2010a) ranged from 34.5 to 278.5 while at NgeZARDI ranged from 0 to 358. Accessions with the highest number of pods per plant (≥ 200) at MUARIK include local checks 20 L and 22L, accessions 2246, 2287, 2336 and AP01 while the lowest pods per plant (≤50) were recorded on accessions 2284, 2282 and KB03. When compared to means across locations, local check 20L gave the highest number of pods (294.50) while the lowest number of pods (24) was registered on accession KB03. Twenty eight percent of the lines produced ≥ 100 pods per plant at MUARIK and these include AP01 (184.50), 22L (179.00), 2251 (142.75), AP 29 (141.00), 2336 (131.75), 2332 (129.25), 2246 (128.25) and 2241 (126.00). About 52% gave > 50 pods per plant while 20%

gave < 50 pods per plant while at NgeZARDI those with pods of > 100 counted for only 9.3% of out of 54 genotypes (Appendix 1).

A large number of genotypes (78% out of 54 lines including local check 20L) reached 50% flowering within 113.50-146.00 days. The earliest to flower in this range include, AP10 (113 days), 2256 (114 days), 20L (114 days), 2251 (115 days), 2266 (116 days) and 2241 (117 days) (Appendix 2). About 22% of the accessions reached 50% flowering between 150-178 days from day of planting. Although a large number of accessions flowered within the same period, they differed significantly in their number of days to reach 75% maturity. For example, out of 78% of the early flowering lines, only 22% of the lines including local checks were within the short duration maturity group (took an average of 150-160 days) to reach 75% pod maturity from day of planting across locations while 77% were in the medium duration group (took 180 -200dys) and one accession (2258) exhibited long duration maturity period (took> 200 days). Finally, on plant height, about 91% of the lines were tall (measured >177.00 cm) for NgeZARDI and across locations means compared to means at MUARIK. The variations in performance of the genotypes across locations indicate that the environmental conditions between these two locations were quite different as such the selection criteria for the traits of interest were based on their stability across these two locations.

3.2.4.2 Performance of agronomic traits of pigeon pea accessions at MUARIK across two seasons (2010a and 2011b).

Analysis of variance for agronomic traits revealed significant differences ($P \leq 0.00l$) among the accessions across two seasons at MUARIK (Table 5).

Table 5 : Means squares of yield, seed weight, pods per plant, days to 50% flowering and 75% maturity and plant height of selected pigeon pea accessions evaluated at MUARIK across two seasons (2010a and 2011b).

			Mean squares					
Source of Variation	d.f	F-test denominator	Yield (kg/ha)	100 seed wt (g)	Pods/ plant	Days to 50% flowering	Days to 75% maturity	Plant height (cm)
Season	1	Season/S/Reps	14398725.4***	743.341**	24821.9*	41417***	6594.6ns	30168.7*
Season/Reps	2	S/Reps/Error	1290ns	4.252ns	429.4ns	8.4ns	11.9ns	330.8ns
Genotype	53	Genotype/GXS	179688ns	16.16ns	4343.3ns	609.5***	738.8***	2331.8***
GX S	53	GXS/Error	127822.9***	14.986***	4090.6***	247.3***	162.7ns	444.1***
Pooled Error	106		639.8	4.263	553	101.8	102.9	205.1

GXS = the interaction between genotype by season. *, ** and *** = significant at P = 0.05, P = 0.01 and P ≤ 0.001, respectively; ns = non-significant at P = 0.05.d.f is degrees of freedom. S/Reps =number of replications within season.

3.2.4.2.1 Yield and yield components

Yield were significantly higher during 2010a (617.4kg ha^{-1}) compared to 2011b (145.3kg ha^{-1}) was observed in 2011b season (Table 6). During 2010a grain yield ranged from 43kg/ha to 1326 kg/ha while in 2011b grain yield ranged from 0 kg/ha to 701kg/ha. About 18.5% of the lines gave yield above 1,000kg/ha during 2010a season and these include; accessions 2256 (1326.67 kg/ha), 2246 (1,273.33 kg/ha), 2306 (1,246.67 kg/ha), KB05-2 (1,219.33 kg/ha) and 2321 (1184.00kg/ha) compared to local check (20L) (1,145.33 kg/ha) while all the accessions including local checks gave yield below 1,000kg/ha during 2011b season. The highest mean yields were recorded for accessions 2328 (701.39 kg/ha) 2256 (348.00 kg/ha), 20L (340.02 kg/ha) and 2238 (246.80 kg/ha) (Table 6 and Appendix1).

The lowest mean yield were recorded on 2243 (83.3 kg/ha), 2267 (94. 00 kg/ha) 2311 (119.33 kg/ha) and 2241 with 130.67 kg/ha) (Table 6 and appendix 1). Like in 2010a season, accession 2243 produced the lowest yield (30.41 kg/ha) during 2011b season compared to mean yield for across season (Table 6 and appendices 1 and 4). However, when genotypes were compared with their across seasons yield means, about 33% of the lines including local check 20L gave yield of ≥ 450 kg/ha. Interestingly some of the lines that gave high yields across locations maintained their yield stability across seasons. These include; 2328 (918.69 kg/ha), 2256 (837.72 kg/ha), 20L (742.77 kg/ha), 2246 (692.60 kg/ha), KB05-2 (681.60 kg/ha), 2306 (654.61 kg/ha), 2321 (616.01 kg/ha) and KB06 (607.41 kg/ha). About 17% gave yield range of 300-415 kg/ha while 33.33% gave yield of > 150kg/ha across seasons. The rest gave lower yield of ≥ 53 kg/ha (Appendix 4).

The weight of 100 seeds did not vary much across seasons at MUARIK. For instance, 2010 a season seed weights ranged from 19.9 to 9.06 g while 2011b and across seasons means showed almost similar range of 16.00 to 9.02g. When the entries were categorized into seed size groups, their seed weight means of across seasons and those of individual seasons fell in the same seed category. For instance, about 88.9 % of the lines produced medium seeds (12-16g/100 seeds) while 11.1% were small seeded (6.9-9.8 g/100 seeds) (Appendix 4). This proportion is close to proportions observed during 2010a (91.8% (38.9% large seeded and 51.9% medium seeded) and 2011b which had 75.9% of the accessions produce medium seeds. About 38.9% of the accessions had 100 seed weight of > 15.00 g in 2010a and some of these include KB06 (19.90 g), KB08 (18.50 g), KB05-1 (18.50 g) and KB03 (17.88 g) while higher 100 seed weights for across seasons were recorded on accessions KB06 (16.58g), AP10 (15.95g), KB03 (15.62), 2287 (15.44g) and KB08 (15.26g) (Appendix 4). Small sized seeds were produced by local checks (9.6g/100 seeds). During 2011b season, accession AP01 had the highest 100 seed weight (16.51 g) which is about 1.9% out of 54 accessions while 75.9% produced medium size seeds (10-14g) (Appendix 4) and 22.2 % of the accessions including local checks were small seeded (<10g per 100 seeds). The lowest 100 seed weights were recorded on the local check 20L (8.61 g) followed by accession 2251 (8.63 g) (Appendix 4).

There was a significant difference ($P < 0.001$) in mean number of pods between 2010a and 2011b experiments at MUARIK (Table 6). The 2010a rain season experiment had a mean of 113.8 pods per plant in a range of 278 to 41 pods per plant while 2011b rain season experiment gave a mean of 105.1 pods per plant with arrange of 276 to 37 pods per plant (Table 6). Higher number of pods during this season were recorded on local check 20L (278.5), 2246 (240.0), 20L (231.0) and 2287 which counted 216.0 pods (Appendix 3). The highest yielding accession 2256 produced 176.0 pods. The lowest pods per plant were recorded on accessions KB03 (34.5), 2282 (35.5), 2284 (41.0) and 786 (50.0). Accessions 2243 (53.0) and 2311 (60.0) had both the lowest number of pods per plant and grain yield (Appendix 1).

Table 6 :Means of yield, seed weight and pods per plant of selected pigeon pea accessions evaluated at MUARIK across two seasons (2010a and 2011b)

Variety	Yield (kg/ha)			100 seed weight			Pods per plant		
	2010a	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**
2047*	267.33	83.70	175.52	14.11	2.77	8.44	54.00	85.25	69.63
2097*	164.67	153.97	159.32	13.60	10.98	12.29	71.00	87.00	79.00
20L[b]	1145.33	340.21	742.77	9.61	8.62	9.11	231.00	87.13	159.06
2238*	245.33	113.41	179.37	15.32	9.13	12.23	62.00	201.00	131.50
2241*	130.67	186.71	158.69	13.08	12.00	12.54	128.00	75.50	101.75
2243[c]	83.33	30.41	56.87	12.05	9.55	10.80	53.50	92.00	72.75
2244*	486.67	163.12	324.89	13.17	10.46	11.81	148.50	96.00	122.25
2245*	300.67	192.71	246.69	13.12	12.71	12.91	57.50	90.00	73.75
2246[a]	1273.33	111.86	692.60	10.94	11.19	11.06	240.00	76.00	158.00
2251*	906.00	98.27	502.13	14.22	8.64	11.43	174.50	186.13	180.31
2256[a]	1326.67	348.78	837.72	12.67	11.16	11.91	175.50	144.63	160.06
AP10*	682.00	157.63	419.81	15.39	16.51	15.95	94.00	90.00	92.00
AP29[d]	944.67	202.85	573.76	16.10	11.81	13.95	137.50	86.38	111.94
KB05-2[a]	1219.33	143.59	681.46	15.38	12.81	14.09	120.00	74.00	97.00
KB06[a d]	1165.33	49.49	607.41	19.88	13.29	16.58	85.50	81.88	83.69
KB08[d]	478.67	47.37	263.02	18.51	12.01	15.26	118.00	93.88	105.94
KB14[d]	995.33	9.64	502.48	14.04	6.32	10.18	72.00	72.38	72.19
Mean	617.4	101.02	359.21	14.21	10.5	12.36	113.79	92.35	103.07
SED(P=0.05)	**375.11**	**21.64**	**252.81**	**2.48**	**2.20**	**2.74**	**57.78**	**46.24**	**45.22**
CV%	**4.6**	**21.40**	**7.00**	**3.70**	**27.40**	**16.70**	**15.50**	**30.50**	**22.80**

SED is standard error of the difference of means and CV is coefficient of variation. .CV was calculated from means for genotype by location interaction for across location.

a = **entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison**

During 2011b rain season, 20.4% of the accessions produced > 100 compared pods per plant to local checks 22L and 20L which had 90 and 87 pods respectively (Table 6). Accession 2251 registered the highest number of pods per plant (276.1) during the season followed by accession 2298 (197.3 pods). Except for 2338 and 22L, all accessions which recorded higher yields recorded > 100 pods per plant. The least number of pods were recorded on accessions KB14 (37), 2266 (40.3 pods), 2306 (69.0 pods) and 2241 with 75.5 pods (Appendix 4).

Accession 2303

Accession AP01

Figure 1: Accessions 2303 and AP01 observed in plots grown during second rain season at MUARIK 2010a.

3.2.4.3.2 Plant height, flowering and maturity periods

Lower mean plant height (170.80 cm) was recorded during 2010a while 2011b season recorded high mean plant height of 200.6 cm (Table 7). A small number of accessions (9.3%) were tall (measured > 200 cm) in 2010a while a large number of accessions (62.96%) were tall in 2011b season. The shortest accession (2265) measured 95.60 cm while the tallest accession 2047 measured 213.30 cm (Figures 2) in 2010a season

Figure 2: Tall growth habit exhibited by accession 2047 in field experimental plots evaluated during 2010a at MUARIK

Accession 2047 emerged the tallest (231.94 cm) in both seasons when compared to local checks 20L and 22L which measured 198.3cm and 208.14 cm respectively (Appendix 4). Other accessions with greater than 200 cm include; 2246 (230.51 cm), 2336 (230.01 cm) and 2284 which was 228.24 cm tall. Accession KB06 was the shortest in both seasons (measured102.3cm and 130.15cm in 2010a and 2011b s respectively) and others include KB14 (147.51 cm), KB05-2 (151.1 cm) and KB08 (182.50 cm) (Appendix 4).

Table 7 :Days to 50% flowering, 75% maturity and plant height of selected pigeon pea accessions evaluated at MUARIK across two seasons (2010a and 2011b)

	Days to 75% maturity			Days to 50% flowering			Plant height (cm)		
Variety	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**
2047*	157.50	189.00	173.25	103.50	169.00	136.25	213.30	233.80	223.55
2097*	170.00	202.00	186.00	88.00	176.00	132.00	179.90	253.08	216.49
20L[b]	162.00	140.00	151.00	103.50	125.00	114.25	174.40	184.65	179.53
2238*	166.50	213.00	189.75	120.50	192.50	156.50	220.60	242.88	231.74
2241*	177.00	134.00	155.50	116.00	118.00	117.00	169.30	222.63	195.96
2243[c]	178.00	211.17	194.58	102.50	176.70	139.60	187.10	241.56	214.33
2244*	173.00	203.50	188.25	144.00	190.00	167.00	176.80	260.23	218.51
2245*	172.50	181.50	177.00	103.50	162.50	133.00	181.90	251.33	216.61
2246[a]	176.50	190.50	183.50	107.00	171.00	139.00	199.90	243.05	221.48
2251*	150.00	159.00	154.50	90.50	140.00	115.25	161.30	257.90	209.60
2256[a]	176.50	142.00	159.25	104.00	124.00	114.00	185.20	224.00	204.60
AP10*	162.00	142.00	152.00	103.00	124.00	113.50	162.45	235.80	199.13
AP29[d]	146.50	170.00	158.25	91.00	151.00	121.00	124.10	191.50	157.80
KB05-2[a]	119.00	216.50	167.75	103.00	201.50	152.25	115.50	235.38	175.44
KB06[a d]	124.00	203.00	163.50	102.00	186.00	144.00	102.30	139.00	120.65
KB08[d]	156.00	193.00	174.50	77.50	177.00	127.25	121.20	155.00	138.10
KB14[d]	124.00	135.00	129.50	80.00	188.00	134.00	134.90	179.25	157.08
Mean	160.41	185.14	172.77	109.36	168.43	138.9	176.96	231.49	204.22
SED(P=0.05)	**17.62**	**12.50**	**9.02**	**18.15**	**11.17**	**11.12**	**25.33**	**23.22**	**14.90**
CV%	**7.7**	**2.3**	**11.7**	**2.8**	**2.2**	**12.9**	**13.5**	**5.3**	**10.6**

SED is standard error of the difference of means and CV is coefficient of variation. .CV was calculated from means for genotype by location interaction for across location.

a = **entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison**

When categorized into different maturity periods, above 50% of accessions maintained their maturity groups. About 96.3% of the lines attained 50% flowering in < 150 days (Table 7). Accession 2306 was the earliest to flower (took 90 days across seasons).The latest to flower took > 150 days and these include accessions 2276 (151.25 days) and 2336 (155.63 days) (Appendix 4). However, when accessions were compared to each other within and between seasons, there was an increase in mean number of days to 50% flowering and 75% maturity in 2011b compared to 2010a season. For instance, days to 50% flowering and 75% maturity increased from 110.0 and 161.0 days in 2010a season to 138.5 days and 172.4 days in 2010b season respectively. During 2010a season, 50% of the accessions exhibited short duration maturity period while the other 50% exhibited medium duration period (took about 160 days to 200 days to reach 75% maturity). Accession 2306 (84.0 days), KB06, 2343 and KB05-2, which were among the earliest to flower and mature compared to local check 20L which took 162.0 days during 2010a rain season. The latest maturing landrace 2325 took 184.0 days to attain 75% maturity.

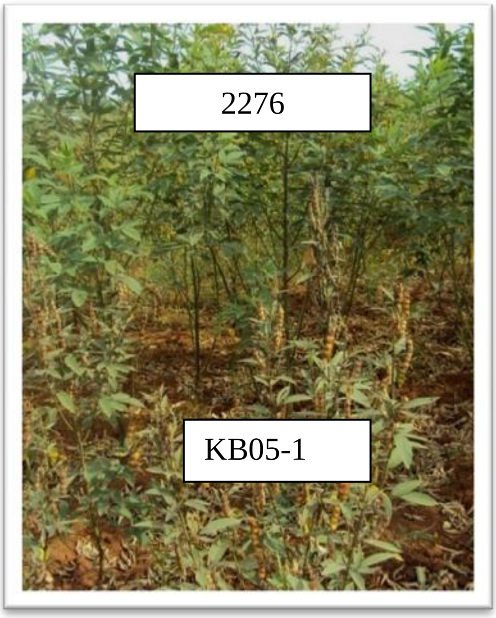

Figure 3: Differences in flowering and maturity periods observed between accessions 2276 and KB05-1 during the second rain season of 2010a

The latest accessions to attain 75% maturity during 2011b were 2243 which took 199 days, 2298 (194days), 2336 (190.0 days) and 2244 which took an average of 187.5 days (Appendix 4). However across seasons means showed two distinct maturity periods among all genotypes thus short and medium duration periods with medium duration dominating (88.89% took ≥ 150 days) while only 11.11% of the accessions were short duration (matured <150 days). And those in the later group include; KB05-1, K%05-2, KB06, KB14, AP01 and 2311.). These results demonstrate that some genotypes recorded similar performance across seasons as expressed by their consistence in performance of other traits like plant height, flowering period and 100 seed weight across the seasons.

3.2.4.3 Major pests of pigeon pea observed in the field plots evaluated at two locations over one season 2010a and across two seasons (2010a and 2011b) at MUARIK

The results of pest damage on pigeon pea accessions evaluated at MUARIK and NgeZARDI in 2010a and at MUARIK during 2010a and 2011b are presented in Tables 8 to 10.

3.2.4.3.1: Performance of accessions across two locations over one season and across two seasons in one location

The results from across location analysis showed that there was no significant difference (P >0.05) in response of the accessions to pests damage at flowering, podding and physiological maturity across the locations (Table 8). Therefore, only combined means across locations are presented for this analysis in Table 9. Accessions showed significant differences (P ≤0.001, 0.05) in response to pest damages during flowering and maturity stages across seasons (Table 8). No significant (P >0.05) pest damages were revealed at podding stage. All tested lines exhibited high pest resistance at this stage across seasons (mean damage=1.93) (Table 10). The means of pest damages for across locations and seasons are presented in Table 9 and 10.

3.2.4.4.2: Performance of accession to pest damages across two seasons at MUARIK

The results of accessions performance on single season basis are presented in Tables 11 and 12. No significant differences ($P > 0.05$) were expressed on response to pest damage among pigeon peas accessions during 2010a rain season. However, high significant differences ($P \leq 0.001$) in response to pest damages at flowering were expressed during 2011a growing season. The season by genotype interaction was highly significant ($P \leq 0.001$) for the pest damages at flowering and significant ($P = 0.05$) at maturity podding for across two seasons at MUARIK. Meaning that, the pest pressure was significantly different between these two seasons.

No significant differences ($P = 0.05$) were observed on pest on podding a mong the accessions at MUARIK across seasons (Table 8) although minimal damages were visually observed among accessions (Figure 4).

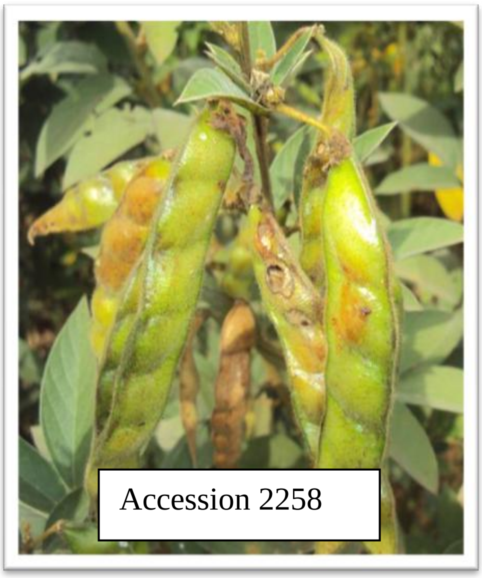

Figure 4: Damage by pod borer observed in experimental plots at MUARIK during 2011b rain season.

Table 8 :Mean squares of pest damages recorded on pigeon pea accessions at reproductive stage evaluated across two locations (MUARIK and NgeZARDI) over one season 2010a and across two seasons (2010a-2011ab) at MUARIK.

		Across two locations mean squares over one season				Across two seasons at MUARIK mean squares			
Source of Variation	Df	f-calc-denominator	[1]Fd	[1]Pd	[1]Md	f-calc-denominator	[2]Fd	[2]Pd	[2]Md
Location	1	Loc./(Loc/Reps)	480.02***	590.04***	362.96**	Season/(S/Reps)	179.67**	271.13***	214.01**
Location/Reps	2	(Loc./Reps)/Error	0.04ns	0.12ns	1.13ns	(S/Reps)/Error	1.06ns	0.27ns	0.84ns
Genotype	53	Genotype/GXL	0.43ns	0.52ns	0.61ns	Genotype/GXS	1.68ns	0.43ns	0.44ns
Genotype X Location	53	GXL/Error	0.49ns	0.47ns	0.77ns	GXS/Error	1.65***	0.68ns	0.76*
Pooled error	106		0.41	0.6	0.82		0.56	0.49	0.5

***,**,* Significant at P≤0.001, 0.01 and 0.05. ns=Non significant P>0.05. Fd=damage at flowering, Pd=damage at podding, Md=damage at physiological maturity. [1] and [2]=damages across two locations over one season, damages across two seasons in one location respectively. For across season, environment stands for location and for across seasons analysis season is used instead of environment just to differentiate how the data was analysed.

Table 9 :Mean of pest damages by flower and pod suckers (*Clavigralla tomentosicollis* Stal.), pod borers (*Helicoverpa armigera* Hubner) and pod fly (*Melanagromyza chalcosoma)* recorded on pigeon pea accessions at reproductive stage evaluated at MUARIK and NgeZARDI in 2010a.

Variety	**Damage at flowering (127 DAP)**	**Damage at podding (155 DAP)**	**Damage at maturity (≥ 155DAP)**
2047*	2.75	3.75	3.25
2097*	2.25	3.50	4.00
20L[b]	2.50	4.00	3.50
2238*	2.00	3.50	3.50
2241*	2.75	3.75	3.25
2243[c]	2.75	3.50	3.25
2244*	2.50	3.75	3.50
2245*	2.75	3.50	3.75
2246[a]	2.50	3.50	3.50
2251*	2.25	4.00	4.00
2256[a]	2.75	3.75	4.50
AP10*	2.25	3.75	3.50
AP29[d]	2.50	3.25	4.00
KB05-2[a]	3.00	3.50	3.50
KB06[a d]	2.50	3.50	3.75
KB08[d]	2.00	3.50	3.50
KB14[d]	2.00	3.75	3.50
Mean	2.51	3.51	3.61
SED(P=0.05)	**0.49**	**0.48**	**0.62**
CV%	**19.7**	**13.7**	**17.2**

SED is the standard error of the difference of means and CV is the coefficient of variation. DAP= days after planting.

Scale; 1-9; where 1 means very low attack, 2 means very low to low attack, 3 means low attack, 4 means low to intermediate attack, 5means intermediate attack, 6 means intermediate to high attack, 7 means high, 8 means high to very high attack and 9 means very high attack.

a = entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison .

Table10 :Mean of pest damages by flower and pod suckers (*Clavigralla tomentosicollis* Stal.), pod borers (*Helicoverpa armigera* Hubner) and pod fly (*Melanagromyza chalcosoma)* recorded on pigeon pea accessions at reproductive stage evaluated for two seasons (2010a and 2011b) at MUARIK

	Damage at flowering (127DAP)			**Damage at maturity (≥ 155DAP)**		
Variety	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**
2047*	1.00	3.50	2.25	2.00	5.50	3.75
2097*	1.00	6.00	3.50	3.00	4.00	3.50
20L[b]	1.00	4.50	2.75	2.50	4.00	3.25
2238*	1.00	4.50	2.75	2.50	5.00	3.75
2241*	1.00	4.50	2.75	1.00	4.50	2.75
2243[c]	1.00	3.50	2.25	1.50	4.50	3.00
2244*	1.00	2.50	1.75	2.50	4.50	3.50
2245*	1.00	4.50	2.75	3.00	3.50	3.25
2246[a]	1.00	4.00	2.50	1.50	5.00	3.25
2251*	1.00	4.00	2.50	2.00	4.00	3.00
2256[a]	1.00	1.00	1.00	3.00	4.00	3.50
AP10*	1.00	2.50	1.75	2.50	4.00	3.25
AP29[d]	1.00	2.00	1.50	2.00	5.00	3.50
KB05-2[a]	1.00	4.00	2.50	2.00	4.50	3.25
KB06[a d]	1.00	4.00	2.50	2.00	5.00	3.50
KB08[d]	1.00	3.00	2.00	2.50	4.50	3.50
KB14[d]	1.00	4.00	2.50	2.50	5.50	4.00
Mean	1.00	2.84	1.98	2.30	4.31	3.31
SED(P=0.05)	**0.10**	**1.29**	**0.91**	**0.46**	**0.62**	**0.62**
CV%	**13.20**	**36.90**	**47.10**	**25.00**	**18.80**	**18.60**

SED is the standard error of the difference of means, CV is coefficient of variation. DAP= days after planting.

Scale; 1-9; where 1 means very low attack, 2 means low attack, 3 means moderately low attack, 4 means moderately low to intermediate attack, 5means intermediate attack, 7 means high, 8 means moderately high attack and 9 means very high attack.

a = **entries selected for yield, b= popular pigeon pea in Lira, d= selected for seed size and earliness,*=others selected for comparison.**

Low mean pest damages (2.51) were recorded during flowering although the differences were not significant (Table 9). Accessions showed similar response to pest damage at podding (mean damage = 3.51) and pod maturity (mean damage = 3.61) (Table 12). The results show that 90% of the accessions including local checks were recorded low mean damage at flowering stage (mean damage < 4). Eighty one percent of the accessions showed intermediate reaction at podding while 19% were tolerant. Seventy eight percent of the accessions including local checks showed intermediate response during pod maturity stage while 22% expressed high tolerant levels.

Low mean pest damages were recorded during the 2010a rain season for flowering, podding and pod maturity compared to 2011b rain season damages (Table 10). All the tested lines expressed high resistance to pest damages during 2010a season although the differences were not significant (P > 05) (Table 10). The mean damage score ranged from 1.00 to 3.00 with the overall mean of 2.30 (Table 10).

During 2011b rain seasons at MUARIK, 92.6% of the accessions recorded intermediate damage at all stages with exception of accessions KB06 (podding mean damage = 6.00), KB14 (pod maturity mean damage = 5.50), 786 (flowering mean damage = 5.50), 2047 (pod maturity mean damage = 5.50) and 2097 (flowering mean damage = 6.00) which showed some significant levels of susceptibility at flowering (Table 10 and appendix 6). Mean pest damages were the lowest at flowering (2.84) compared to podding (4.10) and pod maturity (4.31). Accessions 2256 (mean = 1.00), KB03 (mean = 1.00), AP 29 (mean = 2.00) and AP10 (mean = 2.50) were highly resistant while the rest including local checks expressed intermediate reaction (mean damage ranged from 3.5 -4.5).

In summary, all evaluated pigeon pea lines including checks low mean pest damages during flowering for both across locations and seasons while intermediate reaction was recorded to

90% of the lines during podding and pod maturity at MUARIK in 2011b compared to 2010a. This means that pest pressure was high in 2011b season compared to 2010a season. None of the accessions were highly susceptible except for accessions 2258, KB06, KB14, 786, 2047 and 2097 which had a higher mean damage range of 5.50 to 6.00.

A summary of result and correlation coefficients between dry grain yield and other parameters are presented in Tables 11-15.

Table 11 :Summary of agronomic performance of the traits recorded at MURIAK during 2010a rain season.

	Rank in performance of various agronomic traits					
Accession	**Yield (kg/ha)**	**Pods/ plant**	**Seed Weight (g)**	**Days to**		**Plant height (cm)**
				50% flowering	**75% maturity**	
2256	1	10	41	28	37	42
2246	2	2	49	30	54	6
2306	3	9	46	3	29	35
KB05-2	4	20	18	21	4	48
2321	5	25	10	9	23	27
KB06	6	32	1	18	2	54
*20L	7	3	51	25	17	26

*= local check

Key: 1, 2.3 and 4 are positions in performance of different accessions in particular traits

NB: Accessions were ranked in ascending order of their performance in those traits. For yield and its components, numbers indicate from the highest to lowest in order of performance, for flowering and maturity period numbers indicate earliest to latest while for plant height, small numbers indicate the tallest accession

Table 12:Summary of agronomic performance of the traits recorded at MURIAK during2011b rain season.

Accession	Yield (kg/ha)	Pods per plant	Seed Weight (g)	Days to 50% Flowering	Days to 75% maturity	Plant height (cm)
2328	1	25	42	34	19	18
2256	2	4	35	16	12	31
*20L	3	36	53	37	37	36
2238	4	3	47	8	10	7
2298	5	2	46	13	2	48
2289	6	6	5	38	26	50
AP29	7	7	24	39	40	30

*=local check

Key: 1, 2, 3 and 4 are positions in performance of different landraces in particular traits
NB: Landraces were ranked in ascending order of their performance in those traits. For yield and its components, indicate from the highest to lowest in performance, for flowering and maturity periods numbers indicate earliest to latest in both flowering and maturity while for plant height, small numbers indicate the tallest accession

Table 13:Summary of agronomic performance of the traits recorded at NgeZARDI during 2010a.

Accession	Yield (kg/ha)	Pods per plant	Seed Weight (g)	Days to 50% flowering	Days to 75% maturity	Plant height (cm)
*20L	1	1	19	5	3	47
AP01	2	2	11	30	25	40
2321	3	6	8	28	30	19
2241	4	4	1	1	1	42
AP29	5	3	2	12	13	45
2251	6	5	4	6	8	14

*= local check

Key: 1, 2, 3 and 4 are positions in performance of different landraces in particular traits

The summary results indicate that there were significant differences in the performance of accessions for the traits studied. Accessions were ranked according to yield first then other traits. When traits were ranked from the best to the worst performer, large variations were revealed in yield with the highest being 1326.7kg/ha versus 27.3kg/ha, number of pods per plant (350 to 40 pods) and maturity periods (112 to 200 days).

3.2.5: Correlation analysis of phenotypic traits

Correlation coefficients among phenotypic traits of accessions at NgeZARDI and MUARIK are presented in Tables 14 and 15 respectively. There were significant and positive correlations between dry grain yield and 100 seed weight (r = 0.603***), dry grain yield and number of pods per plant (r = 0.888***), and between 100 seed weight and number of pods per plant (r = 0.436***) Tables 14 and 15.

Table 14:Relationships between yield, yield components and other key agronomic traits recorded on accessions at NgeZARDI during 2010 a rain season.

Character	Grain yield (kg/ha)	100 seed weight (g)	Pods per plant	Days to 50% flowering	Days to 75% pod Maturity	Plant height (cm)
Grain yield (kg/ha)	-					
100 seed weight (g)	0.603***	-				
Pods per plant	0.888***	0.445***	-			
Days to 50% flowering	-0.425**	-0.264*	-0.393**	-		
Days to 75% maturity	-0.436***	-0.296*	-0.402**	0.900***	-	
Plant height (cm)	-0.114ns	0.049ns	-0.188ns	0.268*	0.296*	-

***, **, * = Significant at P≤0.001, 0.01 and 0.05. ns =no significant difference at P≤0

Table 15 :Relationships between yield, yield components and other key agronomic traits recorded on accessions at MUARIK during 2011b rain season.

Character	Grain yield (kg/ha)	100 seed weight (g)	Pods per plant	Days to 50% flowering	Days to 75% pod Maturity	Plant height (cm)
Grain yield (kg/ha)	-					
100 seed weight (g)	0.119ns	-				
Pods per plant	0.261ns	-0.297*	-			
Days to 50% flowering	-0.369**	-0.155ns	0.122ns	-		
Days to 75% maturity	-0.380***	-0.26ns	0.127ns	0.432**	-	
Plant height (cm)	-0.299*	-0.332*	0.215ns	0.443***	0.690***	-

***, **, * = Significant at P≤0.001, P≤0.01 and P≤0.05. ns =no significant difference at P≤0.05

Positive correlations were also shown for plant height and maturity period (r=0.296*), flowering (r=0.900***) and maturity period and pods per plant and 100 seed weight Tables 14 and 15). In contrast significant negative correlations were revealed for dry grain yield and flowering (r=-0.425**) and maturity period (r=-0.436***). The weight of 100 seed was also negatively correlated to maturity period (r=-0.296*). Similar relationships were also reported in pigeon pea by Vange and Egbe, (2009), in chick peas by Atta *et al*., (2008) and in maize by Eleweanya *et al*., (2005).

3.2.4 Discussion

The results so far obtained indicate that 75% of Malawian accessions performed well under local Ugandan conditions in terms of 100 seed weight, maturity periods and pest resistant compared to local check 20L. About 24% of the evaluated accessions including local check gave yield of more than 500 kg/ha across locations which is above current yield (≤ 450 kg/ha) under farmers conditions in Uganda. This means that these lines were partly adapted to these locations and that their performance was to a greater percentage influenced by their genetic makeup. The results also demonstrate that the influence of GXS interactions were so high on the across locations which resulted in large variations in genotypes performance between these locations. For instance, grain yield ranged from 43 kg/ha to 675.67kg/ha across locations versus 43 to 1300kg/ha at MUARIK and 0 kg/ha to 168 kg/ha at NgeZARDI. A number of genotypes (48%) did well at MUARIK compared to NgeZARDI in 2010a season. A variation in performance between these locations is an indication of differences in environmental conditions and that season 2010a was more conducive for genotypes performance at MUARIK compared to NgeZARDI. Additionally, the variability in the performance of the studied traits within and between locations could also indicate the genetic constitution of the individual accessions (Atta *et al*., 2008). Significant differences in performance across seasons were also observed. This was revealed by large variations in pigeon pea performance between seasons 2010a and 2011b at MUARIK suggesting that seasonal variations influenced the performance of pigeon pea differently at MUARIK. For instance, grain yield ranged from 1300 to 43 kg/ha in 2010a season while 2011b grain yield ranged from 701 to 0kg/ha. During 2011b season, flower abortion was more pronounced in a number of accessions compared to 2010a season. Additionally, during 2011b season, MUARIK received heavy and prolonged rains (Appendix 7) which was occasionally accompanied by strong wind. This might have greatly caused flower fall to most of the early maturing accessions and therefore reduced the number of pods per plant.

Similar environmental influence on accession performance at NgeZARDI and MUARIK first experiments (2010a season) were evidently expressed by the results. For instance, number of days to flowering and maturity were significantly high at NgeZARDI 2010a and MUARIK 2011b compared to MUARIK 2010a experiment. The dry grain yield, number of pods per plant and 100 seed weight of three quarters of the accessions were significantly lowered for NgeZARDI 2010a and MUARIK 2011b experiments. Coincidently high pest infestations were also recorded for these experiments. Damage by pod borers might have substantially reduced both numbers of pods per plant and 100 seed weight which in turn translated into low grain yield (Minja *et al*., 2000). The results are also in agreement with previous studies (Night and Latigo, 1994) reduction in grain yield of pigeon peas due to increased damage by pod borers and pod fly.

Despite high GXE interactions, the results demonstrated high stability in performance of accessions for plant height, seed size, yield, and maturity period and pest resistance across locations and seasons. The stability in expression of these traits means that the genotypes had inherent genetic ability to counteract the influence of GXE for both across locations and seasons hence adapted in these environments. These traits could be described as fixed and stable in these accessions and could therefore be used for background selection in these accessions The former traits found in the accessions could be useful sources to enhance the present pool of germplasm in Uganda.

Three quarters of pigeon pea genotypes in this study generally exhibited the tall growth habit at NgeZARDI and MUARIK during the 2010a and 2011b rain seasons respectively probably due to influence of exposure to long-day conditions of June and July. Karim *et al*., (2006) explained that prolonged exposure to long day sunshine increases plant height at the expense of flowering. This explains the reason for taller plants observed at both NgeZARDI and MUARIK during 2010a and 2011b seasons respectively.

The accessions were categorized into two maturity periods namely short and medium duration. With exception of a few accessions, most of the short duration accessions exhibited dwarfness were the earliest to flower and also recorded high seed weight. These traits could somehow be correlated to each other. Accessions with these traits could provide good sources of initial breeding material since they contain more than one desirable trait.

Further analysis on traits correlations revealed that, dry grain yield and its components exhibited varying associations among accessions. The considerable range of variations and trait association recorded for these accessions would provide an opportunity for improvement of Ugandan local materials. Grain yield showed high and positive association with its components (100 seed weight (r=0.603**), and number of pods per plant (r=0.888***). The direct relationship among these traits indicates that they are important yield components and therefore should be considered when selecting for yield (Vange and Egbe, 2009). This relationship also implies that selection to improve these traits could simultaneously improve yield although this would also depend on their heritability (Panse, 1957 in Vange and Egbe, 2009). Days to 50% flower and days to 75% maturity period at both sites reported high and positive correlation coefficients (r=0.900***). The results are in agreement with reports by Atta *et al*., 2008, Vange and Egbe, 2009) who found out consistent, strong and positive correlations among these quantitative traits. However, both summary tables and correlation coefficient tables illustrate that there was no relationship in the performance of yield, number of pods per plant and 100 seed weight at MUARIK for 2011b second season experiment. This scenario is contrary to what is commonly expected of these traits in pigeon peas. In normal circumstances, positive relationships were expected of these traits like the results for NgeZARDI experiment since they are reported to be genetically linked (Upadhyaya *et al*., 2008, Vange and Egbe, 2009). Environmental factors such as high temperatures; heavy and prolonged rainfall at flowering (Appendix 7) and high pest infestations increased flower abortion and grain damage hence directly reducing on number of pods per plant and 100 seed weight that indirectly reduced yield.

Based on dry grain yield and pest resistance the following accessions KB05-2, KB06, KB14, AP02, AP29, 2246, 2256, 2306, 2321 and 2328 did well across locations and at MUARIK compared to local check 20L. These accessions can be considered for multi-location screening. However, when farmers' preference for early-maturing and seed sizes is considered then these accessions 2306, KB05-2, KB06, KB08 and AP 29 are recommended. These were among the top 10 accessions with relatively low pest attack and high yield advantage across locations and seasons. These accessions would still produce good yields if pest carry-over is avoided through synchronous sowings (Karimi *et al*., 2006). However, higher yields and pest tolerance without considering consumer preferences for seed characteristics would lead to low adoption of these materials. Hence future studies on these materials should consider incorporating this aspect right from field to cooking and other organoleptic tests.

CHAPTER FOUR

4.0 PRELIMINARY EVALUATION OF MALAWI PIGEON PEA ACCESSIONS FOR POST-FLOWERING MOISTURE STRESS TOLERANCE UNDER SCREEN HOUSE CONDITIONS

4.1 Introduction

Three main mechanisms for drought tolerance are recognised namely, drought escape, drought avoidance and drought tolerance (Subbarao *et al*., 2000, Mitra, 2001). Breeding based on selecting for earliness as a physiological drought escape mechanism has been the approach used by ICRISAT to select for drought tolerance during the vegetative phase (Silim *et al*., 2006; ICRISAT, 2006). However, this approach has been met with challenges due to increased drought occurrences later in the crops life which significantly reduces grain yield (Odeny, 2007). Since most pigeon pea grown by farmers have long maturity periods (Manyansa *et al*., 2009), breeding for inherent drought tolerance could be the key to managing any type of drought (Odeny, 2007). The other key approaches that could be used breeding for drought tolerant are; breeding under water stress conditions and improving on inherent drought resistance in already high yielding genotypes through introgression of physiological and morphological drought avoidance mechanisms (Kumar *e t al*., 2011). Breeding under water stress conditions is the approach currently being promoted although drastic changes in selection pressure from one generation to another due to variability in drought intensities has been the challenge (Akihiko *et al*., 2008). In Uganda, pigeon pea breeding has been focused more on pest and disease management with less consideration on drought tolerance and as such the status of drought tolerance levels among the cultivated local varieties is unknown (Thelma, 2001). The aim of this study was to identify moisture stress tolerant lines among a set of accessions from Malawi, under screen house conditions, that can be further studied and utilised in crossing programs to develop drought tolerant farmer acceptable pigeon pea varieties for Uganda farmers.

4.2 Material and methods

The common procedure for drought screening has been subjecting the genotypes to moisture stress at different growth stages like, pre and post flowering stage, podding and grain filling stages either in the field during off season or in rain out shelters (Ngugi and Omanga 1992, Nam *et al*., 2001). In this study, the accessions were subjected to different moisture stresses in a potted screen house experiment at MUARIK.

4.2.1 Test Germplasm

Thirteen best performing lines selected in Chapter Three were used in this study. They included; 2311, 2302, 2047, 2300, 2263 selected for high yield, medium seed size, maturity period and tolerance to pests, and KB05-2, KB03, KB06, KB08, AP10, and AP10 (2), AP10 (3), AP01 selected for large seed size and earliness. These accessions had an average yield of 1000 kg/ha that is double the pigeon pea yield under farmers conditions (450 kg/ha) and had average seed weight of 15 g per 100 seeds. The average number of days to flowering was 97. The local check 20L was included for comparisons. Two ICRISAT genotypes, KAT60/8 and ICEAP 00068, reported to have some degrees of tolerance to drought (Ngugi and Omanga, 1992) were also included in this study.

4.2.2 Watering regimes

Two experiments were run with the first one having two watering regimes; 1000 mm and 250 mm per week and the second one with four watering regimes; 1000 mm, 500 mm, 250 mm and 0 mm per week (These watering regimes were selected based on a range of crop water requirements for pigeon pea. These are described further below;

Experiment I: In the first experiment; moisture stress was induced at flowering stage. Watering regimes used in this experiment were: 1000 mm and 250 mm per 7 days. These watering regimes are within pigeon pea watering requirements (Orwa *et al*., 2009). Prior to imposing the designated moisture stress conditions, all the plants were put outside the screen house to allow for normal development. During this period MUARIK received no rainfall and all plants were supplied with optimal water requirement of 1000 mm per 7 days. This water amount was sufficient enough to saturate the soil and freely drain to field capacity through the bucket holes. The plants were returned into the screen house at flower bud initiation and allowed to adjust to screen house environment for 14 days before the treatments were imposed using a well calibrated jar at approximately 50% flowering of all the genotypes. This was approximately 97 days after planting and it was continued till harvesting time.

Experiment II: To develop a better optimum water stress regime, a repeat potted trial was set up with four watering regimes i.e., 1000 mm, 500 mm, 250 mm and 0 mm per week. In this experiment, watering regime 1000mm was optimal amount of water per 7 days and was used as a control. Water was supplied weekly as previously described. However, at attainment of 50% flowering water stress was induced by reducing the amount of water to the above watering regimes.

4.2.3 Experimental design

In order to assess the effect of different watering regimes on genotypes, a split plot design was used with watering regime as the main plot factor and genotype as subplot plot factor. In experiment I, all sixteen pigeon pea lines were screened against two watering regimes, while in the second experiment, three lines, KB05-2, KB06 and AP10 selected from the first experiment and susceptible line, KB08, were subjected to four watering regimes described above. The first experiment had two replicates while the second experiment had three replicates. Genotypes were randomly assigned to each replicate. Pigeon pea accessions were planted in 2000 mm plastic buckets of 60 cm in height to give enough room for root development. Each bucket contained three plants. Basic soil analysis was done to ascertain that the soil used had the optimal soil pH. The soil type used was clay sandy loam and had a pH value of 5.6. To ensure good drainage, holes were poked in the plastic buckets.

4.2.3 Data collection

A number of water stress related parameters were assessed and they included; leaf wilting defoliation, flower fall, leaf chlorophyll content, total root biomass and relative leaf water content (RLWC) and dry grain yield

i) *Leaf wilting, defoliation and flower fall:* These drought stress signs were rated on a 0 to 9 scale described by Ngugi and Omanga (1992); where 0 refers no flower fall, defoliation or leaf wilting and 9 refers to total flower fall, defoliation or 90% of the leaves on the whole plant have permanently wilted. The scoring for leaf wilting and defoliation was done twice a week. All the fallen leaves and flowers in the surrounding of the genotypes were removed at every scoring event to ease judgement. Visual scoring started 7 days after stress was induced and was done once in week for 28 days (4 weeks). The visual scores were averaged and means were subjected to analysis of variance.

ii) *Leaf chlorophyll content*: To assess the level of photosynthetic activity in the leaves, leaf chlorophyll content was measured on the middle aged leaves from the middle section of the plants since high photosynthetic activities in the plants are more associated with these leaves (Sarker *et al.*, 1999). Increase in chlorophyll content under water stress conditions is an indication of drought avoidance mechanism in plants. A chlorophyll meter model CCM 200 plus chlorophyll content meter-Optic Sciences Inc. was used (Arunyanark *et al.*, 2008).

The measurements were taken bi-weekly from time of stress induction for a period of 6 weeks. Data was averaged over this period and the means were subjected to analysis of variance in Genstat.

iii) *Total root biomass:* This was evaluated for each genotype as well as the ability to produce more roots. Increased root production is a sign of compensation to maintain plant water potential (Mallikarjuna *et al*., 2011). After harvesting, roots of each pigeon pea line were removed from the soil and sun dried. Soil particles attached to the roots were removed by means of a sieve of 2µ in diameter. The roots were then weighed and their weights (in grams) were recorded and analysed.

iv) *Relative leaf water content (RLWC)*: This was determined 21 days after water stress was induced following the procedure developed by Salisbury and Ross (1992). Leaf samples were taken 7 days after each watering interval for RLWC analysis to ensure that the measured RLWC is a true reflection of plant leaf water potential. Age effects were minimized by collecting immature leaves from the middle branches of the plants. Transpiration and respiration effects were checked by collection of samples early morning and by immediately weighing the leaves to get their fresh mass and wrapping them in aluminium foil. Collected leaves were immersed in distilled water in closed petri dishes for four hours. Thereafter, any free water was dried off and leaves weighed to get the turgid mass. The leaves were then oven dried at 80 °c for 24hours to get dry matter weight. The relative leaf water content (RLWC) was calculated for each genotype following the formula

RLWC (%) = [(W-DW) / (TW-DW)] x 100……………………………..…………..(i)

Where W = sample fresh weight,

TW = sample turgid weight and

DW = sample dry weight adopted from Kumar *et al*., (2011).

v) *Dry grain yield*

Dry grain yield of each line was weighed at 12 % moisture content and comparisons were made between genotypes under stressed and non stressed environment. Drought tolerance efficiency (DTE) and drought susceptibility indices (DSI) were calculated and the ability to maintain dry grain yield (yield stability) among the stressed genotypes was determined. The formulae used for DTE and DSI as follows:

DTE%=YS/YNSx100 (Fischer and Wood, 1981)…………………………………(ii)

where YS = yield under stress and NYS = yield of without stress.

DSI= (1-(Yield from stressed environment / Yield from non-stressed environment))/D) Fischer and Maurer, (1978);……………………………………(iii)

Where, D is the mean of all genotypes (both stressed and non stressed) and is derived from D = (1- (mean yield from stressed environment / mean yield from non-stressed environment)

'D' determines the level of drought tolerance and susceptibility by comparing the amount of photosynthates accumulated in the grain of stressed and non stressed genotypes.

4.2.4 Data analysis and interpretation

Due to the differences in the treatments, the two experiments were analysed separately. Data on RLWC, leaf chlorophyll content, root biomass, leaf wilting and defoliation and flower fall and dry grain yield were subjected to analysis of variance (ANOVA) using the GenStat statistical package. Where differences were found, Fisher's protected LSD was used to separate the treatment means which showed significant differences at $P \leq 0.05$. Correlations were run on means of the scored parameters and the relationship between and among parameters were established. Tolerance to drought of each genotype was evaluated on the basis of dry grain yield which directly or in directly is positively correlated to drought related traits such as drought tolerance and susceptibility indices. The experiment used the following linear model

$$\mathbf{X_{ijk}=Y...+M_i +B_j +d_{ij}+ S_k+ (MS)_{jk}+ e_{ijk}}$$

Where Xijk = an observation

Y= the experiment mean

M_i = the main plot treatment effect

B_j = replication or block effect

d_{ij} = the main plot error (error a)

S_k = the subplot treatment effect

$(MS)_{ik}$ = the main plot and subplot treatment interaction effect

e_{ijk} = the subplot error (error b)

i = a particular main plot treatment

j = a particular block

k = a particular subplot treatment

4.2.5 Results

Experiment I

When water was varied at only two watering regimes, 1000 mm and 250 mm, interaction between watering regimes and landraces was significant only for leaf wilting ($P \leq 0.001$) (Table 16). No significant interactions between genotypes and watering regimes were observed for the rest of the parameters. However, significant effects were observed on chlorophyll content ($P \leq 0.01$), leaf wilting ($P \leq 0.05$) and root biomass ($P \leq 0.05$) when genotypes were compared to each other indicating that these genotypes responded differently to the specific water stress treatments. Significant variation in genotypes (at $P \leq 0.001$ and 0.01) were also observed for leaf wilting, dry grain yield, chlorophyll content and root biomass (Table 16). No significant effects were observed in relative leaf water content and leaf defoliation.

4.2.5.1 Assessment for tolerance of sixteen accessions tested under two water stress levels.

DTE and DSI classified 90% out of the accessions as tolerant to water stress. With the exception of AP01 and 2303 which recorded low DTE values (25.00% and 54.90%) and high DSIs (3.23, 1.94) respectively, all accessions recorded high values of drought tolerance efficiency (DTE= >60%). The highest drought tolerance efficiency values were recorded for accessions KB06 (92.15%), AP10 (84.76%), 2300 (83.71%) and KAT60/8 (80.00%) while low DTE % values were recorded for AP01 (25.00%) and 2303 (54.90%) (Table17). Despite recording high values of DTE%, only 63% of the accessions were tolerant to water stress conditions (DSI= ≤1). Accessions KB06, KB05-2, AP10 and 2300 showed high tolerance to different water stress levels (recorded very low DSI values) while high DSI values (>1) were registered in AP01, 2302, 2311, KB03, KB08, 2047, 2263 and 20L (Table 17).

Except for KAT60/08 all stressed accessions with the highest DTE% also recorded high chlorophyll content and relative leaf water content and significant grain yield. ICEAP00068 (DSI=0.98) and KAT 60/8 (DSI=0.86) recorded DSI of 0.98 and 0.86 and they also expressed some drought tolerance relative to local check 20L which had DSI=1.28 (Table 17). Small differences in root biomass increase among accessions were measured for these experiments. Of the susceptible accessions, AP01 and 2302 reported high chlorophyll values when compared to the chlorophyll content figures of the unstressed accessions.

Table 16:Mean squares of dry grain yield, chlorophyll content, relative leaf water content, leaf wilting and defoliation, flower fall and root biomass of sixteen (16) pigeon pea accessions screened for water stress tolerance with two watering regimes (1000mm and 250mm)

		Mean squares						
Source	Df	Dry grain yield kg/ha	Chlorophyll content	Relative leaf water content	Root biomass (g)	Leaf wilting	Leaf defoliation	Flower fall
Rep	1	212	309.76	192.6	65.93	1.56	9.77	21.39
Watering regime	1	743ns	2859.58**	131.6ns	2082.1*	144*	221.3ns	23.77ns
Main plot error	1	7035	7.56	764	10.6	0.56	13.14	11.39
Genotype	15	19909*	199.94**	150.1ns	157.7**	4.06***	2.66ns	5.516**
Genotype X Watering regime	15	1616ns	90.44ns	152.6ns	43.4ns	2.37***	2.53ns	1.20ns
Split plot error	30	7985	73.95	124.4	69.64	0.65	2.29	2.36

*****, ** and * means Significant at 0.001, 0.01 and 0.05 alpha levels**

Table 17:Means of dry grain yield, chlorophyll content, relative leaf water content, leaf wilting and defoliation, flower fall and root biomass of sixteen (16) pigeon pea accessions screened for water stress tolerance with two watering regimes (1000mm and 250mm).

Genotype	**Dry grain yield(kg/ha)**		**DTE%**	**DSI**	***Cc**		***Rlwc**		***Root b (g)**		***Lw**		**Ld***		**Ff***	
	Ns	**S**			**Ns**	**S**	**Ns**	**S**	**Ns**	**S**	**Ns**	**S**	**Ns**	**S**	**Ns**	**S**
KB05-2	207	182	87.92	0.52	56.0	42.0	51.7	51.9	16.6	9.70	0.0	0.5	1.0	4.5	2.5	3.5
KB06	191	176	92.15	0.34	53.4	37.7	51.7	53.5	23.2	16.7	0.5	3.5	0.0	6.0	1.0	2.0
KB08	249	162	65.06	1.51	63.7	36.7	59.9	42.4	10.8	6.4	0.0	0.5	1.0	1.0	0.0	1.0
KB03	143	102	71.33	1.24	58.9	43.7	55.3	41.5	34.8	22.1	1.5	4.0	0.0	6.0	0.0	0.5
AP01	44	11	25.00	3.23	30.5	27.9	49.1	50.4	21.4	12.5	0.0	4.5	2.5	5.0	1.5	3.0
AP10	164	139	84.76	0.66	49.8	37.9	65.4	61.2	40.5	11.6	1.0	1.5	0.5	4.0	2.0	3.0
AP10-2	228	178	78.07	0.95	43.0	24.1	38.3	43.7	16.6	12.6	1.5	5.5	2.0	5.0	3.5	2.0
AP10-3	189	157	83.07	0.73	55.2	26.5	36.6	37.2	16.7	8.7	0.5	5.5	1.0	6.0	1.5	1.5
2300	178	149	83.71	0.70	43.6	40.2	55.2	44.5	31.4	9.6	0.0	4.5	0.0	5.0	1.5	3.5
2302	51	28	54.90	1.94	54.0	40.0	54.7	55.7	30.7	17.5	1.5	5.5	0.0	4.0	3.0	5.5
2311	91	61	67.03	1.42	51.8	24.1	47.9	50.2	17.4	10.8	1.0	5.0	1.0	5.0	3.0	4.5
20L	108	76	70.37	1.28	40.5	45.1	40.9	72.3	25.7	12.5	0.0	2.0	2.5	3.5	2.5	4.5
2047	62	47	75.81	1.04	41.5	28.4	49.1	63.8	34.5	24.5	0.5	5.0	1.5	5.5	1.5	2.5
2263	247	183	74.09	1.12	34.1	24.2	38.7	57.6	29.4	12.5	1.0	3.0	6.5	2.5	1.0	4.5
ICEAP 00068	203	157	77.34	0.98	37.5	35.8	47.0	47.6	32.4	23.3	1.0	3.5	1.0	5.5	2.5	3.5
KAT60/8	10	8	80.00	0.86	53.4	39.2	43.0	56.8	28.7	17.3	0.5	5.0	0.5	4.0	3.5	5.0
Mean	147.8	113.5			47.9	34.6	49.0	51.9	25.7	14.3	0.66	3.66	4.78	1.10	1.91	3.12
SED (P=0.05)	40				9.5		12.4		8.6		1.5		1.6		1.1	
CV% (R X WR X G)	85.2				20.8		22.1		41.8		38.8		51.8		61	

*Lw = leaf wilting, *Rlwc = relative leaf water content, *Root b = root biomass, *Cc = chlorophyll content, Ff* =flower fall, Ld* =leaf defoliation, Ns = non stressed ≃ 1000mm per 7 days, S = stressed ≃250mm per 7days, DTE% = drought tolerance efficient, CV% = Coefficient of Variation, S.e.d is the standard error of the difference of means calculated for the interactions between genotypes and watering regimes.

Experiment II

The application of four water stress levels (i.e., 1000 mm, 500 mm, 250 mm and 0 mm) resulted in significant effects on leaf chlorophyll content, leaf wilting and root biomass while effects on leaf wilting and flower fall depended on genotypes assessed ($P \leq 0.05$) (Table 18). Similarly, the effect on dry grain yield and root biomass was dependent on genotypes under observation ($P \leq 0.01$). In general, watering regime was not significant ($P > 0.05$) for RLWC and leaf defoliation (Table 18). Leaf wilting and flower fall were significantly influenced by the interaction between genotypes and watering regimes at P=0.05.The combined effects on dry grain yield, DTE and DSI, chlorophyll content, RLWC, leaf wilting and defoliation, flower fall and root biomass were used as indicators of tolerance of accessions to water stress.

4.2.5.2 Assessment of water stress tolerance of four accessions tested under four watering regimes.

Mean yield, chlorophyll content, relative leaf water content, leaf wilting and defoliation, flower fall and root biomass of pigeon pea accessions under four different watering regimes is presented in Table 19. Significant yield reduction (P=0.05) was recorded when four different watering regimes were applied. With exception of AP10, all accessions demonstrated slightly higher yields when applied with 500 mm of water compared to the control of 1000 mm per 7 days (had mean yield = >400kg/ha) All accessions did not produce grain yield with no water application from flowering to harvesting time. Accession KB06 did well in yield performance and it produced the highest yields values when applied with 1000 mm (776kg/ha) and 500 ml (1,014kg/ha) although yield reduced by 50 -75% when applied with 250 mm of water (313kg/ha) followed by KB08 and KB05-2. Coincidently, these accessions had high values of RLWC and chlorophyll content in that order when applied with 500 mm once a week for six weeks (Table 19). Reduction in chlorophyll content was observed in all accessions when no water was applied.

Table 18:Mean squares of dry grain yield, chlorophyll content, relative leaf water content, leaf wilting and defoliation, flower fall and root biomass of four (4) pigeon pea accessions screened with four watering regimes (1000mm, 500mm, 250mlmand 0mm) in experiment II

		Mean squares							
Source	DF	Dry grain yield kg/ha	Chlorophyll content-a	Chlorophyll content-b	Relative leaf water content	Root biomass (g)	Leaf wilting	Leaf defoliation	Flower fall
Rep	2	17280	3.27	1.20	843.23	5.42	1.16	1.73	0.60
Watering regime	3	702044ns	1553.01**	40.45ns	426.24ns	76.05*	10.20**	1.21ns	1.95ns
Main plot error	6	246270	165.28	94.68	122.61	16.742	0.55	0.57	3.15
Genotype	3	475260**	24.58ns	138.53ns	50.42ns	29.66**	0.15ns	0.29ns	1.55ns
GenotypeXWatering regime	9	151523ns	18.99ns	106.98ns	159.43ns	7.95ns	0.366*	0.10ns	1.63*
Residual	24	99412	19.82	68.14	98.88	5.20	0.165	0.11	0.65

Chlorophyll content-a =readings taken before stress induction, Chlorophyll content-b = readings taken during stress induction; ***, ** and * means Significant at 0.001, 0.01 and 0.05 alpha levels

Table 19: Means of yield, chlorophyll content, relative leaf water content, leaf wilting and defoliation, flower fall and root biomass of four top performing pigeon pea accessions screened for moisture stress tolerance under four water regimes at MUARIK in 2012.

Genotype	Yield kg/ha				Chlorophyll content								Relative leaf water content			
					Before stressing-a				During stressing-b							
	L1	**L2**	**L3**	**L4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
KB05-2	417	801	109	0	43.80	42.1	53	36.10	51.77	43.48	45.10	23.8	54.2	44.2	57.1	39.1
KB06	776	1014	313	0	48.90	45.5	35	35.10	44.59	44.81	40.30	24.3	45.4	49.2	44.7	43.6
KB08	212	435	418	0	32.90	39.5	40	43.70	48.18	49.00	44.00	26.4	43.5	66.0	48.0	39.9
AP10	171	00	00	0	35.90	35.6	37	34.10	51.00	45.43	44.40	20.2	51.8	63.5	45.2	41.9
Mean	**394**	**562.5**	**210**	**0**	**40.38**	**40.68**	**41.25**	**37.25**	**48.89**	**45.68**	**43.45**	**23.68**	**48.73**	**55.73**	**48.75**	**41.13**
S.e.d (P=0.05)	**317.8**				**3.6**					**8.4**			**10.3**			
CV%	**108.2**				**20.7**					**11.0**			**20.5**			

	Root biomass (g)				Leaf wilting				Leaf defoliation				Flower fall			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
KB05-2	4.49	8.03	7.25	1.23	0.62	1.00	1.3	2.56	0.11	0.11	0.67	0.89	0.56	0.44	0.11	0.67
KB06	7.72	5.55	5.77	1.22	0.67	0.78	1.2	2.22	0.22	0.11	0.78	0.56	0.67	0.22	0.33	0.78
KB08	2.80	3.77	4.74	1.63	0.42	1.00	2	2.44	0.28	0.11	0.89	0.56	3.21	0.22	0.22	0.78
AP10	8.20	10.76	7.62	1.75	0.56	0.67	1.2	3.33	0.33	0.67	0.78	1.22	0.00	0.00	0.61	0.56
Mean	**5.80**	**7.03**	**6.35**	**1.46**	**0.57**	**0.86**	**1.43**	**2.64**	**0.24**	**0.25**	**0.78**	**0.81**	**1.11**	**0.22**	**0.32**	**0.70**
S.e.d (P=0.05)	**2.3**				**0.5**					**0.3**				**1.0**		
CV %	**44.2**				**29.5**				**65.2**				**137.9**			

CV%=coefficient of variation. 1, 2, 3, and 4 stand for watering regimes with 1000mm, 500mm, 250mm and 0mm respectively. S.e.d is the standard error of the difference of means calculated for the interactions between genotypes and watering regimes.

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No significant differences (P>0.05) in the amount of leaf chlorophyll content and RLWC were observed among accessions when applied with 1000 mm and 500 mm of water (Table 18 and Figure 5). The effects of these watering regimes on leaf chlorophyll content and RLWC could were not significant (P > 0.05).

There was a significant (P≤0.01) increase in root biomass in all stressed genotypes except for L4 (0mm) where lower root biomasses were recorded for all accession (mean range = 1.4 – 7.0 g (Table 19 and 21). There was a general increase in root biomass of the accessions with decrease in the amount of water applied. Accessions displayed a general increase in leaf wilting, defoliation and flower fall with reduction in the amount of water applied (figure 5). The trend of reaction was similar for all accessions though the degree of reaction differed among accessions.

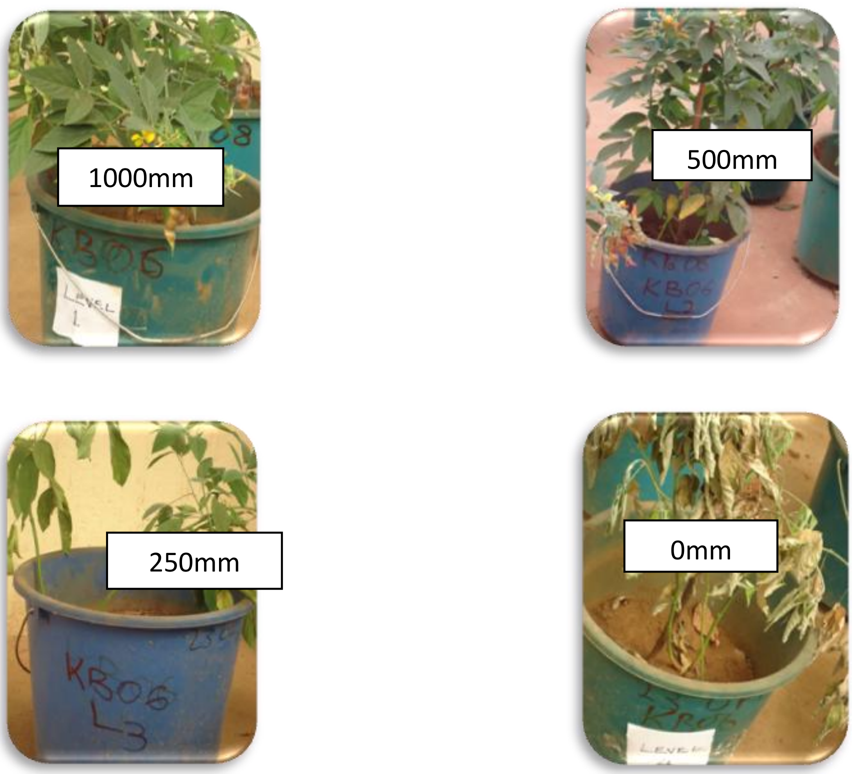

Figure 5: The effects of different watering regimes on leaf wilting on accession KB06. Photos taken from the screen house experiment conducted from March to August 2012

Positive significant correlation coefficients were revealed between relative leaf water content and flower fall (r=0.580**) and between leaf wilting and leaf defoliation (r=0.571*). Similarly, significant negative correlation was found between dry grain yield and leaf wilting Table 22.

Table 20:Relationship among moisture stress tolerance indicators of four accessions subjected to different water stresses at reproductive stage

Character	Dry grain yield (kg/ha)	Relative leaf water content	Chlorophyll content	Leaf wilting	Leaf defoliation	Flower fall	Root biomass (g)
Dry grain yield (kg/ha)	-	-					
Relative leaf water content	-0.23ns	-	-				
Chlorophyll content	-0.002ns	0.225ns	-	-			
Leaf wilting	-0.499*	-0.222ns	-0.448ns	-	-		
Leaf defoliation	-0.148ns	-0.237ns	-0.089ns	0.571*	-	-	
Flower fall	-0.340ns	0.580**	0.061ns	0.128ns	-0.228ns	-	
Root biomass (g)	0.158ns	0.233ns	0.137ns	0.358	0.467ns	0.018ns	-

***, **, *= significant at P≤0.001, 0.01 and 0.05; ns = not significant

4.2.6 Discussion

Based on the DTE and DSI, 10 (64%) out of 16 Malawi accessions were found to posses significant levels of moisture stress tolerance at the reproductive stage. However, there was varying response among accessions to different watering regimes. For instance, while some accessions were observed with increased grain yield upon stressing, others instead reduced grain yield. This suggests that compensatory mechanism exist in certain accessions to counter water stress at some level. In general, when water stress was applied at reproductive stage, grain yield was significantly reduced. In fact, other genotypes produced zero grain yields at all watering regimes. Similar results were previously reported by Lopez *et al*., (1996) that showed > 60 % yield reduction when moisture stress was imposed at reproductive stage. Grain filling stage is a critical stage in most crop plants and is the stage when adequate water is required (Blum, 2005). Nam *et al*., (2001) Munne´-Bosch *et al*., (2001) cite decreased grain weight as the main factor for lower yields. However, the degree of reduction depended on the genotype water stress level. Increase in grain yield was recorded when the accession were supplied with 500mm of water weekly compared to those supplied with 1000mm. However grain yield reduction of more than 50% was obtained for accessions when supplied with 250mm. No yield was obtained in accessions where water was withheld from flowering to harvesting although they survived for another three weeks of drought stress. These results are in agreement with reports by Nam *et al*., (2001) and Lopez *et al*., (1996) who recorded lower pigeon pea grain yield with reduced amount of water application. A reduction in leaf chlorophyll content was also noted where water was not supplied beginning from flowering.

Chlorophyll content is related to photosynthetic capacity of plants. Drought has been reported to have a negative impact on chlorophyll content in many crops including, peanuts (Forster *et al*., 2004), wheat (Sarker *et al*., 1999), grass *Eragrostis curvula* (Colom and Vazzana, 2003). Reduction in grain yield could therefore be an indication of reduced photosynthetic activities and increased leaf abscission due to chloroplasts destruction by peroxidation processes influenced by drought stress (Munne´-Bosch *et al*. 2001).

The results of both experiments further reveal leaf wilting as the only parameter influenced by the interaction of the environment and genotype. This means that this trait might be associated with complex inheritance since it is controlled by multiple genes (Forster *et al*., 2004). No influence of the interaction on chlorophyll content, RLWC, root biomass, leaf defoliation and flower fall means that their expression is less influenced by the environment. And that they can be easily inherited though are quantitative in nature (Forster *et al*., 2004).

Based on grain yield measured by DTE% and DSI, accessions KB05-2, KB06 and KB08 had high grain yields (800 kg/ha,1010 kg/ha and 440 kg/ha in that order) and DTE% and lower values of DSI (< 1) and were therefore identified as highly tolerant to moisture stress while AP01-1 and 2303 were highly susceptible to moisture stress with small values of DTE% (25.00% and 54.90% respectively) and greater DIS value (>1) (Deshmukh *et al*., 2009). ICEAP00068 (DSI= 0.98, 157kg/ha with DSI value close to 1), KAT 60/8 (DSI=0.86, grain yield=8kg/ha of the stressed genotype)) and local check 20L (DSI = 1.28, grain yield = 76kg/ha of the stressed genotype) were classified as susceptible moisture stress. Expectedly, accessions identified as moisture stress tolerant maintained high yield stability and had high levels of chlorophyll content under stress conditions although no specific trend on the effect of watering regimes on chlorophyll content for all accessions was shown. The accessions evaluated also differed in the production of roots depending on level of water stress. Small differences were recorded among accessions when supplied with 1000 mm and 500 mm though a general decrease in root biomass was noted for 500 mm watering regime. In contrast, increased root biomass was recorded with a decrease in water amount (250 mm) for the second experiment. Prolific root system is reported to accelerate plant growth and development through increased water absorption that maintain a requisite osmotic pressure (Lobato *et al*., 2008, Subbarao *et al*., 2000).

Increased root growth under water stress conditions is a plant coping mechanism to water stress and has been reported in crops like rice (Akihiko *et al*., 2008). The results revealed that different watering regimes generally reduced grain yield of all the stressed genotypes. The effects on other parameters such as chlorophyll content, relative leaf water content and flower fall were not consistent across different watering regimes and that high grain yield was associated with high relative leaf water content and high chlorophyll content. These results indicate that screened accessions could provide a good source of germplasm for breeding for moisture stress tolerance. However, the material needs repeated tests since the screen house environment in which the study was conducted might not have allowed full expression of the parameters. No relationship between dry grain yield and all measured parameters except for leaf wilting which showed a significant negative relationship ($r = 0.499^*$). For grain yield and leaf wilting this means that there is some direct relationship between these traits and that a high leaf wilting score meant lower yields (Singh and Mackill, 1990). Yield of the genotypes under water stress environment might sometimes be influenced by factors other than water stress hence no relationship was reported for yield with other parameters (Blum, 2005). Significant differences in leaf and flower fall in different watering regimes were observed among all tested pigeon pea lines. Significant flower and leaf fall was more pronounced in stressed landraces as compared to unstressed landraces. Significant positive relationships were found between RLWC and flower fall ($r = 0.580^{**}$) and between leaf wilting and leaf defoliation ($r = 0.571^*$). Strong and positive relationships among these traits might be attributed to osmotic adjustment as dehydration avoidance by the plants due to reduced amount of water (Blum, 2005, Pirzad *et al*., 2011).

The results of this study were based on fourteen accessions. A number of accessions assessed for superior agronomic traits were left out in this study due to inadequate space. Screening for a large number of accessions could increase the chances of realising lines with potential sources of moisture stress tolerant trait. As such, any follow up study on this should consider including accessions which were left out in this study as they may also contain drought tolerant traits. Lack of proper screening environment (an open place where plants would receive enough light and sunshine) might have greatly affected the performance of the accessions. Testing lines for moisture stress in drought prone areas of Uganda like, Soroti, Moroto, and screening stations like Kiboko should be considered in the follow up studies. Kiboko located at 2° 17□ S, 37° 50'E, 997 m above sea level is one of the dry experimental sites in Kenya where drought screening work has been done. The site receives annual rainfall amounts of 280mm to 550mm (Ngugi and Omanga 1992). Since the place is ever dry it could provide a good environment for drought screening.

CHAPTER FIVE

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Three quarters of Malawian accessions (75%) performed well under local Ugandan conditions in traits like grain yield, seed size, earliness and pest tolerance compared to the local check 20L. High yield recorded (> 450kg/ha) on 50% of the accessions at both MUARIK and NgeZARDI means that these accessions would be useful for both yield and drought traits improvement of Ugandan germplasm since NgeZARDI is a drought prone area.

The across location and seasons results revealed large variability on yield, pods per plant and plant height while flowering and maturity period were stable across locations suggesting that existence of large genetic variations among accessions that could provide some opportunity for selection of these traits. The 22% (11 accessions) short and 77% (40 accessions) medium duration accessions could improve on the maturity periods of local pigeon pea lines.

The existence of direct and positive relationships between dry grain yield, number of pods per plant and 100 seed weight in a number of accessions means that somehow these traits could be linked to each other and should therefore be considered when selecting for yield improvement in drought tolerant cultivars and that improvement on yield components could directly or indirectly improve on yield depending on their heritability. This is also true for days to 50% flower and 75% days to maturity which exhibited similar relationship.

Results on drought screening indicated that drought at reproductive stage reduced dry grain yield in some genotypes by up to 50%. No relationships were observed between grain yield and measured parameters except for negative association with leaf wilting. This could provide an easy selection process for some traits like high chlorophyll content and root biomass as an initial step in selecting for drought tolerance at reproductive stage since no associations could mean very weak or no linkage of these traits hence independent segregation.

Accessions exhibited varying abilities to maintain high dry grain yield which means that these accessions contain some exploitable levels of moisture stress tolerance and that compensatory mechanisms existed in the accessions. Since improving yield in an already moisture stress tolerant genotype is more practical, moisture stress tolerant accessions from this preliminary screening could be useful in improving drought susceptible Ugandan germplasm. Variations in response to different watering regimes and high DTE values exhibited by different accessions indicate that screen house potted experiments could be useful tool for moisture stress screening in pigeon peas.

5.2 Conclusions

High variations existed among Malawian accessions as indicated by consistence in expression of traits like days to 50% flowering, 75% maturity, plant height and seed size across and within sites. The stability in expression could ease the selection process for these traits for improvement of the present pool of germplasm in Ugandan. However, the significant and positive relationship expressed by these traits means that their selection rate for improvement could either be increased or lowered by additive gene effects especially if the interest is only on selection of one or two traits which is or are linked to many other desirable and non desirable traits. The same applies to dry grain yield and its components.

Earliness to 50% flowering and 75% maturity and large seed size were highly associated with dwarf accessions. This means that, these traits were linked and segregate together and that improvement on one trait could mean having either a negative or positive effects on the other traits. These accessions could provide a good source of initial breeding material since they contain more than one desirable trait.

Significant tolerance to pest damages in some accessions could improve the yield advantage of local germplasm in addition to following synchronous sowings. The across location and seasons results indicated that Malawi accessions did well at MUARIK compared to NgeZARDI during 2010a season and genotypes did not do well during 2011b at MUARIK suggesting that the environment as source of variation is for these experiments was so random as such selection for the traits of interest should be based on across environment performance.

Based on grain yield stability, DTE% and DSI, accessions KB05-2, KB06 and KB08 had high grain yields (800kg/ha, 1010kg/ha and 440kg/ha in that order) and DTE% and lower values of DSI (< 1) and were therefore identified as highly tolerant to moisture stress while AP01-1 and AP 10-3 were highly susceptible to moisture stress with small values of DTE% (25.3 and 45.35 respectively) and greater DIS value (> 1).

5.3 Recommendations

Accessions that gave high dry grain yield and were resistant to pest damages compared to local check 20L include; KB05-2, KB06, 2246, 2256, 2300, 2306, 2311, 2321 and 2328..These accessions can be considered as donor parents for these traits and can be evaluated in pigeon pea growing areas to assess their performance across different environment. However, participatory plant selection for farmer preferred traits like; early-maturing and seed sizes, accessions 2306, KB05-2, KB06, KB08 and AP 29 should be considered in the follow up experiments in order to incorporate farmers' preferences in the selection of elite genotypes.

There was lack of consistency in response to different watering regimes for parameters such as dry grain yield, chlorophyll content, relative leaf water content and flower fall .This suggests the presence of some interactions between watering regimes and genotypes which requires further exploration.

Experiments with an objective of establishing the actual percentage in grain yield reduction between field and under screen house conditions should be considered in the follow up experiments so that the yield gap is compared to the standard drought experiment tools like rain out shelters. The information for such studies would help modify the screen house potted experiment.

Although findings from moisture stress experiments gave an indication that screened accessions could provide a good source of drought breeding material, repeating could add more understanding on the physiological behaviour of the measured drought parameters in relation to grain yield probably in a more elaborate drought environment.

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APPENDICES

Appendix 1: Means of yield, seed weight and number of pods per plant of pigeon pea accessions evaluated across two locations in one season (2010a).

	Yield (kg/ha)			100 seed weight (g)			Pods per plant		
Variety	**MUARIK**	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**
2047	267.33	44.67	156.00	14.11	10.60	12.36	54.00	45.50	49.75
2097	164.67	6.67	85.67	13.60	5.00	9.30	71.00	24.00	47.50
20L	1145.33	168.00	656.67	9.61	9.99	9.80	231.00	358.00	294.50
2238	245.33	6.67	126.00	15.32	5.00	10.16	62.00	9.00	35.50
2241	130.67	94.00	112.33	13.08	15.39	14.23	128.00	124.00	126.00
2243	83.33	4.40	43.87	12.05	4.09	8.07	53.50	2.35	27.93
2244	486.67	19.07	252.87	13.17	14.21	13.69	148.50	50.50	99.50
2245	300.67	30.00	165.33	13.12	10.12	11.62	57.50	53.50	55.50
2246	1273.33	9.33	641.33	10.94	7.00	8.97	240.00	16.50	128.25
2251	906.00	88.00	497.00	14.22	14.49	14.35	174.50	111.00	142.75
2256	1326.67	24.71	675.69	12.67	12.15	12.41	175.50	53.00	114.25
2258	312.00	21.33	166.67	12.70	12.06	12.38	77.50	23.50	50.50
2263	744.67	27.33	386.00	11.54	13.35	12.45	99.50	51.00	75.25
2264	408.67	23.22	215.94	9.09	13.46	11.28	193.50	48.00	120.75
2265	237.33	4.18	120.76	10.18	3.14	6.66	99.00	12.50	55.75
2266	467.33	38.67	253.00	11.05	14.04	12.55	57.50	60.50	59.00
2267	94.00	26.67	60.33	9.33	10.16	9.75	96.00	49.50	72.75
2268	408.00	20.43	214.21	17.79	10.49	14.14	166.00	48.50	107.25
2276	424.73	7.74	216.24	14.04	5.81	9.92	123.50	14.50	69.00
2279	395.33	4.00	199.67	14.67	3.00	8.84	79.50	6.50	43.00
2281	171.33	0.65	85.99	15.93	0.49	8.21	76.50	4.00	40.25
2282	598.67	20.67	309.67	14.54	13.96	14.25	35.50	33.50	34.50

2284	305.33	23.91	164.62	14.90	16.36	15.63	41.00	31.50	36.25
2287	790.67	1.07	395.87	16.21	0.01	8.11	216.00	1.66	108.83
2289	906.67	22.67	464.67	13.53	13.80	13.67	65.50	38.00	51.75
2298	295.33	23.95	159.64	16.53	11.21	13.87	60.50	44.00	52.25
22L	522.00	64.00	293.00	9.30	9.47	9.38	278.50	79.50	179.00
2300	544.67	80.67	312.67	12.51	14.13	13.32	155.50	78.50	117.00
2302	256.00	2.65	129.33	17.02	1.99	9.51	80.50	7.50	44.00
2303	876.67	22.87	449.77	13.96	12.28	13.12	113.50	47.00	80.25
2306	1246.67	11.53	629.10	11.80	8.65	10.22	178.00	23.50	100.75
2309	478.67	1.67	240.17	12.61	1.26	6.93	137.00	6.50	71.75
2311	119.33	28.00	73.67	12.16	12.84	12.50	60.50	51.50	56.00
2321	1184.00	72.45	628.23	16.40	13.78	15.09	107.00	88.50	97.75
2323	652.67	3.33	328.00	15.06	2.50	8.78	112.00	15.50	63.75
2324	904.67	34.00	469.33	15.78	12.21	14.00	68.50	49.50	59.00
2325	474.67	0.00	237.33	13.77	0.00	6.89	128.50	0.00	64.25
2328	1136.00	-1.07	567.47	14.56	-0.01	7.27	111.00	-1.65	54.68
2332	711.33	53.53	382.43	15.12	14.91	15.02	192.00	66.00	129.00
2335	923.33	53.33	488.33	13.90	14.46	14.18	94.50	63.50	79.00
2336	134.00	35.33	84.67	17.88	10.30	14.09	200.50	63.00	131.75
786	333.33	78.67	206.00	13.94	12.06	13.00	50.00	75.00	62.50
AP01	238.67	123.15	180.91	14.03	12.28	13.15	200.50	168.50	184.50
AP02	1144.67	2.25	573.46	15.89	1.69	8.79	100.50	13.00	56.75
AP04	1030.00	38.67	534.33	15.48	11.65	13.56	79.00	50.50	64.75
AP10	682.00	40.00	361.00	15.39	8.73	12.06	94.00	56.00	75.00
AP29	944.67	94.67	519.67	16.10	14.93	15.51	137.50	144.50	141.00
KB02	244.00	47.33	145.67	16.82	10.91	13.86	70.00	75.00	72.50
KB03	901.33	3.76	452.55	18.09	2.82	10.46	34.50	14.50	24.50
KB05-1	907.33	20.00	463.67	18.31	8.36	13.33	83.00	35.00	59.00

KB05-2	1219.33	0.58	609.96	15.38	0.44	7.91	120.00	2.50	61.25
KB06	1165.33	4.60	584.97	19.88	3.15	11.52	85.50	6.50	46.00
KB08	478.67	2.00	240.33	18.51	1.50	10.00	118.00	7.00	62.50
KB14	995.33	41.33	518.33	14.04	12.95	13.49	72.00	59.50	65.75
Mean	**617.40**	**31.88**	**324.64**	**14.21**	**8.88**	**11.55**	**113.79**	**49.27**	**81.53**
SED (P=0.05)	**375.11**	**16.74**	**264.9**	**2.48**	**1.35**	**4.4**	**57.78**	**17.05**	**45.06**
CV%	**4.6**	**52.5**	**81.6**	**3.7**	**15.1**	**38**	**15.5**	**34.6**	**55.3**

Appendix 2: Means of days to 50% flowering, days to 75% maturity and plant height of pigeon pea accessions evaluated across two locations in one season (2010a).

	Days to 75% maturity			Days to 50% flowering			Plant height (cm)		
Variety	**MUARIK**	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**	**MUARIK**	**NgeZARDI**	**Mean**
2047	157.50	189.00	173.25	103.50	169.00	136.25	213.30	233.80	223.55
2097	170.00	202.00	186.00	88.00	176.00	132.00	179.90	253.08	216.49
20L	162.00	140.00	151.00	103.50	125.00	114.25	174.40	184.65	179.53
2238	166.50	213.00	189.75	120.50	192.50	156.50	220.60	242.88	231.74
2241	177.00	134.00	155.50	116.00	118.00	117.00	169.30	222.63	195.96
2243	178.00	211.17	194.58	102.50	176.70	139.60	187.10	241.56	214.33
2244	173.00	203.50	188.25	144.00	190.00	167.00	176.80	260.23	218.51
2245	172.50	181.50	177.00	103.50	162.50	133.00	181.90	251.33	216.61
2246	176.50	190.50	183.50	107.00	171.00	139.00	199.90	243.05	221.48
2251	150.00	159.00	154.50	90.50	140.00	115.25	161.30	257.90	209.60
2256	176.50	142.00	159.25	104.00	124.00	114.00	185.20	224.00	204.60
2258	174.00	231.00	202.50	140.50	217.00	178.75	197.75	264.80	231.28
2263	156.50	188.00	172.25	108.00	170.00	139.00	187.20	245.15	216.18
2264	151.00	210.00	180.50	108.50	192.00	150.25	223.70	261.10	242.40
2265	155.50	220.00	187.75	104.00	204.00	154.00	163.00	258.00	210.50
2266	171.00	140.50	155.75	109.00	123.50	116.25	190.10	123.88	156.99
2267	174.00	200.00	187.00	133.50	186.00	159.75	218.50	259.75	239.13
2268	159.50	187.00	173.25	119.50	167.00	143.25	203.10	251.63	227.36
2276	169.00	207.00	188.00	155.00	188.00	171.50	193.40	225.90	209.65
2279	171.00	164.00	167.50	97.50	148.00	122.75	160.20	239.65	199.93
2281	175.00	206.00	190.50	128.00	192.00	160.00	207.60	264.00	235.80
2282	178.00	185.00	181.50	108.00	169.00	138.50	195.90	238.00	216.95
2284	157.50	180.50	169.00	121.50	163.00	142.25	233.20	258.15	245.68

2287	182.50	171.83	177.17	124.00	157.30	140.65	203.35	266.70	235.02
2289	156.50	193.00	174.75	91.00	174.00	132.50	161.90	248.75	205.33
2298	172.50	205.00	188.75	94.00	188.00	141.00	199.85	277.75	238.80
22L	177.50	168.00	172.75	128.50	151.00	139.75	181.90	236.80	209.35
2300	167.50	184.00	175.75	97.50	168.00	132.75	199.00	241.38	220.19
2302	150.00	185.00	167.50	103.00	167.00	135.00	184.40	190.00	187.20
2303	142.00	188.00	165.00	118.00	169.00	143.50	159.10	228.25	193.68
2306	175.00	185.00	180.00	83.50	167.00	125.25	177.90	241.75	209.83
2309	151.00	189.00	170.00	96.50	174.00	135.25	156.40	255.00	205.70
2311	136.00	170.50	153.25	137.00	151.50	144.25	193.10	236.90	215.00
2321	160.00	188.00	174.00	91.50	170.00	130.75	174.20	251.55	212.88
2323	181.00	182.00	181.50	108.00	167.00	137.50	183.90	279.25	231.58
2324	142.00	186.00	164.00	98.00	170.00	134.00	180.60	247.75	214.18
2325	183.50	201.00	192.25	138.50	187.00	162.75	186.10	218.50	202.30
2328	163.00	163.17	163.08	103.00	147.70	125.35	188.90	264.34	226.62
2332	162.50	198.00	180.25	108.00	184.00	146.00	194.90	208.00	201.45
2335	155.00	171.00	163.00	139.00	154.00	146.50	168.90	245.23	207.06
2336	181.50	209.00	195.25	156.00	192.00	174.00	201.90	276.75	239.33
786	172.00	209.00	190.50	118.00	185.50	151.75	178.30	263.50	220.90
AP01	119.50	186.00	152.75	98.00	170.00	134.00	180.15	225.25	202.70
AP02	172.00	187.00	179.50	97.00	167.00	132.00	171.30	257.75	214.53
AP04	156.50	158.00	157.25	113.50	140.00	126.75	174.60	245.75	210.18
AP10	162.00	142.00	152.00	103.00	124.00	113.50	162.45	235.80	199.13
AP29	146.50	170.00	158.25	91.00	151.00	121.00	124.10	191.50	157.80
KB02	157.00	168.00	162.50	98.00	150.50	124.25	124.40	136.35	130.38
KB03	138.00	213.00	175.50	102.50	175.00	138.75	130.90	160.00	145.45
KB05-1	125.00	195.00	160.00	91.00	177.00	134.00	116.00	156.05	136.03
KB05-2	119.00	216.50	167.75	103.00	201.50	152.25	115.50	235.38	175.44

KB06	124.00	203.00	163.50	102.00	186.00	144.00	102.30	139.00	120.65
KB08	156.00	193.00	174.50	77.50	177.00	127.25	121.20	155.00	138.10
KB14	124.00	135.00	129.50	80.00	188.00	134.00	134.90	179.25	157.08
Mean	**160.41**	**185.14**	**172.77**	**109.36**	**168.43**	**138.9**	**176.96**	**231.49**	**204.22**
SED(P=0.05)	**17.62**	**23.06**	**20.24**	**18.15**	**21.7**	**17.96**	**25.33**	**37.98**	**21.68**
CV%	**7.7**	**2.3**	**11.7**	**2.8**	**2.2**	**12.9**	**13.5**	**5.3**	**10.6**

Appendix 3: Means of yield, seed weight and pods per plant of pigeon pea accessions evaluated at MUARIK across two seasons (2010a and 2011b).

	Yield (kg/ha)			100 seed weight (g)			Pods per plant		
Variety	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**	**2010a**	**2011b**	**Mean**
2047	267.33	83.70	175.52	14.11	2.77	8.44	54.00	85.25	69.63
2097	164.67	153.97	159.32	13.60	10.98	12.29	71.00	87.00	79.00
20L	1145.33	340.21	742.77	9.61	8.62	9.11	231.00	87.13	159.06
2238	245.33	113.41	179.37	15.32	9.13	12.23	62.00	201.00	131.50
2241	130.67	186.71	158.69	13.08	12.00	12.54	128.00	75.50	101.75
2243	83.33	30.41	56.87	12.05	9.55	10.80	53.50	92.00	72.75
2244	486.67	163.12	324.89	13.17	10.46	11.81	148.50	96.00	122.25
2245	300.67	192.71	246.69	13.12	12.71	12.91	57.50	90.00	73.75
2246	1273.33	111.86	692.60	10.94	11.19	11.06	240.00	76.00	158.00
2251	906.00	98.27	502.13	14.22	8.64	11.43	174.50	186.13	180.31
2256	1326.67	348.78	837.72	12.67	11.16	11.91	175.50	144.63	160.06
2258	312.00	77.36	194.68	12.70	12.51	12.61	77.50	67.50	72.50
2263	744.67	52.23	398.45	11.54	8.98	10.26	99.50	91.50	95.50
2264	408.67	61.35	235.01	9.09	11.91	10.50	193.50	88.00	140.75
2265	237.33	114.78	176.05	10.18	12.51	11.34	99.00	141.50	120.25
2266	467.33	53.27	260.30	11.05	8.24	9.64	57.50	35.25	46.38
2267	94.00	24.68	59.34	9.33	10.21	9.77	96.00	92.50	94.25
2268	408.00	38.34	223.17	17.79	12.16	14.97	166.00	93.63	129.81
2276	424.73	20.90	222.82	14.04	9.61	11.82	123.50	89.75	106.63
2279	395.33	42.63	218.98	14.67	8.99	11.83	79.50	92.00	85.75
2281	171.33	77.36	124.35	15.93	8.98	12.45	76.50	85.13	80.81
2282	598.67	34.67	316.67	14.54	9.15	11.85	35.50	91.63	63.56
2284	305.33	18.36	161.85	14.90	10.65	12.78	41.00	81.50	61.25

2287	790.67	25.55	408.11	16.21	14.67	15.44	216.00	87.88	151.94
2289	906.67	215.02	560.85	13.53	13.81	13.67	65.50	140.13	102.81
2298	295.33	233.25	264.29	16.53	9.27	12.90	60.50	147.25	103.88
22L	522.00	117.36	319.68	9.30	11.38	10.34	278.50	90.88	184.69
2300	544.67	112.22	328.44	12.51	12.61	12.56	155.50	84.25	119.88
2302	256.00	37.29	146.64	17.02	11.09	14.05	80.50	88.38	84.44
2303	876.67	62.44	469.55	13.96	12.74	13.35	113.50	88.00	100.75
2306	1246.67	62.55	654.61	11.80	10.29	11.04	178.00	69.00	123.50
2309	478.67	62.55	270.61	12.61	10.82	11.71	137.00	85.25	111.13
2311	119.33	26.91	73.12	12.16	9.57	10.86	60.50	83.13	71.81
2321	1184.00	48.02	616.01	16.40	11.19	13.79	107.00	89.25	98.13
2323	652.67	40.25	346.46	15.06	9.57	12.32	112.00	95.88	103.94
2324	904.67	54.55	479.61	15.78	11.09	13.43	68.50	84.75	76.63
2325	474.67	0.00	237.33	13.77	0.00	6.89	128.50	95.38	111.94
2328	1136.00	701.39	918.69	14.56	10.19	12.37	111.00	91.38	101.19
2332	711.33	72.83	392.08	15.12	14.84	14.98	192.00	93.13	142.56
2335	923.33	66.32	494.83	13.90	13.46	13.68	94.50	87.38	90.94
2336	134.00	14.69	74.34	17.88	11.02	14.45	200.50	97.75	149.13
786	333.33	167.46	250.40	13.94	11.36	12.65	50.00	94.38	72.19
AP01	238.67	14.79	126.73	14.03	7.00	10.51	200.50	82.25	141.38
AP02	1144.67	23.43	584.05	15.89	9.32	12.60	100.50	91.13	95.81
AP04	1030.00	149.81	589.90	15.48	13.51	14.49	79.00	86.38	82.69
AP10	682.00	157.63	419.81	15.39	16.51	15.95	94.00	90.00	92.00
AP29	944.67	202.85	573.76	16.10	11.81	13.95	137.50	86.38	111.94
KB02	244.00	15.21	129.61	16.82	11.41	14.11	70.00	78.63	74.31
KB03	901.33	81.63	491.48	18.09	13.15	15.62	34.50	86.00	60.25
KB05-1	907.33	0.00	453.67	18.31	0.00	9.15	83.00	0.00	41.50
KB05-2	1219.33	143.59	681.46	15.38	12.81	14.09	120.00	74.00	97.00

KB06	1165.33	49.49	607.41	19.88	13.29	16.58	85.50	81.88	83.69
KB08	478.67	47.37	263.02	18.51	12.01	15.26	118.00	93.88	105.94
KB14	995.33	9.64	502.48	14.04	6.32	10.18	72.00	72.38	72.19
Mean	**617.4**	**101.02**	**359.21**	**14.21**	**10.5**	**12.36**	**113.79**	**92.35**	**103.07**
SED(P=0.05)	**375.11**	**21.64**	**252.81**	**2.48**	**2.2**	**2.74**	**57.78**	**46.24**	**45.22**
CV%	**4.6**	**21.4**	**7**	**3.7**	**27.4**	**16.7**	**15.5**	**30.5**	**22.8**

Appendix 4: Means of days to 50% flowering, 75% maturity and plant height of pigeon pea accessions evaluated at MUARIK across two seasons (2010a and 2011b).

	Days to 50% flowering			Plant height (cm)			Days to 75% maturity
Variety	2010a	2011b	Mean	2010a	2011b	Mean	Mean
2047	103.50	150.00	126.75	213.30	231.94	222.62	171.00
2097	88.00	124.00	106.00	179.90	201.52	190.71	169.50
20L	103.50	134.00	118.75	174.40	198.33	186.36	164.75
2238	120.50	148.50	134.50	220.60	225.54	223.07	177.13
2241	116.00	135.00	125.50	169.30	217.93	193.61	176.38
2243	102.50	141.50	122.00	187.10	209.68	198.39	178.88
2244	144.00	152.50	148.25	176.80	203.90	190.35	180.38
2245	103.50	134.75	119.13	181.90	181.58	181.74	174.13
2246	107.00	149.75	128.38	199.90	230.51	215.21	182.13
2251	90.50	131.00	110.75	161.30	193.28	177.29	158.88
2256	104.00	144.00	124.00	185.20	201.85	193.53	179.38
2258	140.50	136.00	138.25	197.75	223.45	210.60	173.88
2263	108.00	144.50	126.25	187.20	223.54	205.37	167.25
2264	108.50	133.50	121.00	223.70	203.91	213.81	161.38
2265	104.00	135.50	119.75	163.00	196.81	179.91	164.00
2266	109.00	136.00	122.50	190.10	226.50	208.30	168.13
2267	133.50	140.25	136.88	218.50	216.01	217.26	176.75
2268	119.50	147.50	133.50	203.10	209.99	206.54	170.50
2276	155.00	147.50	151.25	193.40	214.78	204.09	171.88
2279	97.50	134.50	116.00	160.20	211.23	185.71	174.75
2281	128.00	125.75	126.88	207.60	206.70	207.15	169.75
2282	108.00	134.00	121.00	195.90	217.58	206.74	177.63
2284	121.50	127.50	124.50	233.20	228.24	230.72	157.75
2287	124.00	147.50	135.75	203.35	181.55	192.45	175.63
2289	91.00	133.50	112.25	161.90	159.98	160.94	165.50

2298	94.00	145.50	119.75	199.85	177.18	188.51	180.88
22L	128.50	143.25	135.88	181.90	208.14	195.02	176.00
2300	97.50	138.50	118.00	199.00	179.06	189.03	165.38
2302	103.00	137.25	120.13	184.40	218.33	201.36	161.00
2303	118.00	147.25	132.63	159.10	202.24	180.67	156.13
2306	83.50	102.50	93.00	177.90	190.33	184.11	161.00
2309	96.50	131.75	114.13	156.40	201.24	178.82	158.13
2311	137.00	132.75	134.88	193.10	193.75	193.43	148.63
2321	91.50	137.75	114.63	174.20	210.38	192.29	166.63
2323	108.00	143.25	125.63	183.90	225.58	204.74	184.13
2324	98.00	133.25	115.63	180.60	185.61	183.11	153.38
2325	138.50	145.50	142.00	186.10	218.18	202.14	184.38
2328	103.00	134.25	118.63	188.90	214.60	201.75	170.50
2332	108.00	150.75	129.38	194.90	224.20	209.55	171.75
2335	139.00	136.00	137.50	168.90	216.89	192.89	162.50
2336	156.00	155.25	155.63	201.90	230.01	215.96	185.88
786	118.00	148.00	133.00	178.30	211.68	194.99	178.13
AP01	98.00	130.50	114.25	180.15	199.58	189.86	139.13
AP02	97.00	132.25	114.63	171.30	214.29	192.79	174.38
AP04	113.50	141.25	127.38	174.60	201.49	188.04	162.25
AP10	103.00	138.25	120.63	162.45	182.48	172.46	168.50
AP29	91.00	133.75	112.38	124.10	201.91	163.01	156.13
KB02	98.00	116.25	107.13	124.40	167.53	145.96	154.00
KB03	102.50	140.00	121.25	130.90	179.83	155.36	152.63
KB05-1	91.00	111.50	101.25	116.00	179.64	147.82	128.75
KB05-2	103.00	123.75	113.38	115.50	151.05	133.28	130.63
KB06	102.00	137.75	119.88	102.30	130.15	116.23	141.50
KB08	77.50	132.00	104.75	121.20	153.04	137.12	169.38
KB14	80.00	132.50	106.25	134.90	147.51	141.21	131.50

Mean	**109.36**	**137.06**	**123.21**	**176.96**	**200.59**	**188.78**	**165.93**
SED (P=0.05)	**18.15**	**11.17**	**11.12**	**25.33**	**23.22**	**14.9**	**9.02**
CV%	**2.80**	**7.40**	**8.20**	**13.50**	**9.30**	**7.60**	**11.7**

Appendix 5: Mean of pest damages by flower and pod suckers (*Clavigralla tomentosicollis* Stal.), pod borers (*Helicoverpa armigera* Hubner) and pod fly (*Melanagromyza chalcosoma)* recorded on pigeon pea accessions at reproductive stage evaluated at MUARIK and NgeZARDI in 2010a.

Variety	Damage at flowering (127 DAP)	Damage at podding (155 DAP)	Damage at pod maturity (≥ 155DAP)
2047	2.75	3.75	3.25
2097	2.25	3.50	4.00
20L	2.50	4.00	3.50
2238	2.00	3.50	3.50
2241	2.75	3.75	3.25
2243	2.75	3.50	3.25
2244	2.50	3.75	3.50
2245	2.75	3.50	3.75
2246	2.50	3.50	3.50
2251	2.25	4.00	4.00
2256	2.75	3.75	4.50
2258	2.25	3.50	4.00
2263	3.00	3.50	4.00
2264	2.50	3.50	3.25
2265	2.50	4.00	4.00
2266	2.75	3.50	3.50
2267	3.00	3.50	3.75
2268	2.50	3.50	3.50
2276	2.25	4.00	3.75
2279	2.50	4.00	3.25
2281	2.50	3.50	3.25
2282	1.75	3.50	3.50
2284	2.50	3.50	3.25
2287	2.75	3.50	3.25
2289	2.75	3.75	3.75
2298	2.50	3.00	3.25
22L	1.75	2.00	2.75
2300	2.75	3.00	3.50
2302	2.75	3.50	3.75
2303	2.25	3.75	3.50
2306	2.25	3.25	4.25
2309	2.25	3.75	4.00
2311	3.00	3.50	3.50
2321	2.75	3.25	3.50
2323	2.75	3.75	4.00
2324	2.75	3.00	4.25
2325	2.75	3.50	4.00
2328	1.50	2.50	2.25
2332	2.75	4.00	3.50

2335	2.75	3.50	3.25
2336	2.25	3.50	3.75
786	2.75	3.75	3.25
AP01	2.75	3.25	4.25
AP02	2.50	3.50	4.00
AP04	2.75	4.00	3.50
AP10	2.25	3.75	3.50
AP29	2.50	3.25	4.00
KB02	2.25	3.00	3.50
KB03	2.50	3.50	3.75
KB05-1	2.75	3.50	4.00
KB05-2	3.00	3.50	3.50
KB06	2.50	3.50	3.75
KB08	2.00	3.50	3.50
KB14	2.00	3.75	3.50
Mean	**2.51**	**3.51**	**3.61**
SED(P=0.05)	**0.49**	**0.48**	**0.62**
CV%	**19.7**	**13.7**	**17.2**

Appendix 6: Mean of pest damages by flower and pod suckers (*Clavigralla tomentosicollis* Stal.), pod borers (*Helicoverpa armigera* Hubner) and pod fly (*Melanagromyza chalcosoma)* recorded on pigeon pea accessions at reproductive stage evaluated for two seasons (2010a and 2011b) at MUARIK.

	Damage at flowering **(127 DAP)**			Damage at maturity **(≥ 155DAP)**		
Variety	2010a	2011b	Mean	2010a	2011b	Mean
2047	1.00	3.50	2.25	2.00	5.50	3.75
2097	1.00	6.00	3.50	3.00	4.00	3.50
20L	1.00	4.50	2.75	2.50	4.00	3.25
2238	1.00	4.50	2.75	2.50	5.00	3.75
2241	1.00	4.50	2.75	1.00	4.50	2.75
2243	1.00	3.50	2.25	1.50	4.50	3.00
2244	1.00	2.50	1.75	2.50	4.50	3.50
2245	1.00	4.50	2.75	3.00	3.50	3.25
2246	1.00	4.00	2.50	1.50	5.00	3.25
2251	1.00	4.00	2.50	2.00	4.00	3.00
2256	1.00	1.00	1.00	3.00	4.00	3.50
2258	1.00	3.50	2.25	3.00	5.00	4.00
2263	1.00	4.50	2.75	2.00	5.00	3.50
2264	1.00	3.50	2.25	1.50	4.00	2.75
2265	1.50	3.50	2.50	2.50	5.00	3.75
2266	1.00	1.00	1.00	2.50	4.00	3.25
2267	1.00	2.00	1.50	2.00	5.00	3.50
2268	1.00	4.00	2.50	2.00	4.00	3.00
2276	1.00	1.00	1.00	2.00	5.00	3.50
2279	1.00	2.00	1.50	2.50	4.50	3.50
2281	1.00	3.00	2.00	2.00	4.00	3.00
2282	1.00	2.00	1.50	2.00	4.50	3.25
2284	1.00	3.50	2.25	2.50	4.50	3.50
2287	1.00	1.50	1.25	1.50	5.00	3.25
2289	1.00	2.50	1.75	2.50	4.00	3.25
2298	1.00	1.00	1.00	2.00	4.00	3.00
22L	1.00	3.50	2.25	2.50	5.50	4.00
2300	1.00	1.50	1.25	2.50	4.50	3.50
2302	1.00	1.50	1.25	3.00	3.50	3.25
2303	1.00	1.00	1.00	2.50	3.50	3.00
2306	1.00	2.00	1.50	3.00	4.00	3.50
2309	1.00	1.50	1.25	3.00	3.50	3.25
2311	1.00	2.00	1.50	2.00	4.00	3.00
2321	1.00	1.50	1.25	2.50	4.00	3.25
2323	1.00	2.00	1.50	2.00	3.50	2.75
2324	1.00	3.00	2.00	3.00	3.50	3.25
2325	1.00	3.00	2.00	2.50	3.00	2.75
2328	1.00	2.00	1.50	2.00	4.50	3.25
2332	1.00	3.00	2.00	2.00	4.50	3.25

2335	1.00	1.00	1.00	2.50	3.00	2.75
2336	1.00	2.50	1.75	2.50	4.00	3.25
786	1.00	5.50	3.25	2.50	5.00	3.75
AP01	1.00	4.50	2.75	3.00	4.50	3.75
AP02	1.00	1.00	1.00	2.50	4.00	3.25
AP04	1.00	3.50	2.25	2.00	3.00	2.50
AP10	1.00	2.50	1.75	2.50	4.00	3.25
AP29	1.00	2.00	1.50	2.00	5.00	3.50
KB02	1.50	3.00	2.25	2.00	4.50	3.25
KB03	1.00	1.00	1.00	2.50	4.00	3.25
KB05-1	1.00	3.50	2.25	2.50	4.50	3.50
KB05-2	1.00	4.00	2.50	2.00	4.50	3.25
KB06	1.00	4.00	2.50	2.00	5.00	3.50
KB08	1.00	3.00	2.00	2.50	4.50	3.50
KB14	1.00	4.00	2.50	2.50	5.50	4.00
Mean	**1.00**	**2.84**	**1.93**	**2.30**	**4.31**	**3.31**
SED(P=0.05)	**0.1**	**1.29**	**0.91**	**0.46**	**0.62**	**0.62**
CV%	**13.2**	**36.9**	**47.1**	**25**	**18.8**	**18.6**

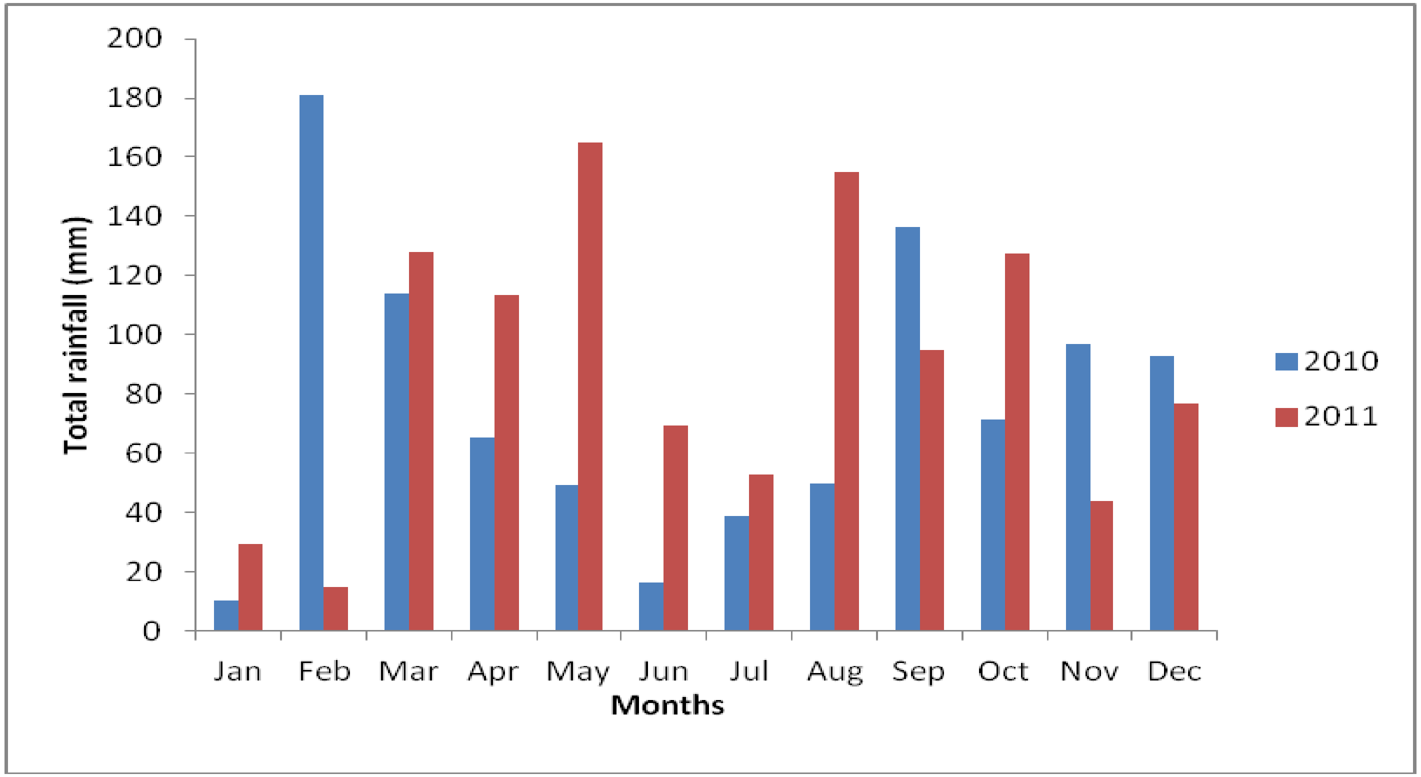

Figure 6: Rainfall data recorded at MUARIK during 2010 and 2011.

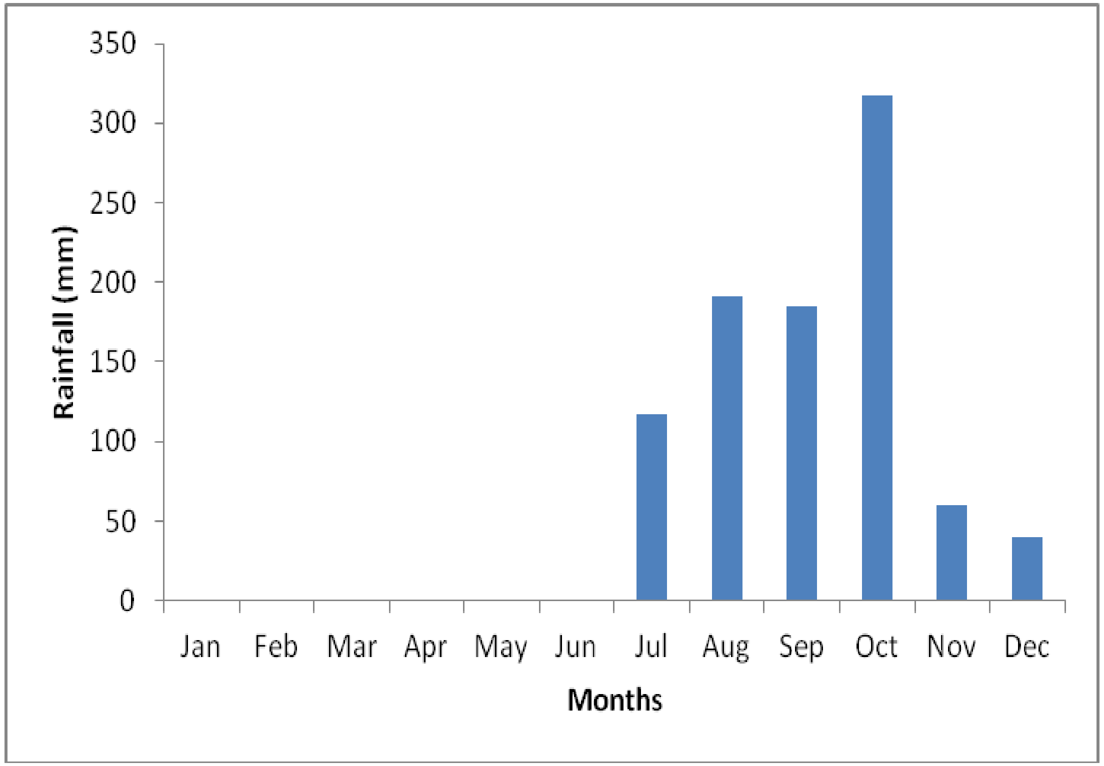

Figure 7: Rainfall data recorded at NgeZARDI during 20l0.