

**GENETIC ANALYSIS OF DROUGHT TOLERANCE IN
COWPEA [*VIGNA UNGUICULATA* (L.) WALP]**

By

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**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN
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DECLARATION

I hereby declare that except for references to works of other researchers, which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.

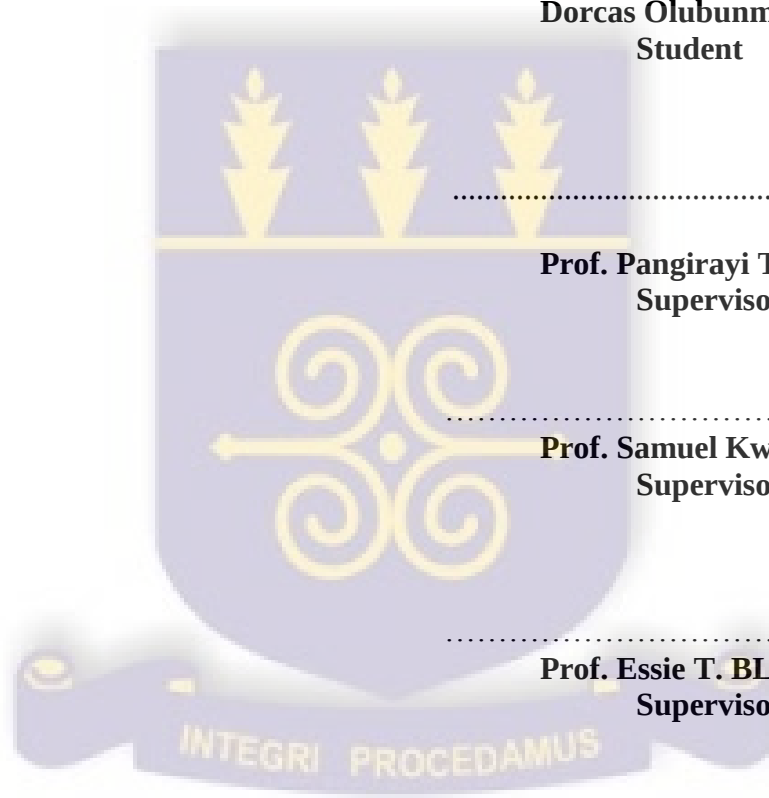
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ABSTRACT

Agriculture in Sub Saharan Africa (SSA) is under serious threat due to water shortage, population pressure and climate change. Cowpea, a protein-rich legume crop complements staple cereal and tuber crops in the diets of rural and urban people of the tropical and sub-tropical regions of the world. It therefore, plays a significant role in the sustainability of food and nutrition security in SSA. Cowpea, though reported to be inherently drought tolerant; but because it is mostly grown under rain-fed conditions towards the end of the rainy season in the drier parts of Nigeria, its productivity is still being adversely affected by the erratic pattern of rainfall which occurs frequently in these areas. Increasing the level of drought tolerance in existing cowpea varieties that will possess farmers' preferred traits will increase farmers' adoption of these varieties and ensure high and stable yield from farmers' fields under the ever changing climatic conditions. The objectives of this study were therefore, to: (i) identify the impact of drought on cowpea production and farmers' preferred traits in new cowpea varieties (ii) assess the diversity of cowpea germplasm for drought tolerance (iii) assess the combining ability of cowpea lines under drought and well-watered conditions and (iv) determine the gene action controlling drought tolerance in cowpea. The results of a Participatory Rural Appraisal (PRA) conducted in fifteen cowpea growing communities of Kano State, Nigeria established that drought, pests and diseases were major constraints to cowpea production. Drought reduced grain yield and fodder yield to about 62% and 56% of realizable yield under normal condition respectively. Fifty-eight percent of the farmers confirmed drought at the flowering / pod-filling stage was more devastating than drought occurring at the vegetative stage (32%) while 10% of the farmers confirmed that both growth stages were both growth stages are susceptible to

drought. Consumer-based traits such as large seed, short cooking time and dual-purpose varieties which increase farmers' income were identified as important preferred traits as well as traits for biotic and abiotic tolerances in new cowpea varieties. Ninety-one cowpea varieties were screened for tolerance to drought using the wooden box screening technique with the aim to identify parents to be used for genetic analysis studies. Twenty lines were selected based on their responses to the screening and were mated in a North Carolina Design II to generate 100 single F_1 crosses. The F_1 progenies and their parents were evaluated under drought and well-watered conditions at two locations. Grain yield of the F_1 progenies ranged between 2533 kg ha⁻¹ for TVu6707 x TVu9797 and 18 kg ha⁻¹ for TVu11986 x TVu2736 under drought stress, 3786 kg ha⁻¹ for TVu6707 x TVu9797 and 45 kg ha⁻¹ for TVu633 x TVu2736 under well-watered conditions. General Combining Ability (GCA) and Specific Combining Ability (SCA) mean squares were significant for grain yield and other traits across all research environments indicating that both additive and non-additive gene effects were important in the control of grain yield and other drought adaptive traits across all research environments. The contribution of GCA (71%) to the total sum of squares was higher than that of SCA (21%) for grain yield under drought stress indicating that additive gene action was more important in the inheritance of grain yield under drought stress. Similarly, the superior positive GCA (GCA-female and GCA-male) effects for 100-seed weight, number of seeds per pod, Normalized Difference Vegetation Index (NDVI) measured at three different growth stages, the number of pods and seeds per plant under drought stress indicated that additive gene action was more important in the inheritance of these yield related traits under drought stress. The lines TVu79, TVu6707, TVu9693 and TVu9707 were identified as general good combiners with outstanding

positive GCA effects for grain yield under drought stress. These can be used as parents to generate improved cowpea varieties for drought tolerance. Considering both mean yield and stability performance, TVu8670 x Sanzi, IT89D-288 x TVu8670, TVu6707 x TVu79 and TVu8670 x TVu79 can further be advanced for development of novel drought tolerant varieties.



DEDICATION

To my husband – Omoniyi David **Ibitoye**

To my lovely girls – **Anjolaoluwa** Lois and **Tiwaladeoluwa** Sharon

To the loving memory of my late father – Pastor Jacob Ogunleye **Ajisafe**



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LIST OF ABBREVIATIONS

ABL	Advanced breeding line
ASL	Above sea level
DAP	Days after planting
DLSC	Delayed Leaf Senescence
DS	Drought stress
FAO	Food and Agricultural Organization
GCA	General Combining Ability
IITA	International Institute of Tropical Agriculture
LDR	Landrace
LG	Linkage group
NCII	North Carolina mating design II
NDVI	Normalized Difference Vegetation Index
SCA	Specific Combining Ability
SSA	Sub-Saharan Africa
TVu	Tropical <i>Vigna unguiculata</i>
WECA	West and Central Africa
WW	Well-watered

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walpers] is the most economically important indigenous African grain legume producing a source of economic livelihood and nutritional well-being for rural poor and urban consumers (Agbicodo et al., 2009; Langyintuo et al., 2003; Timko, 2006).

Cowpea plays a critical role in the lives of millions of people in Africa and other parts of the developing world, where it is a major source of dietary protein that nutritionally complements staple low-protein cereal and tuber crops, and is a valuable and dependable commodity that produces income for farmers and traders (Singh, 2002; Langyintuo, et al., 2003). Cowpea is a valuable component of farming systems in many areas because of its ability to restore soil fertility through nitrogen fixation, for succeeding cereal crops grown in rotation with it (Carsky et al., 2002; Tarawali et al., 2002; Sanginga et al., 2003). The N contribution to a cropping system by a cowpea cover crop was reported to be about 145.7 kg N/ha per season if the crop is turned under (Valenzuela and Smith, 2002). Early maturing cowpea varieties can provide food earlier than any other crop (in as few as 55 d after planting), thereby shortening the “hunger period” that often occurs prior to harvest of other crops in farming communities in the developing world. Cowpea haulms and chaff are used as livestock feeds and are also beneficial in maintaining soil fertility thus making it an important component of any cropping system (Sanginga et al., 2000, Muchero et al., 2008). Dry grain for human consumption is the most important product of the cowpea plant; these grains can either be boiled or converted into other food products such as moin-moin, akara, bean soup etc. in Nigeria. The green leaves/twigs, are also used in preparing

nutritious vegetable soup; the fresh pods and peas are used for salad in vegetarian diets (Timko et al., 2007).

The estimated world cowpea production area is over 14.5 million ha, with an annual production estimated at about 7.64 million tonnes. Out of this estimate, West and Central Africa (WECA) account for over 9 million ha and 3 million tonnes. West Africa is the key cowpea production zone, mainly from the dry savanna and semi-arid agro-ecological zones. In West Africa, Nigeria and Niger Republics are the major cowpea producers with Nigeria contributing over 60% of the total production (FAOSTAT, 2015). Compared with many other crops, cowpea is reported to thrive in places considered too dry for the production of other grain legumes but because it is mostly grown under rain-fed conditions on sandy soils having low water-holding capacity in the drier regions that receive between 300 - 600 mm annual rainfall, its productivity is adversely affected by erratic rainfall patterns which occur frequently in these areas (Belko et al., 2013).

Drought can cause direct reduction of about 50 - 67% in cowpea grain yield (Fatokun et al., 2012; Sanda and Maina, 2013). In addition to the direct effect on yield, many aspects of plant growth are affected by drought stress (Hsaio, 1973), including leaf expansion, which is reduced due to the sensitivity of cell growth to water stress. Water stress also reduces leaf production by promoting senescence and abscission (Karamanos, 1980), resulting in decreased total leaf area per plant. Reduction in leaf area reduces crop growth and thus biomass production. Seed production, which is positively correlated with leaf area (Rawson and Turner, 1982), may also be reduced by reduction in leaf area caused by drought stress.

There are various ways of reducing the effect of drought or addressing the problem of drought stress including irrigation and breeding. However, irrigation requires large capital outlay and availability of water throughout the growing season, especially at flowering and pod filling stages. This makes it less feasible especially for small scale farmers in Africa. Developing drought tolerant varieties is a more sustainable option of managing drought since there would be no additional cost to the farmer once drought tolerant seeds are available. Breeding for drought tolerance and grain yield however is complex because they are governed by minor genes whose effects are often confounded by interaction of morphological, physiological and biochemical characters of the crop with the environment thus making genetic improvement of these traits in crops a slow and difficult process (Fatokun et al., 2012; Mir et al., 2012).

In cowpea research, drought tolerant factors have been separated into shoot and root tolerance using simple, rapid and cheap screening methods (Singh and Matsui, 2002; Hall et al., 2003). For selection, two classical approaches are followed when breeding for drought tolerance: (i) utilization of grain yield as selection criteria, and (ii) identification of physiological traits that might contribute to yield production under drought (Singh et al., 2003; Hamidou et al., 2007; Badu-Apraku et al., 2011).

In order for a rapid progress to be made in the development of more drought-tolerant cowpea varieties, it would be necessary to identify easily recognized and measurable characteristics that are associated with the physiological traits upon which selection could be applied. Numerous efforts in this direction have led to discovery of some traits such as stomatal conductance, lower leaf area development and lower canopy conductance, stay

green or delayed-leaf-senescence (DLSC) that are associated with drought tolerance (Agbicodo et al., 2009; Belko et al., 2013; Muchero et al., 2013). Studies on shoot tolerance in cowpea using wooden boxes placed in the greenhouse revealed positive significant correlation between drought tolerance at the seedling stage and drought tolerance in the field (Ewansiha and Singh, 2006; Muchero et al., 2010). They concluded that lines possessing shoot tolerance should also perform well under drought in the field. However, this does not exclude field evaluation in order to identify lines with reproductive-stage drought tolerance and stay-green characteristics, both of which could enhance better performance of cowpea under drought.

Breeding for earliness is important in cowpea adaptation in water-limited areas since early maturing crops are bred to escape terminal drought stresses. However, they are susceptible to water deficits occurring during the flowering and reproductive stages (Cisse et al., 1995, 1997; Ehlers et al., 2000). They can suffer significant reductions in plant stature that lower potential yield when stress occurs at the seedling stage. Because it has become more frequent for farmers' fields to experience irregular rainfall during cropping seasons, varieties that combine earliness and stay-green characteristics should be able to give farmers some grain yield even with irregular rainfalls. While early flowering is a drought escape mechanism, drought tolerance at the seedling stage and 'delayed leaf senescence' (DLSC) should enhance the plants' ability to survive drought during early, mid-season and at pod filling stages. In Senegal, an early DLSC cowpea variety was reported to produce higher yield because of its ability to produce two flushes of pods (Hall et al., 2003). The prolonged life span that DLSC confers on plants would also add to the plants' ability to tolerate terminal drought better. It can as well serve as an indirect selection for grain yield

and biomass under drought (Gwathmey et al., 1992a, c; Hall, 2004, Muchero et al., 2013). If cowpea varieties that combine the above attributes become available, they will enable farmers to obtain a better grain yield in those years when rainfall is irregular.

To be able to develop tolerant cowpea varieties that will be adopted by farmers, their involvement at the beginning of breeding effort is very crucial for adoption of developed varieties (Thagana et al., 2009; Kaloki, 2010). Their participation will provide the demand-pull necessary to ensure that the effort in breeding work is focused on key issues of value to the farmers and consumers (Witcombe et al., 1996, 2006). In this regard, a Participatory Rural Appraisal (PRA) was conducted to identify farmers preferred traits that should be bred into drought tolerant varieties in order to increase cowpea productivity.

Polygenically controlled traits such as yield, quality and drought tolerance are complex traits because they are under the control of many genes each contributing small effects to the phenotype and thus cannot be easily identified (Babu et al., 2004). The regions within genomes that contain genes associated with a particular quantitative trait are known as quantitative trait loci (QTL). Identification of these QTL based on phenotype observation is impossible because they exhibit significant genotype by environment interactions ($G \times E$), which necessitate extensive multi-location testing and breeding efforts targeted to specific production environments (Heffner et al., 2009; Bharadwaj et al., 2011). Multi-location testing, however, usually results in genotype-by-environment interactions that often complicate the interpretation of results obtained and reduce efficiency in selecting the best genotypes (Annicchiarico and Perenzin, 1994). Better understanding of the level of $G \times E$ interaction and performance stability in crops serves as a decision making tool,

particularly at the final stage of the variety development process, to generate essential information on pattern of adaptation in breeding lines as well as new varieties for release, and to determine the recommendation domains where a given cultivar would be better adapted (Yan, 2011).

Rapid progress in the development of polymorphic molecular markers has led to the intensive use of QTL mapping in genetic studies for quantitative traits (Wang et al., 2007). The principle of QTL analysis is based on detecting an association between the phenotype and the genotype or the marker tightly linked to the trait of interest. QTL analysis effectively improves breeding for difficult characters (Collard et al., 2005, Muchero et al., 2013). Five stay-green QTL showing positive pleiotropic effects between delayed senescence, increased biomass, and grain yield have been reported by Muchero et al., (2013). Three of these five QTL: QTL, Dro-1, 3, and 7 were identified in RIL population and diverse germplasm suggesting they may be invaluable targets for marker-assisted breeding in cowpea. Early vegetative delayed leaf senescence was co-located with biomass and grain yield suggesting the possibility of using delayed senescence at the seedling stage as a rapid screening tool for post-flowering drought tolerance in cowpea breeding (Agbicodo et al., 2009; Muchero et al., 2013). Investigations on G x E interactions at important crop growth stages for yield components would help to develop strategies that integrate conventional plant breeding with modern molecular marker-based selection for tailoring cultivars for high yield and target environments.

Although grain yield between 2500 kg/ha to 4000 kg/ha is achievable for cowpea, several constraints have kept farmers' yields constantly low at levels between 350 and 700 kg/ha

(Ajeigbe et al., 2010a). If the yield barrier is to be overcome, strategies to improve the genetic potential of cowpea plants by introducing novel genes is required. For this to be achieved, genotypes with potential for higher yield and other desirable traits are needed as parent lines to develop improved varieties (Aremu, 2005).

The identification of suitable parental genotypes, potentially generating superior lines with traits contributing to the overall yield of a crop, is an important step in the development of improved varieties because if parents are precisely selected, the desired recombinants will be found in the segregating generations (Moalafi et al., 2010; Ayo-Vaughan et al., 2013). Knowledge of the genetic control of complex quantitative traits and the magnitude of genetic variability that exists among available germplasm are therefore important for selection and genetic improvement of crop plants. Selection of parents based on combining ability has been used as an important breeding approach in crop improvement. The combining ability and gene effects of yield and its components have been studied by many researchers. Basbag et al. (2007) suggested that combining ability analysis is an important tool for selection of desirable parents together with the information regarding nature and magnitude of gene action controlling quantitative traits. Combining ability study provides useful information on how two inbred lines can be combined to produce a productive hybrid or breed novel varieties. Selection and development of parental lines with high combining ability is one of the most important breeding objectives whether the goal is to create a hybrid with strong vigour or develop a pure line cultivar with improved characteristics compared to their parents (Kadam et al., 2013). The genetic variability among the crosses is partitioned into effects due to additive (GCA) or non-additive (SCA) variances (Shiri et al., 2010). In self-pollinated crop species like cowpea, lines with high

and positive GCA estimates for a character will be good candidates to be used as parents. Preponderance of GCA was reported for hundred seed weight, pod per plant and grain yield of cowpea under moisture stress (Carvalho et al., 2012; Alidu et al., 2013), for inheritance of resistance to cowpea-aphid borne mosaic virus (Orawu, 2013). These results showed that these traits can be improved by exploiting additive gene effects through selection schemes such as recurrent selection capitalizing on favourable additive variation. Rupela and Johnansen (1995) used pure line selection to improve nodulation in pigeon pea as a result of large GCA effects. Cho and Scott (2000) reported predominance of additive effects for seed vigour and yield in soybean. Nkalubo et al. (2009), who studied the genetic control of anthracnose resistance in common bean, obtained both additive and non-additive effects controlling this trait, but with a slight predominance of additive genetic effects over dominance effects. Information regarding combining ability and nature of gene action governing the inheritance of desirable traits are therefore efficient ways to achieving maximum genetic gain when developing high yielding cowpea cultivars with higher and more stable yields across drought prone regions where it is grown. This study is among the few studies to provide information on the combining abilities of cowpea lines of diverse germplasm under contrasting soil moisture regimes in order to be able to efficiently develop novel varieties that meet farmers' demand and high yielding under varying moisture stress.

The objectives of this study were to:

1. Elicit farmers' understanding of drought and its impact on cowpea production and productivity.
2. Assess the genetic diversity for drought tolerance in cowpea germplasm.
3. Assess the performance of the F_1 crosses under drought and well-watered conditions.
4. Determine the gene action controlling yield and drought tolerance in cowpea.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cowpea taxonomy, origin, domestication and economic importance

Cowpea, [*Vigna unguiculata* (L.) Walp] is a *Dicotyledoneae* belonging to the order Fabales, family Fabaceae, subfamily Faboideae, tribe Phaseolaeae, subtribe Phaseolinae, genus *Vigna* and section Catiang (Verdcourt, 1970; Marechal et al., 1978). The genus *Vigna* has many species varying according to authors but all cultivated cowpeas are under *Vigna unguiculata*. The species *unguiculata* is subdivided into four culti-groups viz: (1) *unguiculata* which is the common form, (2) *biflora* or *catjang* with small erect pods; (3) *sesquipedalis* or yard-long beans characterized with very long pods and consumed as green snap bean; (4) *textilis* characterized with its long peduncles which is used for fibers (Padulosi and Ng, 1997).

Information based on range of variation and number of varieties found in wild cowpea as well as their primitive characteristics suggested that cowpea originated from the southern Africa regions encompassing Namibia, Zambia, and Zimbabwe but further distributed through the Western Africa regions (Ng, 1995). Cowpea is considered to have been domesticated in Africa from its wild ancestral form, *V. unguiculata* subsp. *dekindtiana* (Harms) Verdc. (Ng and Marechal, 1985). The center of maximum genetic diversity of cultivated cowpea is considered to encompass region of Nigeria, southern Niger, and part of Burkina Faso, northern Benin, Togo and northwestern part of Cameroon (Ng, 1995).

Cowpea is a vegetable legume which provides an inexpensive source of protein complementing staple cereal and starchy tuber crops and minerals for the urban and rural populations of SSA where it is predominantly cultivated and consumed. According to

Ehlers and Hall (1997), dry grain for human consumption is the principal product of the cowpea plant, but leaves (many parts of eastern Africa), fresh peas (the southern USA and Senegal) and fresh green pods (humid regions of Asia and Caribbean) are consumed. The crop is also used for green manure (southern USA and Australia) and fodder (parts of the Sahel). Cowpea cultivars differ in nutritional composition and cooking characteristics. For example, seed protein ranged from 23 to 33% on dry weight basis (Nielsen et al., 1993); fat content ranged from 1.4 to 2.7% and cooking time ranged from 21 to 62 minutes (Ehlers and Hall, 1997).

Cowpea is favoured by farmers for its diverse uses which include: rich protein source feed for livestock feed, its ability to improve soil fertility through its nitrogen fixing ability and its ability to control erosion and as an intercrop with cereals like millet and sorghum thus making it an important integral part of crop farming system in West Africa (WA). It also provides household benefits in the form of cash and income diversity for farmers (Eaglesham et al., 1992; Fabunmi et al., 2012). Demand for cowpea and low-cost nutritive food is increasing because of population increase and more knowledge on healthy nutrition (Singh et al., 2003; Yewande and Thomas, 2015).

2.2 Cowpea production, productivity and production constraints

At present, cowpea is grown throughout the tropic and subtropic areas around the whole world where rainfall resources are characteristically low (300-600 mm) (Fatokun et al., 2012) and variable (Fussell et al., 1991). Information available on the Food and Agriculture Organization (FAO) database estimated that cowpea is now cultivated on at least 11.3 million hectares worldwide with an annual production of 5.7 million tonnes with 95%

being produced in Africa (Figure 2.1). Although cowpea is widely cultivated throughout the tropics, West and Central Africa (WCA) account for over 64% of the area (9.2 million hectares) followed by about 2.4 million hectares in Central and South America, 1.3 million hectares in Asia and about 0.8 million hectares in Eastern and South Africa. A substantial part of cowpea production from WCA comes from the drier parts of northern Nigeria (about 3.2 million ha from 2.5 million tonnes), and southern Niger Republic (about 4.7 million ha from 1.3 million tonnes) (FAOSTAT, 2015).

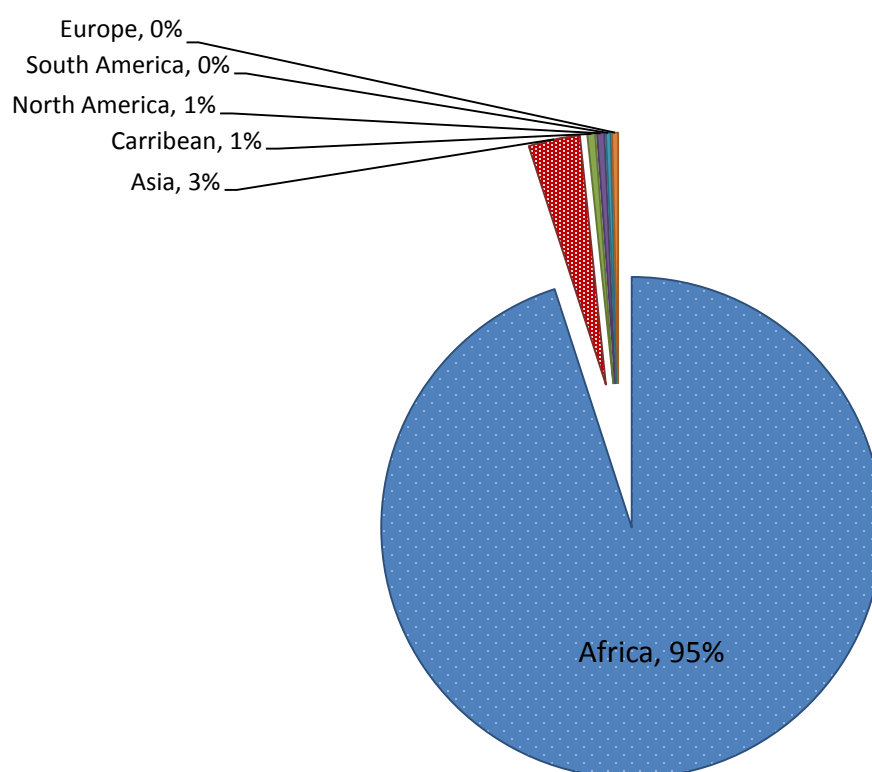


Figure 2. 1: Share of Africa in world cowpea production

Source: Adapted from FAOSTAT (2015)

Cowpea in WCA is traditionally often intercropped with cereals like sorghum, maize or millet by small-holder farmers. Fertilizers and pesticides are generally not used and when used, farmers do not apply the adequate dosage needed for optimum yield potential of the

crop because these inputs are expensive and/or not readily available for the small-holder farmers (Ajeigbe et al., 2010b).

The large differences between on-farm yield of cowpea in WCA (0.025 to 0.3 tonnes/ha) and the potential yield reported from experimental stations (1.5 to 3 tonnes/ha) (Ajeigbe et al., 2010a) showed that the high production estimate arising from these regions mainly comes from increase in land area rather than the genetic potential of the crop (Singh et al., 1997; van Ek et al., 1997). For instance, average cowpea yield in the United States of America is 1.9 tonnes/ha while it is 0.97 tonnes/ha for WCA (FAOSTAT, 2015). Several biotic and abiotic factors such as insect pests, diseases (fungal, viral, bacterial and parasitic weeds), poor soil fertility, metal toxicity and drought contribute to the reduction of cowpea yield potential in SSA (Singh and Tarawali, 1997; Wang et al., 2001; Emechebe and Lagoke, 2002; Singh and Ajeigbe, 2002). Other factors contributing to low yield in SSA include lack of improved varieties that can withstand these stresses and lack of adequate production practices and inputs needed for higher productivity and profitability. This yield gap therefore can be bridged if improved varieties and production practices are available to farmers through participatory on-farm training and evaluation with farmers (Ajeigbe et al., 2010a, b).

Drought is one of the most important abiotic constraints threatening food security in the world. This is so because the economies of African nations depend largely on rain-fed agricultural systems which are seriously affected during periods of severe drought thus making drought a serious natural disaster in Africa (Oladipo, 2008). Drought conditions can either be intermittent when they occur at one or more intervals due to limited periods

of inadequate rain or irrigation during the crops' growing period or terminal when there is progressive decrease in available soil water resulting in severe drought stress at the later period of crop growth at grain-filling stage.

Crop response to water stress at various stages of growth is related to crop species, stage of growth, economic portion of the crop, the duration and intensity of the stress (Shouse, 1979, 1981). Cowpea is reported to be more tolerant to drought (Whitbread and Lawrence, 2006) however, it still suffers considerable damage due to frequent drought in the Savanna and Sahel sub-region. Studies have indicated that cowpea could maintain good seed yield when subjected to drought at vegetative stage provided subsequent conditions were conducive for flowering and pod set (Ziska and Hall, 1983a, b; Singh et al., 1997; Akyeampong, 2012). However, Akyeampong (1986) showed that the crop is highly sensitive to water deficits during flowering and pod filling stages. To this end, early maturing varieties have been developed to escape terminal drought (Singh, 1987) but they have been reported to perform poorly if exposed to intermittent moisture stress occurring at the vegetative growth stage (Mai-Kodomi et al., 1999; Fatokun et al., 2012).

Moreover, these early varieties tend to be sensitive to drought that occurs during the early stages of the reproductive phase (Thiaw et al., 1993). Cowpea is a dual-purpose crop; it is grown for the purpose of green manure as much as for its grains. Early moisture stress that can reduce the quantity of green manure is sometimes unavoidable because cowpea solely grown under this system is terminated at the vegetative (Fabunmi et al., 2012). Therefore, genetic enhancement of cowpea for tolerance to both vegetative and terminal drought will be a most effective method for ensuring sustainable and improved yield under variable and changing climate.

2.3. Impact of drought on agriculture and food security

Agricultural production remains the main source of livelihood for rural communities in Sub-Saharan Africa, providing employment to more than 60% of the population and contributing about 30% of gross domestic product. Agriculture production and productivity are highly sensitive to changes in climate and weather conditions. Therefore, the climatic variability has been implicated in affecting local as well as global food, fiber and forest production (Easterling et al., 2007). Food security in its most basic form is the access of all people to the food needed for a healthy life at all times. It refers to the availability of food and one's access to it. A household is considered food secure when its occupants do not live in hunger or fear of starvation while a country is considered as food-secure when food is not only available in the quantity needed by the population consistent with decent living, but also when the consumption of the food does not pose any health hazard to the citizen. (Baro and Deubel, 2006; Pinstup-Andersen, 2009).

Drought is a naturally occurring phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems (UNCCD, 2011). It can be attributed to inadequate seasonal precipitation, a prolonged dry season or a series of sub-average rainy seasons (Sheikh and Soomro, 2006). In agricultural terms, drought is said to occur when there is not enough moisture available at the right time for the growth and development of crops. It often results from insufficient and/or poor distribution of rainfall when crops are still growing in the field (Nhlane, 2001; Ganapathy and Ganesh, 2008). As a result, yields and/or absolute production decline (Sharfiq-ur-Rehman et al., 2005). Drought is especially problematic in developing countries where agriculture is predominantly rain-fed. It is

considered the most serious threat to world agriculture and food security because it is the main cause of desertification, major cause of severe food shortages resulting in malnutrition and famine (Mir et al., 2012). It therefore affects the four pillars of food security: availability, stability, access and utilization (FAO, 2009).

In the agricultural sector, its effects include: crop losses, lower yields in both crop and livestock production, increased livestock deaths, increases in insect infestation and plant and animal diseases, damage to fish habitat, forest and range fires, desertification and soil erosion. Its impacts on human health include increased risk of food and water shortages, increased risk of malnutrition and higher risk of water- and food-borne diseases. Economic impacts include: income losses, high prices of food products as supplies are reduced, with severe effects on the poorest and most vulnerable. Shortfalls in food production leads to substantial increases in imports to meet local needs, which can result in increased fiscal pressure on national budgets (Oladipo, 2008). Twelve million hectares are lost globally annually (23 hectares/minute), where 20 million tonnes of grain could have been grown as a result of drought and desertification (<http://www.un.org/en/events/desertificationday/background.shtml> accessed 28/10/2014 at 1.15pm). For instance, during the drought of 1972–73 in the northeastern Nigeria about 300,000 animals representing 13% of the livestock population of the region were reported dead, while agricultural yield dropped to between 12% and 40% of the annual averages (Fagbemi, 2002). The effects of drought in terms of reduced food production have been even more severe during 1982 - 84 than 1972 - 74. In some parts of Borno State (then, comprising Borno & Yobe States) nearly 100% crop losses were recorded (Enabor, 1987). Agriculture consumes the largest available water through irrigation and in 2004 it was

reported that 80% of world available water was consumed alone by irrigated agriculture (Condon et al., 2004). With expected increase in world population by 2025 to 9.6 billion, agricultural water consumption will have to decrease which in turn will affect agricultural production and productivity (Ribaut et al., 2009).

2.4. Mechanisms of drought tolerance in plants

Drought is by far the most important environmental stress in agriculture which reduces the productivity of crops (Parameshwarappa and Salimath, 2007; Abdou-Razakou et al., 2013) preventing them from expressing their full genetic potential. Drought stress reduces leaf size, stems extension and root proliferation, disturbs plant water relations and reduces water-use efficiency. Many efforts have been made to improve crop productivity under water-limiting conditions. While natural selection has favoured mechanisms for adaptation and survival, breeding activity has directed selection towards increasing the economic yield of cultivated species. Many years of breeding activities have led to some yield increase in drought environments for many crop plants. Meanwhile, fundamental research has provided significant gains in the understanding of the physiological and molecular responses of plants to water deficits, but there is still a large gap between yields under optimal and stress conditions. Minimizing the ‘yield gap’ and increasing yield stability under different stress conditions are of strategic importance in guaranteeing food for the future.

In agriculture, drought resistance refers to the ability of crops to achieve economic production with minimum loss in water-deficit environments compared to the water-constraint-free management (Mitra, 2001). Nevertheless, direct selection for grain yield

under water-stress conditions has been hampered by low heritability, polygenic control, epistasis, significant genotype by environment (G x E) interaction and quantitative trait loci (QTL) by environment (QTLx E) interaction (Piepho, 2000). The complexity of drought tolerance mechanisms explains the slow progress in yield improvement in drought prone environments. In recent years, crop physiology and genomics have led to new insights in drought tolerance providing breeders with new knowledge and tools for plant improvement (Tuberosa and Salvi, 2006).

The occurrence of morphological and physiological adaptation to drought stress may vary considerably among species. When plants are subjected to drought stress, a number of physiological and morphological responses have been observed and the magnitude of the responses varies among species and between varieties within a crop species (Kramer, 1981).

Different mechanisms may make a plant tolerant to drought such as drought escape, avoidance or drought tolerance. Plants may use more than one mechanism to cope with drought (Ludlow, 1989; Mitra, 2001; Yue et al., 2006). Drought escape is the ability of the plant to complete its life cycle before the onset of serious water deficit (Yue et al., 2006; Bhatnagar-Mathur et al., 2010). This mechanism involves rapid phenological development (early flowering, early podding and early maturity) (Gaur et al., 2008). Although studies have revealed that there is yield penalty for any reduction of crop maturity duration below the optimum (Caliskan et al., 2008), selection for earliness is still a common practice in breeding crops for drought tolerance because early cultivars provide quick income at the beginning of cropping season; they can be grown in diverse cropping systems and they can escape some insect infestation (Ehlers and Hall, 1997).

Drought avoidance is plants' capacity to sustain high plant water status or cellular hydration under the effects of drought (Blum, 2005). Under this mechanism, plants minimize water loss through stomata closing and lenticular conductance (Chaves et al., 2003), reducing absorption of solar radiation through leaf rolling or folding/paraheliotropism (Fatokun et al., 2012) and reducing evapotranspiration surface (leaf area) and development of dense trichome layer that increases reflectance (Yue et al., 2006; Taiz and Zeiger, 2006). They maximize water uptake through increase of the capacity of the root system (Jackson et al., 2000) and root characteristics such as thickness, depth, length and density e.g. in rice (Ekanayake et al., 1985). This mechanism has effects on the effective water use and control of evapotranspiration.

Drought tolerance is the ability of plants to withstand water-deficit with low tissue water potential. The mechanism involves maintenance of turgor through osmotic adjustment (accumulation of solutes in the cell), increased cell elasticity and decreased cell size, production of other stress relieving agents and desiccation tolerance by protoplasmic resistance (Agbicodo et al., 2010). It involves the resurrection and survival of genotypes after extended and intense internal water deficit. These genotypes can be still alive when there is 95% of leaf water loss (Scott et al., 2000). Dehydration tolerance enables the plants to survive a long and harsh periods of water deficit and regrow when rain falls. It allows also plants to maintain metabolic activities longer and transport assimilates to the storage tissues (Fukai and Cooper, 1995). Biochemical processes which involve accumulation of compatible solutes mainly nitrogen compounds, result in dehydration avoidance in plants (McCue and Hanson, 1990). Plants contain these solutes and antioxidants at varying levels and in different types. These solutes work together with antioxidants which intervene to

eliminate reactive oxygen species (ROS) and to repair their damages; adaptive role by osmotic adjustment and protection of cellular compounds; control the equilibrium between the production and the elimination of free radicals (McCue and Hanson, 1990; Lin et al., 2006; Brosché et al., 2010). Crop varieties that are drought resistant or tolerant express a higher quantity of antioxidants than sensitive varieties (Herbinger et al., 2002). Although the quality and quantity of these molecules are crop species dependent, their expression is affected by environmental conditions (Blokchina et al., 2003; Lin et al., 2006). Understanding the expression, mechanisms and mode of functioning of these molecules will help to identify and develop tolerant crop varieties and improve cowpea productivity in dry lands.

2.4.1 Consequences of drought adaptation mechanisms in plants

Reitz (1974) classified plants into three based on their responses to drought stress: (i) those with superior yield across diverse production environments (ii) those with better yield performance in stress environments (iii) those with better performance under optimum environment (Reitz, 1974). Breeders are interested in the first category because they are stable and will have better performance across diverse environments. It has been reported that plants adopt more than one mechanism at a time to cope with moisture deficit (Mitra, 2001; Yue et al., 2006). However, none of these adaptations exists without its undesirable consequences on the plants' growth and productivity (Larcher, 2000; Acquah, 2012). For instance, escape adaptation characterized by short life cycle; these genotypes usually yield less compared to the genotypes that attain normal maturity cycle. On the contrary, if these genotypes are exposed to intermittent water stress at the vegetative period they perform

very poorly (Muchero et al., 2008). Avoidance adaptation such as stomata closure and reduced leaf area decrease carbon assimilation due to reduction in physical transfer of carbon dioxide molecules and increase leaf temperature thus reducing biochemical processes which negatively affects yield (Lawlor and Tezara, 2009). Dehydration tolerance with the accumulation of compatible solutes, the synthesis of antioxidants and the process of ROS scavenging depletes assimilates and energy.

Consequently, these mechanisms reduce the ability of crop genotypes to synthesize organic end-products (Mitra, 2001). It is therefore important to focus on the type of drought prevalent in the target environment when incorporating drought tolerance mechanisms into improved cultivar and breeding for drought tolerance should combine a balance among escape, avoidance and tolerance while maintaining good productivity (Mitra, 2001).

2.5 Mechanisms of drought tolerance in cowpea

Cowpea is inherently more tolerant to drought than other crops which is why it is cultivated in low-rainfall areas with annual rainfall less than 400 mm (Fatokun et al., 2012). Early maturing cowpea cultivars are better adapted in many cowpea production zones of Africa than late maturing ones in some dry environments because they reach maturity in as few as 60-70 days (Singh, 1994). IT84S-2246 and Bambey 21 are examples of early cowpea cultivars already released and adopted by farmers, they however perform poorly under intermittent drought at the vegetative or reproductive stages. Late maturing fodder-type varieties planted as sole crops or relay intercrops on the other hand may suffer severe drought stress due to early cessation of rains. Efforts now are being geared towards

breeding cowpea varieties with enhanced drought tolerance for early-, mid- and terminal-season drought stresses (Watanabe et al., 1995).

Two types of drought tolerance have been described in cowpea at the seedling stage using the wooden box technique (Mai-Kodomi et al., 1999). At fifteen days after termination of water supply, the “Type 1” drought tolerant genotypes stopped growth after the onset of drought stress and maintained uniformity, but displayed a declining turgidity in all tissues of the plants including the unifoliates and the emerging tiny trifoliates for over 2 weeks and death of all plant parts such as the growing tip, unifoliates and epicotyl gradually almost at the same time. Suggested mechanism for type 1 was drought avoidance with the display of closure of stomata to reduced water loss through transpiration and cessation of growth was suggested for this type of tolerance (Lawan, 1983; Boyer, 1996). On the contrary, the “Type 2” drought tolerant lines remained green for a longer time and continued slow growth of the trifoliates under drought stress. With continued moisture stress, the trifoliates of these varieties started wilting as well and died about 4 weeks after drought stress started. Three combinations of mechanisms were suggested to interplay in the type 2: stomatal regulation (partial opening), osmotic control and selective mobilization with distinct visible differences in the desiccation of lower leaves compared to the upper leaves and growing tips (Mai-Kodomi, 1999; Muchero et al., 2008).

Association between crop performance carbon isotope discrimination (Δ) was reviewed for cowpea, common bean and peanut (Condon and Hall, 1997). The authors positively related the differences in the grain yield with Δ , indicating that more productive genotypes have a higher photosynthesis rate resulting in higher internal carbon dioxide concentration in their leaves. Similarly, studies on Pima cotton (*Gossypium barbadense*) and bread wheat (*Triticum aestivum*) showed a positive correlation between yield increases and increases in stomata conductance (Lu et al., 1998). These authors argued that the higher Δ in more productive genotypes of cowpea, cotton and wheat was probably due to their having more open stomata which could have resulted in greater rates of photosynthesis effects (Condon and Hall, 1997), or beneficial effects on the plant resulting from greater evaporative cooling (Lu et al., 1998). Cruz de Carvalho et al. (1998) in his study to compare physiological responses of cowpea and common bean reported that cowpea genotypes kept their stomata partially opened and thus had a lower decrease in their net photosynthetic rates than the common bean. Further study was therefore recommended in order to demonstrate whether partial opening of stomata under drought conditions would have significant effects on grain yield

Ability to maintain low water potential of about -18 bar (-1.8 MPa) has been reported as a mechanism through which cowpea is able to withstand vegetative-stage drought stress even under extreme drought (Turk and Hall 1980; Hall and Schulze 1980). This mechanism has also been reported in peanut with as low as -82bar (-8.2Mpa) (Turner, 2000). Cowpea leaves under drought stress display paraheliotropism, a drought avoidance mechanism where the leaves are orientated parallel to the sun rays in order to reduce evapotranspiration (Fatokun et al., 2012).

Cowpea displays tolerance mechanism by exhibiting delayed leaf senescence (DLSC) which is similar to the stay-green characteristics in cereals such as (Gwathmey and Hall 1992; Hall et al., 1997). Their studies revealed that cowpea plants that exhibit DLSC trait were able to survive the mid-season drought caused by intermittent rainfall and were able to produce second flush of pods for additional grain yield (Hall et al., 2003). Drought can occur at the onset of the growing season in which rainfall ceases after planting; or during mid-season before the plants flower or during the reproductive to the pod-filling stage. While early maturity is a drought escape mechanism, drought tolerance at seedling stage and DLSC will enhance the plants' ability to survive drought during early and mid-season and at pod filling stages. It has been reported in sorghum, that genotypes with DLSC (stay green) are able to remain physiologically active during the late stages of grain filling under terminal drought (van Oosterom et al., 1996).

Ziska et al. (1985) reported that in cowpea, grain yield is strongly dependent upon the water available to the plant during the reproductive stage for pod-filling. A detailed study by Belko et al. (2012) on water-saving traits in cowpea observed that traits such as lower early vigour, lower transpiration rate under well-watered conditions during vegetative stage, lower leaf area development, sustained transpiration until soil was drier and lower canopy conductance under high vapour pressure deficit (VPD) conditions discriminated drought tolerant from susceptible cowpea genotypes. Similar results were observed in pearl millet (Kholova et al., 2010) and chickpea (Zaman-Allah et al., 2011). They reported that these genotypes will be desirable in low humidity environments with high atmospheric VPD, limited available water, and where water deficits commonly develop later in the growing season.

Limited progress is still recorded so far in increasing drought tolerance in cowpea because (1) the basis for drought tolerance in cowpea is yet to be well established and (2) information on combining abilities of tolerant genotypes that can be hybridized together in order to be able to produce drought tolerant segregating populations on which breeders can make efficient selection is still limited.

2.6 Advances in conventional breeding for drought tolerance in cowpea

Although conventional approach for breeding for drought tolerance is challenging because the occurrence of drought over time and space is unpredictable, breeding drought tolerant crops still remains the most viable and economical strategy to improve productivity under drought conditions (Blum, 2005; Carena et al., 2009).

2.6.1 Tolerance to vegetative stage drought

Survival of vegetative-stage drought by cowpeas has been associated with the maintenance of higher leaf water status than pearl millet (Petrie and Hall, 1992a, b, c). Cowpeas also have stomata that are very sensitive to soil drying, partially closing before any changes in leaf water potential are detected (Bates and Hall, 1981). When cowpea plants are subjected to drought under field conditions, their leaves do not usually wilt but tend to orient more vertically, tracking the sun in a manner that minimizes the interception of solar radiation (Shackel and Hall, 1979). These mechanisms contribute to the unique ability of cowpeas to survive extreme vegetative-stage droughts that kill most other crop plants.

Screening technique for survival under drought at the seedling stage has been developed that uses a shallow soil layer in boxes (Singh and Matsui, 2002). This method eliminates

the influences of the root system on drought tolerance, and permits nondestructive visual identification of shoot dehydration tolerance (Singh et al., 1999a, b). Wooden box, field and pot testing of different cowpea varieties demonstrated a close correspondence between drought tolerance at the seedling stage and reproductive stage (Singh and Matsui, 2002). These authors concluded that the wooden box technique was a faster way of identifying tolerant varieties which can be saved and transplanted for further progeny testing and selection.

Muchero et al. (2008) reported stem greenness, survival and recovery dry weights as the most reliable greenhouse-based assayable traits in separating tolerant cowpea genotypes from susceptible genotypes. Breeding strategies that involve selection for early and extra-early cowpea varieties to escape terminal drought have been exploited by cowpea breeders for some years. Early variety “Ein El Gazal” bred and released in UC-Riverside by crossing an erect early California cultivar that had tolerance to vegetative stage drought with an erect line from Senegal performed very well across different environments (Hall and Patel, 1985). “Melakh”, an extra-early cowpea variety which has resistance to two seed-borne diseases: cowpea aphid, and partial resistance to flower thrip was released in Senegal (Cisse et al., 1997) and “Vuli-1” and early variety was bred for cultivation during the short rains in Tanzania (Mligo and Singh, 2007).

Although these varieties can survive vegetative-stage droughts and produce significant quantities of grains under very short rainy season, they produce little hay and can be devastated by mid-season drought (Thiaw et al., 1993) and some biotic stresses. Two conditions have been identified that can render vegetative drought tolerance ineffective namely: condition where *Macrophomina phaseolina* organism that causes ashy stem blight

disease of cowpea is present in the soil and the presence of the lesser corn stalk borer (*Elasmopalpus lignosellus*) (Hall, 2012). It is important to incorporate resistance to these pests in cowpea varieties that are being bred for drought tolerance at the vegetative-stage.

2.6.2 Tolerance to mid-season drought

Many approaches have been taken to breed cowpea varieties for tolerance to mid-season drought compared to the extra-early cultivars because these varieties are dual purpose; producing significant hay and grains. The variety “Mouride” combines high yield with tolerance to mid-season drought and resistance to *Striga gesnerioides* and cowpea weevil was released in Senegal (Cisse et al., 1995). A delayed-leaf-senescence (DLSC) trait has been discovered that enables cowpeas to maintain a green canopy after the first flush of pods is mature and more consistently produce a second flush of flowers and pods (Gwathmey et al., 1992a). When genotypes with this trait were subjected to a mid-season drought during the first flowering period, they had the ability to survive and then produce second flush of pods and grain (Gwathmey and Hall, 1992a). The mechanism of the DLSC trait is complex. It results in the accumulation of greater reserves of carbohydrates in the base of the stem (Gwathmey et al., 1992b) and probably also in the roots. DLSC is strongly expressed when *Fusarium solani* f. sp. *phaseoli* a soil borne fungus which causes the senescence of cowpea during pod maturation is present in the soil. Presumably, roots with greater carbohydrate reserves are more resistant to this root rotting organism (Hall, 2012). Irrespective of the complexity of the trait, it has been consistently expressed by plants in soils where cowpeas have been grown in rotations for several years in many locations in California and also at Bambey in Senegal. DLSC dual purpose cowpea cultivars have been

developed and released (Dingkhun et al., 2006). DLSC has been reported to be a useful indirect selection criterion in breeding for post-flowering drought tolerance in crops (Rosenow et al., 1983). The relatively high heritability, low genotype by environment (GxE) interactions in cowpea could enable its successful incorporation in improved varieties (Hall et al., 1997; Ismail et al., 2000).

Root systems cannot be overlooked because it is through them that the plant obtains its water and mineral requirements for growth and unavailability of these resources often impose limit on productivity. Screening for root characteristics confirming drought tolerance have been studied in cowpea using the ‘pin-board root-box’ (Matsui and Singh 2003), herbicidal band screening (Robertson et al., 1985; Khalfaoui and Havard, 1993) and polyethylene glycol (PEG) (Badiane et al., 2004) methods. However, ‘pin-board root-box’ is not as widely accepted as the wooden box technique for vegetative screening probably because it is not practical for screening large numbers of plants (Matsui and Singh, 2003). Limited progress has been made on root system and drought tolerance in cowpea perhaps because some studies have reported that deeper and larger root systems may not be of additional advantage for the areas of cowpea production that are characterized by sandy soils with only about 8% of soil water and secondly, possession of larger roots require additional carbohydrates and energy for their construction and maintenance (Hall et al., 2012). Studies have, however, been more directed towards the water saving traits in cowpea (Belko et al., 2013); pearl millet (Kholova et al., 2010) at the vegetative growth stage which helps the crop to retain water in the soil profile to support plant growth at pod-filling stage. No root characteristics for drought tolerance were studied in the work.

2.6.3 Adaptive traits for drought tolerance in cowpea

Breeding improved genotypes for the arid and semiarid tropics by selection solely for seed yield is difficult, because of the variability in amount and temporal distribution of available moisture from year to year. The relatively low heritability for grain yield under drought conditions has resulted in the use of other efficient traits that are indirectly related to grain yield (Omae et al., 2007; Singh et al., 2004, 2007; Sharma et al., 2007). These traits are referred to as secondary traits and are highly heritable, cheap and easy to measure thus making selection for drought tolerance easier and faster.

In cowpea, traits such as stem greenness at vegetative stage (Muchero et al., 2008) or DLSC (during pod-filling) stage (Fatokun et al., 2012); number of pods and seeds per plant (Ajibade and Morakinyo, 2000) are frequently used as secondary traits to identify tolerant genotypes under water limited conditions. Recently, precision phenotyping for drought tolerance using more sophisticated instruments (Mir et al., 2012) that can give accurate measurement of the health of green tissues of plants are now being employed to complement visual scoring for the stay green trait which though convenient is subjective (Joshi et al., 2007). The instruments provide measurements of the normalized difference vegetation index (NDVI) of the crop growing under stress. NDVI is a mathematical formula derived to form a single spectral-based number, which is more sensitive than just a single wavelength and it is a measure of greenness (Sembiring et al. 2000; Hazratkulova et al., 2012).

2.6.3.1 Stem greenness or Delayed leaf Senescence

Maintenance of green stem was shown to be an important criterion for seedling stage drought tolerance in cowpea (Muchero et al., 2008) while maintenance of DLSC trait has been shown to be important for mid-season and terminal drought tolerance in cowpea (Fatokun et al., 2012). Studies have demonstrated a link between late-season DLSC, a trait similar to ‘stay-green’ in cereals and grain yield in cowpea (Gwathmey, 1992a, b). Recent studies have also described field and greenhouse protocols to screen for DLSC at seedling stage in cowpea (Mai-Kodomi, 1999; Muchero et al., 2008; Muchero et al., 2009). Plants exhibiting this phenotype are characterized by maintenance of green leaf area under drought stress. It is believed that the maintenance of green leaf area contributes to continued carbohydrate formation during drought and faster recovery following a rainfall event (Borrell et al., 2000). Therefore, selection for DLSC in cowpea genotypes allows more photosynthates to be synthesized and distributed leading to production of higher yields.

2.6.3.2 Number of pods per plant and number of seeds per pod

In cowpea, variations in yield due to environmental stresses were mainly due to variations in number of pods per unit area but drought occurring at pod-filling stage reduced the number of pods per plant and poor pod-filling (Turk et al., 1980; Bala Subramanian and Maheswari 1992). Decrease in number of pods per plant is mainly due to the abscission of flowers and pods of cowpea under drought stress. This detrimental effect at flowering and pod-filling stage is rather not reversible by re-watering (Ziska et al., 1985). Higher number

of pods per plant and seeds per pod and good pod-filling (big seed size) is therefore a reflection of tolerance to drought (Gwathmey et al., 1992a).

2.6.3.3 Normalized Difference Vegetation Index (NDVI)

NDVI which measures leaf greenness (chlorophyll content) is considered to be correlated with crop productivity under abiotic stress. NDVI has been used in drought improvement for drought tolerance (Hazratkulova et al., 2012); maize for drought tolerance (Adebayo et al., 2014). This may also be useful in cowpea improvement for drought tolerance. Because NDVI is a measure of chlorophyll content in leaves (Hu et al., 2010), maintaining higher NDVI longer during pod-filling would contribute to grain development through photosynthesis. Hence, maintaining higher NDVI under stress, such as terminal drought occurring during pod-filling in the semi-arid regions of SSA could be considered a sign of stress tolerance with potential use in cowpea germplasm screening (Hazratkulova et al., 2012).

2.6.4 Drought tolerance genes in cowpea

Candidate gene approach and differential expression of mRNA has been used in cowpea to identify genes that are involved in the drought response. Iuchi et al. (1996) isolated 24 cDNA clones that corresponded to dehydration-induced genes from cowpea variety IT84S-2246-4 by a differential screening method. The cDNA clones represented ten different genes collectively named cowpea clones responsive to dehydration (CPRD). Nine of the CPRD genes were induced by drought. Two additional novel drought-inducible genes were reported from the same cowpea variety (IT84S-2246-4) by Iuchi et al. (2000). Drought-stressed cowpea plants accumulated ABA to a level that was 160 times higher than that in

unstressed plants. The regulation of protein degradation through the use of protease-specific inhibitors is a common mechanism in metabolic processes and adaptive processes, including adaptation to drought stress in cowpea (Fernandes et al., 1993; Diop et al., 2004). Expression of the cowpea cystatin gene was studied at the mRNA and protein levels, using Northern blot and Western blot analysis (Diop et al., 2004). In cowpea seeds, multiple minor cystatin-like polypeptides were identified in addition to the major cystatin-like polypeptides of 25 kDa (Flores et al., 2001). Water deficit usually triggered by drought and desiccation is known to induce the production of reactive oxygen species (ROS). Among these, H_2O_2 is produced mainly in the chloroplasts and mitochondria of stressed cells and is the source of major cell damage (Foyer et al., 1994; Dat et al., 2000). Recently, sequencing and analysis of the gene-rich, hypo-methylated portion of the cowpea genome has been initiated (Timko et al., 2008). Over 250,000 gene-space sequence reads (GSRs) with an average length of 610 bp were generated from 183,000 expressed sequence tags (EST) developed at University of California Riverside (UCR). Sixty-two (62) out of Sixty-four (64) well characterized plant transcription factor (TF) gene families are represented in the cowpea GSRs. The generated GSRs may provide a source for functional markers in genes linked to drought tolerance traits in cowpea which could be used for marker-assisted selection.

2.6.5 Molecular breeding for drought tolerance in cowpea

Most agronomically important traits are quantitatively inherited. Improvement of these traits through marker assisted breeding would have the greatest impact because traditional plant breeding for quantitative traits is usually slow and difficult. Marker assisted selection

could potentially improve selection of traits that have low heritability by using markers with high heritability (Chapman et al., 2003). The use of molecular markers in plant breeding for indirect selection of agronomically important traits can have an impact on the efficiency of plant breeding systems. Some aspects of plant breeding that can be improved by use of molecular markers include: identification and elimination of undesirable individuals in the early stages of selection, identification of individuals prior to flowering that will be useful to transfer genes governing the favourable expression of quantitative traits, accelerating generations of new varieties, especially for traits that are difficult to score and facilitation of selection for several traits simultaneously (Allen, 1994; Bharadwaj et al., 2011).

Selection of traits by molecular markers is based on molecular marker(s) tightly linked to the trait of interest, unlike direct selection of traits in conventional breeding which is based on visual observation. The selection can be beneficial when the genotype x environment interaction is significant but marker x environment interaction is not significant, allowing a stable selection of genotype (Chapman et al., 2003). Molecular breeding (genomics-assisted breeding) uses several modern breeding strategies such as marker assisted selection (MAS) and genomics selection (GS) (Varshney et al., 2005). Marker assisted selection includes marker assisted backcrossing (MABC), marker assisted recurrent selection (MARS) and most currently genome-wide selection (GWS) (Ribaut et al., 2010). Molecular markers serve as efficient and powerful tools for MAS of agronomically important traits (Bharadwaj et al., 2011) and also in biotic and abiotic tolerance traits. Marker-enhanced breeding helps breeders to discriminate genotypes directly and offers a great opportunity for developing drought tolerant varieties (Xiao et al., 2005; Romano et

al., 2011). Complex traits such as drought tolerance can be analyzed as Mendelian factors with molecular markers (Paterson et al., 1988). Many DNA-based molecular marker technologies can now be accessed for constructing dense genetic maps for any crop species (Quarrie et al., 1999). Hence, molecular mapping and genomics techniques present unique opportunities for dissecting major genes and quantitative trait loci (QTL). Drought is controlled by multiple genes, hence, is a quantitative trait. Regions within genomes that contain genes associated with a particular quantitative trait are known as quantitative trait loci (QTL) (Collard et al., 2005). QTL could be detected by employing molecular markers in genetic linkage analysis, i.e. QTL mapping. With the help of molecular markers linked to QTL, the heredity of some related QTL could be tracked and the ability of genetic manipulation of the QTL is greatly enhanced, thus improving the accuracy and predictability to select genotypes with superior quantitative traits.

2.7 Quantitative trait loci (QTL) mapping in cowpea

QTL analysis as applied to plant breeding typically involves a two steps process. First step is QTL discovery. Parental lines are identified which differ for one or more quantitative traits of agronomic importance. The parents are hybridized and a segregating population(s) is created in which markers can be used to identify linked QTL. The second step is to utilize knowledge of QTL map locations to create a superior variety using appropriate breeding methods (Tanksley and Nelson, 1996; Bernardo, 2008; Lucas et al., 2013). Varshney et al. (2012) have suggested that for successful introgression of QTL in elite breeding materials or varieties, the targeted QTL should be major QTL that contribute >20% phenotypic variation.

In cowpea, many researchers have utilized different genetic maps based on molecular markers to locate many QTL associated with cowpea yield and other traits. Andargie et al. (2011) identified the QTL of cowpea agronomic traits related to domestication (seed weight, pod shattering) by SSR markers. Six QTL for seed size were revealed with phenotypic variation ranging from 8.9%-19.1%. Four QTL for pod shattering were identified with phenotypic variation ranging from 6.4%-17.2%. The QTL for seed size and pod shattering mainly clustered in two areas of LGs 1 and 10. QTL associated with seed size were revealed with phenotypic variation ranging from 8.9%-19.1%. One major and six minor QTL were identified for pod length variation between yard-long bean and wild cowpea (Kongjaimun et al., 2012). Agbicodo et al. (2010) used a SNP (single nucleotide polymorphism) genetic map with 282 SNP markers constructed from the recombinant inbred line (RIL) population to perform QTL analysis. Three QTL, CoBB-1, CoBB-2 and CoBB-3 were identified on linkage group LG3, LG5 and LG9, respectively explaining between 4.3-22.1% of the phenotypic variation.

QTL for *Macrophomina phaseolina* resistance and maturity in cowpea with SNP markers were identified by Muchero et al. (2011). QTL for resistance to *Thrips tabaci* and *Frankliniella schultzei* based on an amplified fragment length polymorphism (AFLP) genetic linkage map were mapped on LG 5 and 7 accounting for between 9.1% and 32.1% of the phenotypic variance respectively (Muchero et al., 2010). QTL associated with tolerance to flower bud thrips (*Megalurothrips sjostedti*) was detected in five LGs of RILs. The QTL together explained 77.5% of the phenotypic variance (Omo-Ikerodah et al., 2008). In a study on leaf morphology, QTL for leaf shape, Hls (hastate leaf shape) locus accounting for 71.5% -74.7% phenotypic variance for greenhouse and field conditions

respectively was identified on linkage group (LG) 4 using SNP markers (Portoff et al., 2012). Muchero et al. (2009) reported the mapping of 12 QTL associated with seedling drought tolerance and maturity in a cowpea RIL population. Regions harboring drought-related QTL were observed on linkage groups 1, 2, 3, 5, 6, 7, 9, and 10 accounting for between 4.7% and 24.2% of the phenotypic variance. Two more QTL for maturity were mapped on linkage groups 7 and 8 separately from drought-related QTL. The main application of QTL identification in breeding is to aid conventional method for selection and subsequently reduce time taken to release improved lines. It is therefore important to introgress identified QTL into elite germplasm through the use of appropriate breeding methods to develop improved varieties (Bernardo, 2008). In a study to breed cowpea varieties with large seeds, QTL C_{ss}-1 from an African buff seed type cultivar, IT82E18 (18.5g/100seeds), into a black eye seed type cultivar, CB27 (22g/100seed) was successfully introgressed with the goal of stacking large seed haplotypes into a CB 27 background. Results of the field performance trials identified breeding lines with large seeds and desirable traits such as yield, maturity and plant architecture (Lucas et al., 2013, 2015).

2.7 Genetics of drought tolerance in cowpea

Understanding the nature of genes controlling a specific trait of interest is the baseline of any breeding programme. Genetic information regarding the gene effects and magnitude of gene action controlling such traits must be determined and well understood (Hinkossa et al., 2013). Traits like drought and yield are polygenically controlled and affected by environmental factors which are not transmissible from parents to offspring. It is therefore

important to determine the genetic factors affecting these traits for an efficient breeding programme.

There are three types of gene effects i.e. additive, dominance and epistatic (Gamble, 1961). The dominance and epistatic constitute the non-additive part. The dominance can either be ambidirectional, a situation of positive and negative dominance at different gene loci or unidirectional, dominance in one direction (Kearsey and Pooni, 1998). Epistasis refers to interaction of alleles at different loci. Epistatic gene action occurs when the additive-dominance model cannot explain variation alone (Derera, 2005). The additive gene effects reflect the degree to which progenies are likely to resemble their parents, as reflected in narrow-sense heritability (Derera, 2005).

Estimation of the relative proportion of additive genetic effects (or general combining ability of a line, GCA) and non-additive genetic effects (or specific combining ability of a cross, SCA) controlling the drought-adaptive traits and their interactions with the environment is useful for designing breeding programmes and assembling germplasm for population advancement (Shahi and Singh, 1985). Information on the GCA and SCA of parents is helpful in the analysis and interpretation of the genetic basis underlying inheritance pattern of the trait of interest. It estimates the average performance of a line in series of hybrid combination (GCA) and the contribution of a line to hybrid performance in a cross with a specific other line in relation to its contribution in crosses with an array of other lines (SCA) (Ogunbodede et al., 2000; Rajani *et al.*, 2001; Acquaaah, 2012). Alidu et al. (2013) reported a significant GCA effect for cowpea grain yield under drought stress suggesting that yield under drought can be improved by exploiting the preponderance of additive gene effects. In the study on combining ability for pod and seed traits in cowpea,

Ayo-Vaughan et al. (2013) reported that additive gene effects significantly controlled number of pods per plant, pod length, seeds per pod and 100-seed weight.

In self-pollinating crops such as cowpea, ability to accurately identify parental combinations which will generate superior pure lines for farmers' adoption is very crucial to the success of the breeding programme. For this reason, many studies have been devoted to developing and evaluating methods of predicting cross potential in early generations (Thurling and Ratinam, 1987). Selection of suitable parents and proper choice of good mating designs are important to successful plant breeding schemes depending on the objectives of the study, time, space, cost and other biological limitations (Khan et al., 2009; Acquah, 2012; Nduwumuremy et al., 2013).

Mating design refers to the procedure of producing the progenies on which further selection is carried out. Breeders and geneticists theoretically and practically use different types of mating designs and arrangements for targeted purposes. The mating designs have four main uses: (1) to provide information on the genetic control of the character under investigation; (2) to generate a breeding populations to be used as a basis for the selection and development of potential varieties; (3) to provide estimates of genetic gain and (4) to provide information for evaluating the parents used in the breeding programme (Acquaah, 2012; Nduwumuremyi et al., 2013). Combining ability depends on the gene action controlling the trait to be improved. General combining ability (GCA) is the average performance of a line in hybrid combinations and is due to additive gene action. The estimation of GCA for a particular line depends upon the mating design, but essentially, it is the deviation of its progeny mean from the mean of all lines included in the trial (Acquaah, 2012). There is no and/or limited information on the combining ability of lines

that have been used in previous cowpea breeding programmes in IITA for the development of drought tolerant lines. This may in a way have contributed to the slow progress that has been recorded in enhancing the drought tolerance level of the improved cowpea varieties.

2.8 Participatory Rural Appraisal (PRA)

Farmer participatory research in agriculture is a systematic dialogue between farmers and scientists to solve agricultural problems. Farmers will choose varieties that overcome their challenges and meet their needs. Several instances exist where huge investments have been made to develop improved agricultural technologies that were not eventually adopted by the target population (Emad, 1995; Becker et al., 1995; Kormawa et al., 1999). Many such situations have often been associated with technologies developed using the top bottom approach, characterized by the involvement of the target population only when the development of the technology has been finalized by scientists and would not normally involve the farmers. Involving farmers from the beginning in breeding programme engages method such as participatory rural appraisal (PRA) in order to identify their needs and preferences, to develop a programme together with them that will suit their needs and hence encourage their adoption (Bellon, 2001). Developed and tested methods of PRA studies include: participatory mapping and modeling transect walks, matrix scoring, well-being grouping and ranking, institutional diagramming, seasonal calendars, trend and change analysis and analytical diagramming all undertaken by local people (Chambers, 1994). Other methods of involving farmers at other breeding stages include: participatory plant breeding (PPB) and participatory variety selection (PVS) (Kiiza et al., 2012).

Participatory Rural Appraisal (PRA) started in the late 1980s and spread at an astonishing pace across the world over the course of the 1990s (Cornwall and Pratt, 2010). If

participatory techniques are appropriately employed in plant breeding they can have an impact by quickly and cost-effectively producing much-improved crop varieties. These varieties may be for resource-poor farmers in marginal environments who previously were entirely dependent on landraces (Virk et al., 2003; Witcombe et al., 2003) or for farmers in more productive environments where they were dependent on very old improved varieties (Witcombe et al., 2001). The aim of involving farmers in plant breeding activity is to empower farmers develop their skills and knowledge of using crop genetic diversity and processes of maintaining and exchanging varieties (Witcombe et al., 2006).

Farmers' knowledge about the crops in their areas has a high potential to strengthen participatory varietal selection (PVS) / participatory plant breeding (PPB) programs. It would serve well to empower scientists' knowledge for designing site, - crop- and farmer-gender - specific activity. Since the adoption of the PRA technique in Nigeria, many PRAs have been conducted both in animal and crop production. PRA conducted on Bambara groundnut production in Nigeria labour and lack of finance ranked the highest considerations for constraints to production (Alhassan and Egbe, 2013). Kamara et al. (2006) identified variation in the preferred choices of farmers for improved maize varieties. He observed that in the market-driven production systems in the communities in Borno State, earliness and high yield were preferred while in resource-poor sorghum-based production systems in Kano State; extra-earliness was preferred over high yield because it provided food security during the food scarcity period. In Malawi, findings from PRA and PVS studies were used by breeders to select and release six elite cowpea accessions (Nkogolo et al., 2009) that are still being grown in Malawi because these varieties were well adapted to their environment and also met the need of the different farmer gender

groups and consumers in the country (Nkongolo et al., 2009). In Benin, sustainable integrated pest management technologies were developed with cowpea farmers using a participatory approach to identify the biotic constraints they experienced in cowpea production (Kossou et al., 2001). Even within the same locality, farmers' preferences regarding which cowpea variety to plant may differ as a result of wealth class, gender, farming systems and other livelihood factors. It is therefore appropriate to obtain information on these factors before setting up an improvement programme. This understanding will help breeders develop varieties that will be acceptable by all categories of farmers.

PRA was conducted among cowpea farmers in four local government areas of Kano State, Nigeria. This study was carried out in order to identify farmers' information on the impact of drought on cowpea production its productivity and to identify their preferred traits in new drought tolerant varieties.

CHAPTER THREE

3.0 Participatory rural appraisal in cowpea growing areas in Kano State, Nigeria

3.1 Introduction

Cowpea has the potential to make a significant contribution to food and nutritional security and poverty reduction in Sub-Saharan Africa (SSA) as it provides nutritious grain and a less expensive source of protein for both the rural poor and urban consumers (Coulibaly and Lowenberg-Deboer, 2002). In addition to food for humans, it is a valuable source of livestock fodder (Singh et al., 2003) making it very attractive to farmers. As a leguminous crop, cowpea improves soil fertility through its ability to fix atmospheric nitrogen (Sanginga et al., 2000). Although the production trend of cowpea shows a significant increase of 410% in production, this has resulted mainly from 440% increase in land area planted (Ortiz, 1998). The challenges of meeting the rapidly growing food needs of SSA cannot be successfully overcome without due consideration of the capacity and limitations of the natural environment which include land tenure system and increasing evidence of climate change (Abaje et al., 2014).

Kano State in Nigeria is located in the Sudano-Sahelian Ecological Zone (SSEZ). This zone suffers from seasonal and inter-annual climatic variability. There have been droughts and effective desertification processes, particularly since the 1960s (FRN, 2005) in this zone. The Sahelian droughts of the 1970s and the 1980s that ravaged this zone left farmers impoverished (Ati et al., 2007). Frequent occurrences of drought in this zone (Alatise and Ikumawoyi, 2007) and increase in human population (FRN, 2005) have been implicated as part of the factors for the low quality of living among the people of the zone who are mostly farmers.

Effects of drought on cowpea include impaired germination and poor plant establishment (Harris et al., 2002; Kaya et al., 2006) if it occurs at the seedling stage, reduced flowers (Kawakami et al., 2006), small seed size (Samarah, 2005) and poor pod filling (Ogbonnaya et al., 2003) if mid-season or terminal droughts are experienced.

Since rain has become less reliable and growing seasons shorter, development and release of cowpea varieties that tolerate drought that can occur at any period within the growing season is inevitable. However, it is important that these improved varieties meet farmers' preferences in order to facilitate adoption. This therefore means that farmers' preferences must be included in the drought tolerant varieties. According to Jallela (2007), generating new technology alone does not provide solutions to help farmers increase agricultural productivity. Despite the efforts of national and international development organizations, low adoption of technology and concomitant low agricultural productivity are still major concerns. One cause of low adoption of new technology appears to be that new innovations from researchers don't address the constraints of the smallholder farmers as well as being inappropriate to their physical, cultural and economic environment (Jones, 2000; Mulatu and Beleke, 2001). According to Ceccarelli et al. (2001), these factors clearly highlight the need to involve farmers at a very early stage through to the advanced stages of varietal selection.

By responding closely to farmers' concerns and conditions, researchers can develop technologies that are adopted more widely and that respond to important social issues such as equity and sustainability (Bellon, 2001; Chambers, 1994). Their participation in breeding can be achieved in various ways namely: farmer field schools (FFS), participatory plant breeding (PPB), participatory varietal development (PVD), farmer participatory

varietal selection (FPVS), participatory research and extension (PRE) and participatory rural appraisal (PRA) among others. The use of any of these approaches has been reported to help reduce possibility of developing varieties or technologies that do not meet farmers' needs (Ellis-Jones et al., 2004, Kiiza et al., 2012). PRE was used in the three agro-ecological zones in the northern Nigeria to encourage farmers to test new IITA-bred cowpea varieties, to identify well adapted varieties for their conditions and to promote adoption (Kamara et al., 2010). In the study based on improving productivities of cowpea-cereal systems in the savannas of West Africa, farmers participated in selecting for seed type and plant type and the combination of the two traits (Ajeigbe et al., 2010b).

In Southern Guinea Savanna of Nigeria, labour and lack of finance ranked the highest consideration by farmers as constraints to the production of Bambara groundnut (Alhassan and Egbe, 2013). Another survey conducted among cowpea farmers in Upper East region of Ghana on farmers' knowledge and cultivation of cowpea showed that insect pests were the major constraints to production and the land tenure system of cowpea which involved its cultivation on small areas of land (Akpalu et al., 2014). In another study on the on-farm evaluation of drought tolerant maize in Guinea Savannah of Nigeria, farmers laid more emphasis on earliness in crop maturity than on high yield (Kamara et al., 2006). In a PVD conducted for sorghum in Burkina Faso, it was observed that farmers' criteria for selection for a trait were more encompassing than breeders understanding of the same. This clearly showed that farmers can effectively select for traits on the basis of progeny and single plants while pursuing specific agronomic aims such as adaptation (vom Brocke et al., 2006). Farmers identified grain yield, cob size, grain size and earliness as the most important criteria for adoption of maize varieties in an evaluation study of drought tolerant

maize varieties in the guinea savanna of Ghana using a mother and baby trial design (Buah et al., 2013).

PRA in plant breeding is designed to bridge the gap between breeders and farmers (Banziger and de Meyer, 2000) and also ensure that new varieties satisfy farmers' preferences and suit their socioeconomic situation (Abedi and Vahidi, 2011; Kiiza et al., 2012).

Farmers' participation in agricultural research is therefore more than talking to six farmers or putting ten experiments in their fields but a systematic dialogue between farmers and scientists to solve problems related to agriculture and ultimately increase the impact of agricultural research. Sequences of events include: learning from farmers, identification of technological options to test, designing methods to test and evaluate their impact. These activities are jointly carried out by farmers and scientists to achieve more productive, stable, equitable and sustainable agricultural systems (Witcombe et al., 1996; Bellon 2001; Odendo et al., 2002; Ellis-Jones et al., 2004).

This study was therefore conducted in cowpea growing regions of Kano, Nigeria with the following objectives:

1. Identify farmers' sources of information on climate change, seed and relevant agricultural related technologies.
2. Identify prominent climatic factors limiting cowpea production.
3. Assess farmers' perception of drought, mitigation measures and their impact on cowpea production.
4. Identify cowpea farmers' production constraints

5. Identify farmers' preferred traits in improved cowpea varieties.
6. Obtain information on farmers' perceptions of their involvement in development of improved varieties and new agricultural technologies.

3.1 Materials and Methods

3.1.1 Site selection

Participatory Rural Appraisal (PRA) study was conducted in fifteen cowpea growing communities sampled from four Local Government Areas (LGA) of Kano State (Gwarzo, Tofa, Bichi and Garko) (Table 3.1). Co-ordinates of the communities were captured using the geographical positioning system (GPS). ArcGIS software was used to draw Kano State map with showing the position of each community visited (Figure 3.1)

Kano State lies approximately between latitudes 10° 33'N and 12° 23'N and longitudes 7° 45'E and 9° 29'E and 473 metres above sea level (masl). Kano has a subtropical steppe/low-latitude semi-arid hot climate. It has an annual mean rainfall of 600mm $\pm$ 30%. It has an estimated land size of 21,276.872 km² with 1,754,200 hectares agricultural and 75,000 hectares forest vegetation and grazing land. The mean annual temperature is about 26°C (Falola, 2002; Olofin, 2008; <http://www.kano.climateemps.com/> accessed 09/05/2016 at 5.33pm).).

Table 3. 1: PRA sites, coordinates and the number of farmers interviewed in each community.

Local Government Area	Selected communities	Latitude (N)	Longitude (E)	*Elevation (asl) (m)
Gwarzo	Katsinawa	11°52.900'	007°53.587'	587
	Kogon Kura	11°55.546	007°54.007'	591
	Kutama	11°52.039'	007°52.064'	564
	Katsira	11°55.764'	007°58.740'	554
Tofa	Kwami	12°01.269'	008°18.470'	509
	Wangara	11°58.863'	008°19.602	509
	Tofa	12°03.592'	008°16.377'	513
	Doka	11°59.625'	008°18.096'	511
Bichi	Yakasai	12°12.135'	008°17.599	528
	Mintsira	12°11.468'	008°13.304'	516
	Badume	12°11.484'	008°18.520'	532
	Jobe	12°09.473'	008°12.325'	492
Garko	Kafin Malami	11°39.788'	008°52.914'	472
	Kogon Doki	11°31.509'	008°46.576	527
	Garko	11°39.355	008°48.190'	468

*asl= above sea level

**Plate 3. 1: Cross section of farmers being interviewed in Tofa and Garko villages.**

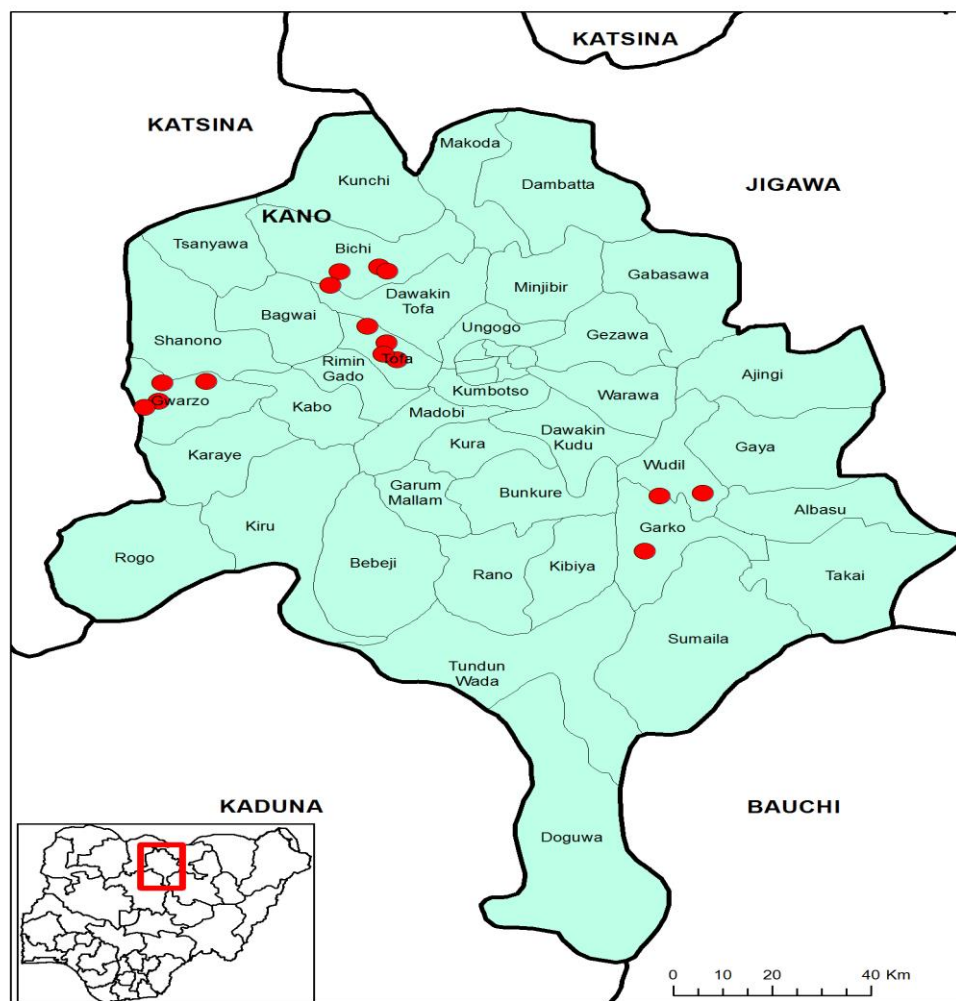


Figure 3. 1: Map of Kano State showing the 15 communities where the PRA was conducted.

3.1.2 Selection of farmers

One group of 15 farmers was formed for focus group discussions (FGD) in one community per LGA using interview guide. The information gathered from the FGD was used to develop semi-structured questionnaires. Members of the group were selected based on recommendations from the Agricultural Extension Agent in the enumeration area.

One hundred and fifty individual farmers comprising of 135 males and 15 females were interviewed using semi-structured questionnaires (Plate 3.1). The state was experiencing social unrest at the time of questionnaire administration hence the few number of the female participants. Male and female farmers were separately interviewed in line with cultural and religious beliefs of the communities.

3.2 Data collection techniques and data analysis

Interview guide was used for focus group discussion and questionnaires were administered to individual respondents at various locations. Questions were put to individual farmers with translators clarifying issues in their local language and enumerators recording the information where necessary. The responses from farmers in all the study areas were coded and compiled in SPSS. Ranking was done using excel software. Criteria for evaluation were placed on the vertical axis of the matrix while the elements generated were placed on the horizontal matrix. Farmers' responses were then ranked using a scale of 1 (highest value or most important) to 5 (lowest value or least important). Derived scores were calculated for the different criteria by assigning the criterion/rank a value that was inversely proportional to the rank i.e. a rank of 1 received a score of 5, 2 received 4, 3 received 3, 4 received 2 and 5 and above received 1. Mean Derived Scores (MDS) were calculated from the derived scores (De Groote *et al.*, 2002).

The socio-economic characteristics of respondents observed in the study area were age, measured in years, sex, level of education (measured in years invested in formal education) and marital status. Others included primary occupation, land ownership type and area of their total farmland cultivated to cowpea the cropping season prior the survey.

3.3. Results

3.3.1 Socio-economic characteristics of respondents

Table 3.2 presents the summary of the socio-economic characteristics of respondents. The mean age of respondents was 47 years and males dominated farming activities in the surveyed areas. Farming was the primary occupation of the respondents (57%). Most of the respondents belonged to one farmer group or the other (86%). The number of respondents with formal education was above two-thirds of the total respondents across surveyed areas. Respondents owned their farmlands either through family inheritance or purchase. Only a few of them used rented farmland for farming. Mean area of land cultivated to cowpea during the season prior to the survey was 1.5 ha with 87% of them using between 0.5 – 2 ha for growing cowpea.

Table 3. 2: Distribution of farmers based on socio-economic characteristics.

Characteristics	Frequency (N=150)	Percentage (%)
Age Range		
20 - 40	58	38.7
41 - 50	42	28
51 - 60	30	20
61 and above	20	13.3
Mean age = 47years		
*Educational Attainment		
FSCL	33	22.5
"O Level"	80	54.4
Tertiary Education (NCE, BSc etc)	34	23.1
Marital Status		
Married	145	97
Single	3	2
Widow / widower	1	1
Gender		
Male	135	90
Female	15	10
Membership of farmer group		
Yes	129	86
No	21	14
*Primary occupation of respondents		
Farming	89	59
Trading	67	45
Civil service	18	12
Artisan	17	11
*Land ownership type		
Owned through inheritance	135	90
Rent	24	16
Owned through purchase	70	47
Area of farmland cultivated with cowpea		
< 0.5ha	4	2.7
0.5 - 2ha	128	87.1
> 2ha	15	10.2
Mean land area = 1.5ha		

*FSLC=first school leaving certificate; "O Level" = Secondary school leaving certificate.

*multiple responses. No response = where N < 150

Source: Field survey conducted by author in 2014

3.3.2 Cropping systems and frequency of cultivation

Results in Table 3.3 show the farming calendar of farmers interviewed in the four LGAs. Eighty three percent of the farmers grew cowpea in mixed cropping with other crops such as maize, millet, sorghum and onions. Growing cowpea as a rotational crop after maize and other cereals was highlighted as important by interviewed farmers because it restores soil fertility. Although some respondents indicated that they grew cowpea as a sole, these respondents were identified to be the direct owners of their farmlands and so were able to grow cowpea as a sole crop while others who hired their farmlands did mixed cropping so as to maximize production per unit area. Frequency of cropping was mainly dependent on availability of irrigation facilities since many of them grew cowpea under rain-fed conditions and irrigation is an additional expense for the farmers during the growing season. Most of the respondents therefore grew the crop once in a year (63%) while some that were close to natural sources of water or irrigation schemes grew the crop twice in a year (34%).

Table 3. 3: Types of farming system and frequency of cultivation of farmers in Tofa, Bichi, Gwarzo and Garko LGAs of Kano State, Nigeria in the year 2014.

		Frequency (N=150)	Percentage (%)
Cropping system	Mono-cropping	24	16
	Mixed cropping	125	83.33
	No response	1	0.67
	Total	150	100
Frequency of cultivation per year	Once	95	63.33
	Twice	51	34.00
	Thrice	2	1.33
	No response	2	1.33
	Total	150	100

3.3.3 Farmers' sources of information on cowpea seeds, climate change and other agricultural related technologies.

The majority of farmers, averaged over all the communities indicated that they sourced their seeds during the growing season from the open market (31.69%), followed by seeds from farmer friends or relatives (25.73%). Considering the trend on LGA basis however, most farmers in Garko LGA sourced their seeds from seed companies or agro dealers (37.93%). During the focus group discussions held in this LGA, it was observed that extension agents worked very closely with the farmers in this LGA and secondly Garko LGA had a formidable farmers' association where they shared information on new technologies (Figure 3.2). There was a decline in the use of own saved local seeds across all LGAs. The farmers confirmed that they had good crops and bountiful harvests which translated to high income whenever they sourced fresh seeds from agro-dealers and IITA. This confirmed the readiness of farmers to embrace new varieties as long as they met their needs. Figure 3.3 shows that most farmers got their information on climate change and other related technologies from extension agents (81.75%) followed by mass media (10.14%) especially the transistor radios.

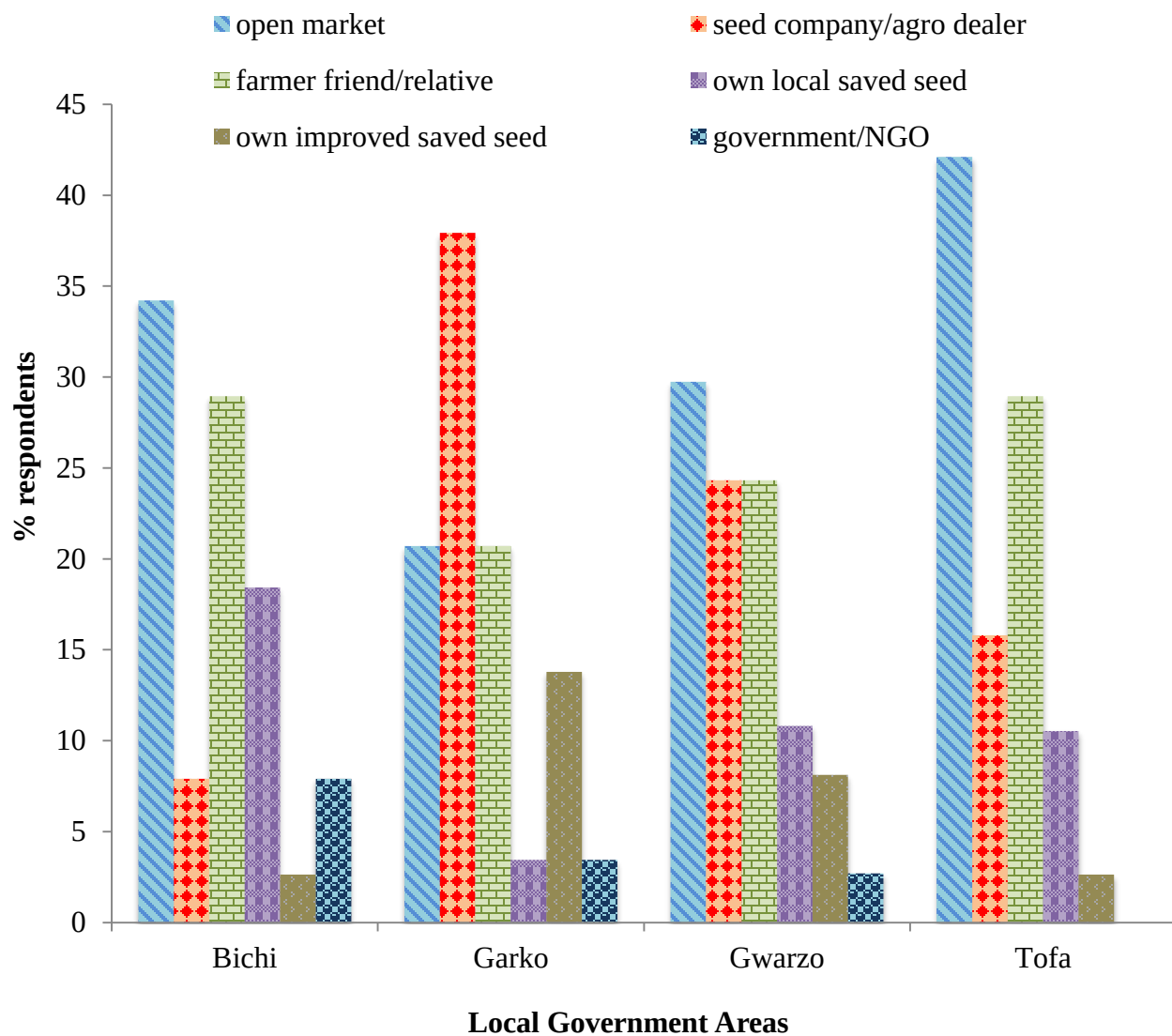


Figure 3. 2: Farmers' sources of cowpea seeds in 4 LGAs of Kano State in the year 2014

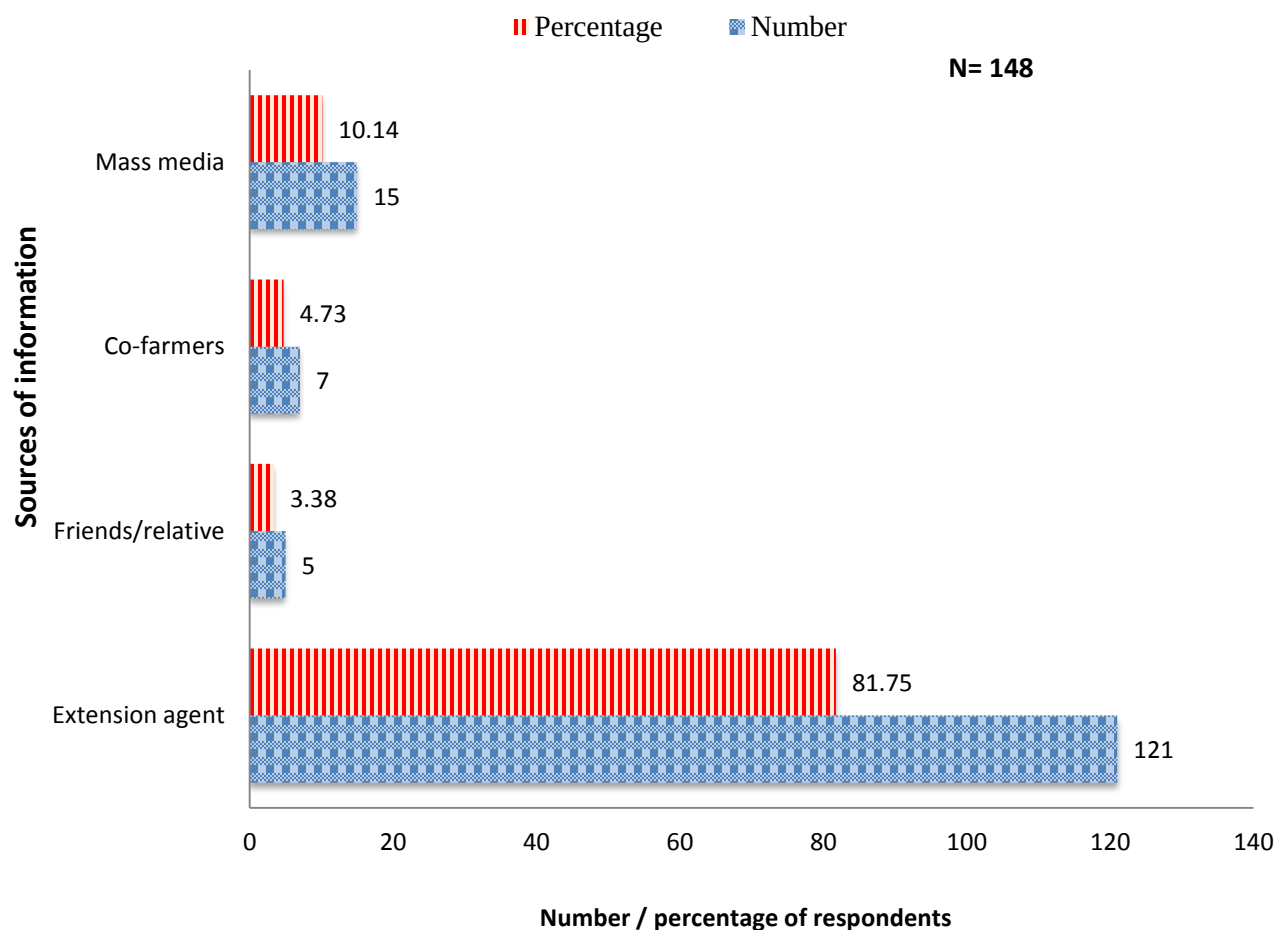


Figure 3. 3: Sources where farmers in the 4 LGAs surveyed in Kano State get information on climate change and related agricultural technologies.

3.3.4 Prominent climatic factors limiting cowpea production in surveyed areas

There are two seasons in Kano, the wet/rainy season which occurs between May and September with temperatures ranging between 24°C - 29°C and the dry season between October and April with maximum temperature between 28°C - 34°C and minimum temperature between 25°C - 27°C. For farmers growing cowpea under rain-fed conditions, the planting season starts in June/July with harvesting in September/October. However, farmers growing cowpea with irrigation facilities have the advantage of growing twice in a year, first in December to March/April and the second planting in June/July. Figure 3.4 shows the responses of farmers on community basis and across all communities on climatic constraints to production. Rainfall was the most prominent climatic factor limiting production (62%) followed by high temperature (35.3%). From the focus group discussions held in all the LGAs, farmers reported that the irregularity in rainfall pattern hindered their farming activities which at times led to total crop failure whenever there was shortage in precipitation during the growing season.

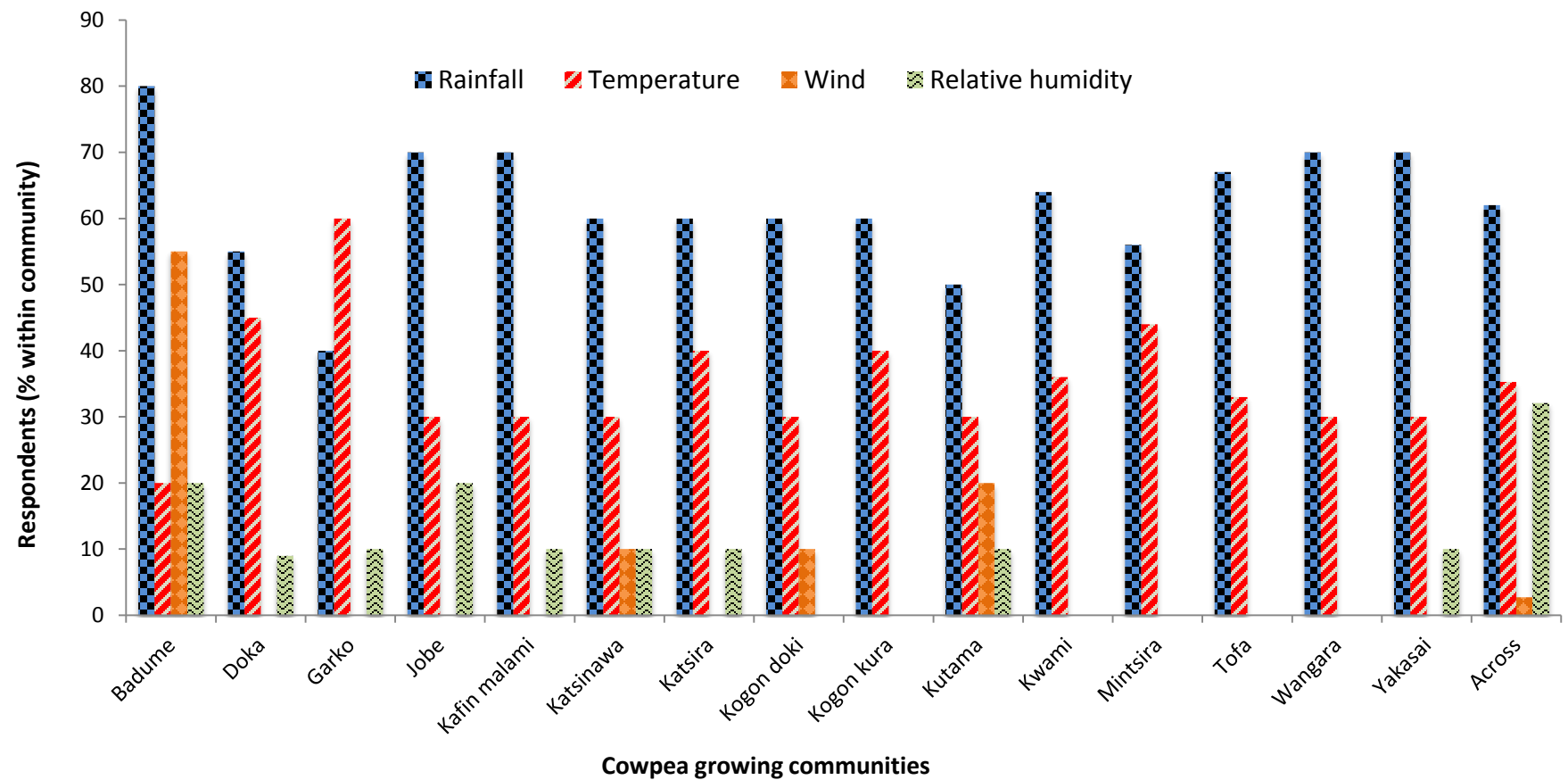


Figure 3. 4: Prominent climatic factors limiting cowpea production in 15 cowpea growing communities of Kano State, Nigeria in the year 2014.

3.3.5. Farmers' perceptions of drought, mitigation measures and impact of drought on cowpea production

One of the objectives of this study was to find out from the cowpea farmers the effect drought has on cowpea production. Tables 3.4 - 3.7 show various questions posed to farmers in order to assess their perception of drought and its impact on cowpea production. From Table 3.4, 88% of farmers responded to have experienced drought during growing seasons; 96.93% declared that the effect was severe on grain yield. When farmers were asked for the growth stage of cowpea that is more susceptible to drought, 58.11% affirmed that the flowering/grain filling stage was more susceptible to drought, 32% said vegetative while 10% said both stages were susceptible to devastation by drought. The majority of the farmers interviewed (55%) did not have access to irrigation facilities. Ninety five percent planted improved varieties as mitigation to drought because the extension agents gave them adequate information on new varieties. Ninety three percent manipulated planting and harvesting times as a drought avoidance measures. Seventy two percent of respondents said that they got information on tolerant varieties from extension workers, followed by information through radio (58%) and farmer friends / relatives (28%).

The results in Table 3.5 show the responses of farmers on the extent of drought devastation on plant aspect. Eighty seven percent and 77% of farmers said that the incidence of pests and diseases increased to a great extent whenever drought occurred at vegetative and grain filling stages respectively. Eighty one percent and 66% affirmed that the incidence of drought at vegetative and grain filling stages resulted in stunted growth of cowpea

respectively. Seventy seven percent and 75% confirmed the increase in flower abortion and poor pod-filling to a great extent when drought occurred during the reproductive stage.

Table 3.6 and Table 3.7 show the economic impact of drought on farmers' realized yield of harvestable parts of cowpea. Reduction in grain yield ranged between 50-73% and 40-73% for drought stress occurring at vegetative and grain-filling stages respectively while it ranged between 56-81% and 36-79% for fodder yield for drought occurring during vegetative and grain-filling stages respectively. From the information gathered from interviewed farmers, it was deduced that under optimum condition, a farmer could generate a net income of about N230, 860 (\$1282) on a hectare from grain and fodder yields for instance if he has/she has 1,027 kg ha⁻¹ of cowpea grains and 460 rolls ha⁻¹ of fodder. However, he/she could lose up to N131, 140 (\$728) and 144,300 (\$801) in the event of drought occurring at vegetative and grain-filling stages respectively (Table 3.6 and 3.7).

Table 3. 4: Drought incidence, its impact on cowpea production and mitigation measures employed by farmers in the 15 surveyed communities of Kano State in the year 2014.

Question	Response	Frequency	Percentage (%)
Experienced drought during cowpea growing season	No	18	12.0
	Yes	132	88.0
		N=150	
Effect of the drought experienced on grain & fodder yield	Very severe	97	74.62
	Moderately severe	29	22.31
	Not severe	4	3.08
		N=130	
Crop growth stages susceptible to drought devastation	Vegetative stage	47	31.76
	Flowering & grain-filling stage	86	58.11
	All growth stages	15	10.14
		N=148	
Drought mitigation measures			
Irrigation	No	80	54.79
	Yes	66	45.21
		N=146	
Planting improved varieties	No	8	5.33
	Yes	142	94.67
		N=150	
Manipulation of planting and harvesting times	No	8	5.33
	Yes	140	93.33
		N=150	
Other measures	No	8	72.73
	Yes	3	27.27
		N=11	
Access to cowpea varieties tolerant to drought	Yes	122	83.6
	No	24	16.4
		N=146	
Sources of information on tolerant varieties	NGOs	20	13.3
	Radio	88	58.7
	Television	3	2
	Farmer field school	5	3.3
	Extension agents	108	72
	Farmer friend/relatives	42	28
	Other sources	4	2.7
		*N=270	

***Multiple responses**

Table 3. 5: Devastation of drought expressed by extent to which the stage of occurrence of drought affects cowpea plant in 15 surveyed communities of Kano State in the year 2014.

Plant aspect	% respondents							
	great extent		Some extent		Little extent		No extent	
	Vegetative	Grain-filling	Vegetative	Grain-filling	Vegetative	Grain-filling	Vegetative	Grain-filling
Yellowing of leaves	77	76	19	5	4	11	-	1
Stunted growth	81	66	17	15	2	11	-	1
Plant wilting	77	74	19	9	3	9	-	1
Increase in pest & disease incidence	87	77	8	13	3	2	-	1
Flower abortion	82	77	9	10	4	6	3	1
Poor pod formation	77	74	13	15	7	4	1	2
Poor pod filling/seed set	82	75	12	15	4	3	1	1
Low grain yield	79	71	17	14	2	9	1	1
Low fodder yield	69	66	25	15	6	12	-	-

- = no response

Table 3. 6: Economic impact of drought on grain yield of cowpea in 15 surveyed communities of Kano State, 2014

*Grain yield (Kg ha⁻¹)					
Communities	Optimum condition	Drought stress		% grain yield loss under drought stress	
		Vegetative	Grain-filling	Vegetative	Grain-filling
Badume	587	215	191	63	68
	105660	38700	34335		
		-66960	-71325		
Doka	638	255	213	60	67
	114840	45900	38340		
		-68940	-76500		
Garko	727	254	257	65	65
	130860	45720	46260		
		-85140	-84600		
Jobe	967	441	421	54	56
	174060	79380	75780		
		-94680	-98280		
Kafin malami	639	307	263	52	59
	115020	55260	47340		
		-59760	-67680		
Katsinawa	803	270	213	66	73
	144540	48600	38340		
		-95940	-106200		
Katsira	826	294	317	64	62
	148680	52920	57060		
		-95760	-91620		
Kogon doki	594	186	188	69	68
	106920	33480	33840		
		-73440	-73080		

Table 3.6 continued

Communities	Optimum condition	*Grain yield (Kg ha ⁻¹)			
		Drought stress		% grain yield loss under drought stress	
		Vegetative	Grain-filling	Vegetative	Grain-filling
Kogon kura	1027	479	397	53	61
	184860	86220	71460		
		-98640	-113400		
Kutama	726	314	342	57	53
	130680	56520	61560		
		-74160	-69120		
Kwami	730	295	265	60	64
	131400	53100	47700		
		-78300	-83700		
Mintsira	792	283	299	64	62
	142560	50940	53820		
		-91620	-88740		
Tofa	515	256	308	50	40
	92700	46080	55440		
		-46620	-37260		
Wangara	678	181	183	73	73
	122040	32580	32940		
		-89460	-89100		
Yakasai	592	227	251	62	58
	106560	40860	45180		
		-65700	-61380		

*First row indicates harvested grain or fodder per hectare; row 2 indicates income generated and row 3 indicates loss in income in the event of drought. 1bag of cowpea grain =100Kg sells for N18, 000. \$1= N180 at survey period.

Table 3. 7: Economic impact of drought on fodder yield of cowpea in 15 surveyed communities of Kano State, 2014

Fodder yield (roll ha ⁻¹)					
Communities	Optimum condition	Drought stress		% fodder loss under drought stress	
		Vegetative	Grain-filling	Vegetative	Grain-filling
Badume	400	94	105	77	74
	40000	9400	10475		
		-30600	-29525		
Doka	279	116	122	58	56
	27900	11600	12200		
		-16300	-15700		
Garko	339	125	167	63	51
	33900	12500	16700		
		-21400	-17200		
Jobe	404	151	159	63	61
	40400	15100	15900		
		-25300	-24500		
Kafin malami	385	173	166	55	57
	38500	17300	16600		
		-21200	-21900		
Katsinawa	323	102	138	68	57
	32300	10200	13800		
		-22100	-18500		
Katsira	476	89	102	81	79
	47600	8900	10200		
		-38700	-37400		
Kogon doki	282	120	142	57	50
	28200	12000	14200		
		-16200	-14000		

Table 3.7 continued

Communities	Optimum condition	Fodder yield (roll ha ⁻¹)			
		Drought stress		% grain yield loss under drought stress	
		Vegetative	Grain-filling	Vegetative	Grain-filling
Kogon kura	460	135	151	71	67
	46000	13500	15100		
		-32500	-30900		
Kutama	339	104	130	69	62
	33900	10400	13000		
		-23500	-20900		
Kwami	406	180	172	56	58
	40600	18000	17200		
		-22600	-23400		71
Mintsira	493	126	142	74	
	49300	12600	14200		71
		-36700	-35100		
Tofa	375	97	108	74	36
	37500	9700	10800		
		-27800	-26700		
Wangara	288	148	184	49	36
	28800	14800	18400		
		-14000	-10400		
Yakasai	277	123	178	56	36
	27700	12300	17800		
		-15400	-9900		

*First row indicates harvested grain or fodder per hectare; row 2 indicates income generated and row 3 indicates loss in income in the event of drought. 1roll of fodder sells for N100. \$1= N180 at survey period.

3.3.6 Cowpea production constraints

Farmers were asked about problems faced in cowpea production and were asked to rank using extent of limitation each constraint had on cowpea production. Results are presented in Tables 3.8 – 3.9. In Table 3.8, 89.33% and 83.33% of farmers indicated that insect pests and drought constrained cowpea production to a very great extent respectively. Floods were also identified by farmers as a constraint to production. Educational level (74%) and gender with respect to land ownership (84.67%) did not have any negative effects on cowpea production across the communities surveyed. Results in Table 3.9 shows the differential ranking of production constraints across the communities nested within respective local government areas. The same trend was observed for insect pests and drought as they were both ranked first among other constraints in all the LGAs (Table 3.8). Different constraints however were ranked 2nd in each LGA. For instance, In Bichi LGA, lack of improved varieties was ranked 2nd while inadequate marketing channels, high cost of land preparation and maintenance and diseases were ranked 2nd in Garko, Gwarzo and Tofa LGAs respectively. Overall, the first three major constraints identified were drought, insect pests and diseases.

Table 3. 8: Constraints expressed by extent to which factors limit cowpea production in four local government areas of Kano State.

Production constraints	Local Government Areas	*Number of responses			
		‡Great Extent	Some Extent	Little Extent	No Extent
Lack of improved varieties	Bichi	25(23.6)	6(26.10)	2(28.6)	6(42.9)
	Garko	19(17.9)	6(26.10)	2(28.6)	3(21.4)
	Gwarzo	30(28.3)	5(21.7)	2(28.6)	3(21.4)
	Tofa	32(30.2)	6(26.1)	1(14.3)	2(14.3)
	‡Total (N=150)	106(70.67)	23(15.33)	7(4.67)	14(9.33)
Drought	Bichi	32(25.6)	5(31.2)	2(22.2)	---
	Garko	23(18.4)	4(25)	3(33)	---
	Gwarzo	35(28)	3(18.8)	2(22.2)	---
	Tofa	35(28)	4(25)	2(22.2)	---
	Total (N=150)	125(83.33)	16(10.66)	9(6)	---
Diseases	Bichi	26(22.4)	10(43.5)	3(37.5)	---
	Garko	22(19)	6(26.1)	2(25)	---
	Gwarzo	36(31)	1(4.3)	---	1(100)
	Tofa	32(27.6)	6(15.5)	3(37.5)	---
	Total (N=148)	116(78.38)	23(15.54)	8(5.41)	1(0.68)
Insect pest	Bichi	37(27.6)	2(15.4)	---	---
	Garko	27(20.1)	2(15.4)	1(33.3)	---
	Gwarzo	37(27.6)	2(15.4)	1(33.3)	---
	Tofa	33(24.6)	7(53.8)	1(33.3)	---
	Total (N=150)	134(89.33)	13(8.67)	3(2)	---
Poor soil fertility	Bichi	14(24.6)	4(17.4)	14(34.1)	39(26.4)
	Garko	9(15.8)	1(4.3)	11(40.7)	9(22)
	Gwarzo	15(26.3)	16(69.6)	6(22.2)	3(7.3)
	Tofa	19(33.3)	2(8.7)	3(11.1)	15(36.6)
	Total (N=148)	57(38.51)	23(15.54)	27(18.24)	41(27.7)
Educational level	Bichi	3(42.9)	3(25)	2(10)	31(27.9)
	Garko	---	1(8.3)	8(40)	21(18.9)
	Gwarzo	1(14.3)	4(33.3)	5(25)	30(27)
	Tofa	3(42.9)	4(33.3)	5(25)	29(26.1)
	Total (N=150)	7(4.67)	12(8)	20(13.3)	111(74)

Table 3.8 continued

Production constraints	Local Government Areas	*Number of responses			
		‡Great Extent	Some Extent	Little Extent	No Extent
Gender and land ownership	Bichi	---	2(14.3)	2(28.6)	35(27.6)
	Garko	---	2(14.3)	2(28.6)	26(20.5)
	Gwarzo	1(50)	5(35.7)	1(14.3)	33(26)
	Tofa	1(50)	5(35.7)	2(28.6)	33(26)
	¥Total (N=150)	2(1.33)	14(9.33)	7(4.67)	127(84.67)
High cost of land rent	Bichi	4(17.4)	2(15.4)	4(25)	27(28.1)
	Garko	1(4.3)	2(15.4)	7(43.8)	20(20.8)
	Gwarzo	5(21.7)	3(23.1)	2(12.5)	30(31.2)
	Tofa	13(56.5)	6(46.2)	3(18.8)	19(19.8)
	Total (N=148)	23(15.54)	13(8.78)	16(10.81)	96(64.86)
Flood	Bichi	22(22)	1(14.3)	7(53.8)	8(27.6)
	Garko	16(16)	---	2(15.4)	12(41.4)
	Gwarzo	31(31)	3(42.9)	1(7.7)	5(17.2)
	Tofa	31(31)	3(42.9)	3(23.1)	4(13.8)
	Total (N=149)	100(67.11)	7(4.7)	13(8.72)	29(19.46)
High cost of land preparation and maintenance	Bichi	14(20.3)	9(28.1)	6(24)	10(41.7)
	Garko	16(23.2)	7(21.9)	4(16)	3(12.5)
	Gwarzo	18(26.1)	8(25)	13(52)	1(4.2)
	Tofa	21(30.4)	8(25)	2(8)	10(41.7)
	Total (N=150)	69(46)	32(21.33)	25(16.67)	24(16)
Inadequate marketing channels	Bichi	11(19)	1(4.5)	12(30.8)	15(48.4)
	Garko	8(13.8)	8(36.4)	11(28.2)	3(9.7)
	Gwarzo	15(25.9)	8(36.4)	11(28.2)	6(19.4)
	Tofa	24(41.4)	5(22.7)	5(12.8)	7(22.6)
	Total (N=150)	58(38.67)	22(14.67)	39(26)	31(20.67)

*Percentages in parentheses; ‡=percentage within extent of constraint; ¥=percentage across total respondents; --- = no response

Table 3. 9: Ranking of production constraints in 15 communities surveyed nested within each local government area.

Constraints	Bichi LGA		Garko LGA		Gwarzo LGA		Tofa LGA		*MDS	Overall rank
	[‡] Responses	Rank	Responses	Rank	Responses	Rank	Responses	Rank		
Lack of improved varieties	84.6	2	90.0	3	92.5	4	95.0	3	3.0	3
Drought	100.0	1	100.0	1	100.0	1	100.0	1	5.0	1
Diseases	100.0	1	100.0	1	97.3	3	99.0	2	4.3	2
Insect pests	100.0	1	100.0	1	100.0	1	100.0	1	5.0	1
Poor soil fertility	64.1	5	70.0	5	92.5	4	61.5	7	1.3	6
Educational level	20.5	8	30.0	8	25.0	7	29.3	9	1.0	7
Gender and land ownership	10.2	9	13.4	9	17.5	8	19.5	10	1.0	7
High cost of land rent	27.0	7	33.3	7	25.0	7	53.6	8	1.0	7
Flood	78.9	3	60.0	6	87.5	5	90.2	4	1.8	5
High cost of land preparation and maintenance	74.4	4	89.9	4	97.5	2	75.6	6	2.3	4
Inadequate marketing channels	61.6	6	90.1	2	85.0	6	82.9	5	1.8	5

[‡]Percentage respondents within LGA. *MDS= mean derived scores of ranks obtained across LGAs. A rank of 1 received a score of 5, 2 received 4, 3 received 3, 4 received 2 and 5 and above received a score of 1.

3.3.7 Traits preferred in improved cowpea varieties

Farmers were asked to rank cowpea traits they preferred to be incorporated into cowpea varieties that would enhance easy and high adoption by them (Table 3.10). In Bichi, high market acceptability was ranked first followed by tolerance to drought and large seeded varieties. In Gwarzo, early maturity and high market acceptability were tied in rank as their major preferred traits while in Tofa, early maturity, short cooking time and dual purpose were tied as their major preferred traits. When the scores for the criteria were computed across all the communities nested within their respective LGAs, it was observed that resistance to pest and diseases, large seeds, tolerance to drought, dual-purpose, short cooking time and high market acceptability were tied in rank as the major preferred traits followed by high yield (Table 3.10). Responses between male and female farmers were similar although data was not captured based on gender therefore no gender analysis was carried out.

Table 3. 10: General criteria for preferred cowpea varieties as ranked by farmers in the 15 surveyed communities of Kano State, 2014

Local Government Areas										
Criteria	Bichi		Garko		Gwarzo		Tofa		Across	
	‡MDS	Rank	MDS	Rank	MDS	Rank	MDS	Rank	MDS	Rank
High yield	1.27	5	1.64	3	1.18	6	1.64	3	1.82	2
Pest and disease resistance	1.36	4	1.45	4	1.45	3	1.73	2	1.91	1
High palatability	1.36	4	1.45	4	0.64	8	1.27	5	1.46	3
Early maturing	1.73	2	1.73	2	1.64	1	1.82	1	1.82	2
High storability	0.72	6	0.54	8	0.72	7	1.46	4	1.82	2
Large seeds	1.73	2	1.36	5	1.36	4	1.27	5	1.91	1
Drought tolerance	1.73	2	1.73	2	1.27	5	0.91	6	1.91	1
Dual-purpose	1.45	3	0.91	6	1.18	6	1.82	1	1.91	1
Short cooking time	1.27	5	1.64	3	1.55	2	1.82	1	1.91	1
High market acceptability	1.81	1	1.81	1	1.64	1	1.73	2	1.91	1
Late maturing	0.18	7	0.64	7	0.27	9	0.55	7	1.18	4

‡MDS=Mean Derived Score; Every time a criterion is ranked first it receives a score of 5, each second ranking scores 4, each third ranking scores 3, each fourth ranking scores 2, and each other ranking scores 1.0=no response.

3.3.8 Farmers' willingness to participate in specific aspects of in cowpea breeding and other agricultural development research

The results in Table 3.11 reveal farmers' readiness to be involved in plant breeding research from formulation of objectives to selection. Ninety-seven percent of the farmers responded in the affirmative that their involvement in the formulation of demand-driven plant breeding objectives would enhance the adoption of varieties or technologies. The majority of respondents disagreed (95.6% with the idea of breeders/researchers pushing out new varieties on them without seeking their input on the objectives and also involving them in the on-farm trials (Table 3.11).

Table 3. 11: Farmers' willingness to participate in crop development research

Communities	*Objective formulation		On-farm trials, evaluation and selection		No involvement	
	No	Yes	No	Yes	No	Yes
Badume	0(0)	10(100)	0(0)	10(100)	9(100)	0(0)
Doka	0(0)	11(100)	0(0)	7(100)	4(100)	0(0)
Garko	2(25)	6(75)	0(0)	10(100)	8(100)	0(0)
Jobe	0(0)	10(100)	0(0)	10(100)	9(100)	0(0)
Kafin malami	1(12.5)	7(87.5)	0(0)	10(100)	8(100)	0(0)
Katsinawa	0(0)	10(100)	0(0)	10(100)	9(100)	0(0)
Katsira	0(0)	10(100)	0(0)	10(100)	9(100)	0(0)
Kogon doki	1(12.5)	7(87.5)	0(0)	9(100)	8(100)	0(0)
Kogon kura	0(0)	10(100)	0(0)	10(100)	6(85.7)	1(14.3)
Kutama	1(10)	9(90)	0(0)	9(100)	7(100)	0(0)
Kwami	0(0)	11(100)	0(0)	11(100)	6(85.7)	1(14.3)
Mintsira	0(0)	9(100)	0(0)	9(100)	9(100)	0(0)
Tofa	0(0)	9(100)	0(0)	8(100)	5(100)	0(0)
Wangara	0(0)	9(100)	0(0)	8(100)	5(62.5)	3(37.5)
Yakasai	0(0)	10(100)	0(0)	10(100)	8(100)	0(0)
Across	5(3.5)	138(96.5)	0(0)	141(100)	109(95.6)	5(4.4)

**Percentage responses within community in parentheses*

3.4. Discussions

The approach of the PRA used in this study yielded meaningful results as farmers willingly shared their experiences and knowledge. Relevant information gathered from farmers can assist breeders to incorporate farmers' varietal preferences into new varieties in order to enhance adoption. With farmers' active participation, it is believed that research will develop technologies that farmers will play a key role in the diffusion which will result in more productive, stable, and sustainable agricultural systems (Odendo et al., 2002; Ellis-Jones et al., 2004).

Age is considered as a basic population characteristic. The age of a person influences his needs, occupation and the pattern of public demand of him (Okafor et al., 1994). The major proportion of the respondents fell within the range of 20–50 years and the average age was 47 years. They are classified as young adults that still possess both strong mental alertness and physical strength needed for their work. This finding agrees with Awotide et al. (2015) who reported 47 years as the mean age of farmers they interviewed from their study on the input use and profitability of arable crops in Nigeria. Similarly, Musa et al. (2013) reported 42 years as the average age of farmers they interviewed and Mazza et al. (2012) reported that 82.59% of the Fadama users they interviewed were within the range of 40-49 years. This finding revealed the active participation of Nigerian young adults in farming and disagrees with the general belief that they are not interested in agricultural activities.

Education has been reported to be very important as it helps refine a person's perceptions of issues and help him/her make reasonable decisions based on information. Level of education of farmers will contribute to adoption of improved technologies as well as facilitates their participation in research activities (Krueger, 1993; Mazza et al., 2012). The

number of respondents found to have formal education in this study was above two – third of the total respondents. Similar results were reported by Awotide et al. (2015) and Mazza et al. (2012). This high rate of literacy might be due to the existence of free basic education in the country which has improved school enrolment. Owing to the communal co-operation among the farmers, information on new technologies were shared among all and therefore there was no difference in the responses of the one-third illiterates with the literate farmers.

The size of land (farm size) of an individual usually determines his production capacity. Under normal circumstances, it is expected that the larger the land size, the greater the output that can be produced. In addition, the adoption of some agricultural technologies (such as those related to mechanization) which improve efficiency are related to farm size. Results from this study showed that the average farm size grown to cowpea was 1.5 ha out of an average of 4.5 ha of total farm size for all crops. This implies that there is high level of land fragmentation to accommodate cultivation of other crops for security reasons which hinders full mechanization which could boost cowpea productivity.

Farmers' groups are socio-economic groups because they are formed to accomplish some common social and economic goals in relation to their farming activities. Farmers join these groups because they use the membership to access credit facilities and agricultural information (Ofuoku and Urang, 2009; Ofuoku and Chukwuji, 2012; Kolade and Harpham, 2014). Ofuoku and Urang (2009) asserted in their study that farmers will only remain in their various groups as long as the group still supports their needs. Although, most of the farmers interviewed in this study belonged to one farmer group or the other, 14% of respondents said they pulled out of farmer groups because their individual goals were no longer being met by the group as a result of poor leadership and financial mis-management.

This finding agrees with Ofuoku and Chukwuji (2012) who reported that most farmers group in South-Eastern Nigeria experienced membership withdrawal because of mismanagement and that the groups no longer satisfy their needs. Eighty-six percent that still belong to farmers' associations because they believe that their membership will enable to access loans as a group and also make them benefit from other interventions from government or non-governmental organizations (NGOs).

Cowpea was grown as an intercrop or in rotation with cereal crops like maize, millet and sorghum. Cowpea was often planted about 4-6 weeks after planting the first crop using a wider spacing of 75 cm x 50 cm. Norman (1960) reported that it was relatively more profitable to grow crops in mixtures than sole cropping in Northern Nigeria based on the fact that there was no significant difference between the marginal value product of resource used and opportunity cost of the resource. Also, Ibeawuchi (2007) and Rashid et al. (2000) reported that factors such as population pressure, climatic conditions, risk management and high economic returns from efficient use of land resources, soil improvement were among other reasons why farmers intercrop (Ibeawuchi, 2007; Rashid et al., 2007; Ajeigbe et al., 2010b; Marinus, 2014). It has been reported that higher yields of cowpea can be obtained using furrow irrigation (Hussain et al., 2004). Findings from this study however revealed that most farmers could not afford the high cost associated with irrigation and therefore cultivated cowpea once in a year under rain-fed conditions, although, 34% of the respondents indicated that they cultivated cowpea twice a year under irrigation. They however complained of associated problems such as shortage of irrigation water or pressure, sudden shut-down of irrigation by authorities without prior notice and high cost.

Availability of seeds is an important criterion that cowpea farmers consider together with size and colour of the variety before adopting the varieties. The environment or community they are growing and the market they are targeting are also important factors that drive adoption (Dugje et al., 2009). In this study, most of the farmers obtained their seeds from the open market except in Garko LGA where the majority of the respondents indicated that they bought their seeds from agro dealers. Most of the farmers however said they had access to drought tolerant cowpea varieties through the extension services.

Farmers indicated that they got information on climate change and other agricultural related developments from the extension agents followed by mass media such as radios and television. The use of local languages on media enables all the categories of farmers to have access to information on agricultural technologies (Musa, 2011).

Changes in climate are threatening agricultural productivity. Farmers interviewed in this study indicated that rainfall was becoming very erratic and unpredictable and that it was negatively affecting their productivity. Ajetomobi and Abiodun (2010) reported reduction in cowpea yield due to climate change and its impact on cowpea productivity. The negative impact of reduced precipitation affected both cowpea grain and fodder yields. Most of the farmers in the surveyed communities have experienced drought at one time or the other during cowpea growing seasons. They indicated that drought at vegetative stage affected leaf production, abscission, and leaf yellowing, stunted growth and wilting of the whole plant. This agrees with findings by other researchers on cowpea and soybean who reported that drought stress at vegetative stage reduced rate of leaf expansion, followed by cessation of new leaf production and eventually, leaf increment was reduced to zero (Akyeampong, 1986; Mustapha et al., 2014). Farmers indicated from their experience that drought stress

occurring at the reproductive stage was more devastating than that occurring at the vegetative stage. In their responses, they stated that there was increased flower abortion, poor pod filling and eventually low grain yield. Farmers' observations are supported by the findings of Sakamoto et al. (2012) who reported that reduction of flower buds in cowpea under drought stress is caused by rapid stomatal closure which leads to reduced assimilation of photosynthates. Similarly, Daneshnia et al. (2013) reported lower grain and biological yield of cowpea varieties when irrigation treatment ended at flowering stage.

Drought was ranked overall as the first major constraint to cowpea production. Cowpea is predominantly grown towards the end of the rainy season which is characterized by erratic pattern of rainfall and high temperatures. Although, cowpea is considered drought tolerant compared with other legume crops, its yield is highly reduced under terminal drought and high temperature. Studies have reported that a combination of high temperature, drought and long days can slow down or inhibit floral bud development (Nielsen and Hall, 1985; Patel and Hall, 1990), resulting in fewer flowers being produced and substantially reduced cowpea productivity (Ahmed et al., 1992; Suliman, 2007). Generally, drought has been reported to cause grain yield reduction between 58 – 95% in chickpea (Leport et al., 2006) and 67% in cowpea (Fatokun et al., 2012).

Pest infestation was tied in ranking with drought across the four LGAs surveyed followed by diseases. Hall (2012) reported that diseases like ashy stem blight caused by *Macrophomina phaseolina* and pests such as lesser corn stalk borer (*Elasmopalpus lignosellus*) destroyed cowpea seedlings under hot, dry soil conditions. Some authors indicated that the aggressiveness of pests to extract water from weak plants contributes to

the increased damage they cause during drought stress (Popov et al., 2006). Farmers also indicated that the incidence of *Striga gesnerioides* was increased under drought stress. Muranaka et al. (2011) reported probable restriction of water uptake by *Striga* which magnifies the effect of drought stress in cowpea. Ishiyaku and Aliyu (2013) in their study reported that cowpea genotype IAR-07-1050 showed high resistance to *S. gesnerioides* thus had higher grain yield under drought stress than susceptible genotypes.

Although drought tolerance, resistance to pest and diseases were ranked first among production constraints, farmers ranked consumer-based quality traits such as large seeds, short cooking time, dual purpose and high market acceptability before high yield and early maturity on the same level as the former while high yield and early maturity were ranked lower. From this study, it was observed that farmers sold two-thirds of their cowpea produce and thus they preferred varieties with high demand in the market which is a direct indication of consumer preference. Farmers' ranking of large seeds as an important trait is supported by studies by Langyintuo et al. (2004), Mishili et al. (2007) and Egbadzor et al. (2013) that traders in cowpea grains, whether for food or seed, prefer large seeds to small ones because consumers in West Africa regions are ready to pay premium prices on them. Therefore, improving cowpea grain size while other traits remain intact will mean better varieties for farmers to accept. A study by Egbadzor et al. (2013) in Ghana revealed that farmers chose easy to cook/ short cooking time trait above other traits.

Farmers indicated that seeking their input in formulating plant breeding objectives will ensure their full participation and easy adoption of the resulting varieties. Farmers' knowledge about the crops in their areas has a high potential to strengthen PVS/PPB programmes. It would serve well to empower scientists' knowledge for designing site-,

crop- and farmer-specific activities. For instance in Malawi during a PVS, an accession of maize that ranked high by scientists using only data from multi-locational trials was not selected at all by farmers because of its long cooking time and poor taste when the grains are processed (Nkongolo et al., 2009). Witcombe et al. (2005) reported that the rapid acceptance of some varieties in Nepal was as result of participatory trial approach system which illustrated the success of a highly client-oriented breeding approach.

3.5. Conclusions

Based on the evidence provided in this study, farmers gained knowledge on climate change, seeds and other related agricultural developments through extension agents and farmer friends. This information is also aired in their local languages through mass media. Impact of drought is severe on all the harvestable parts of the crop as it adversely affects yield and monetary returns on investment. Farmers were interested in cowpea varieties with the following characteristics: high market acceptability, dual purpose, short cooking time, large seeds and tolerance to biotic and abiotic stresses. This study revealed that farmers have multiple criteria apart from yield for evaluating cowpea varieties for adoption, it therefore reiterates the need to involve farmers at the appropriate stages of a plant breeding programme in order to capture farmers' desired traits in the new varieties. This will increase the selection of these varieties and increase the adoption by farmers. Whereas breeders cannot incorporate all desired traits in one variety, many varieties could be bred focusing on the demands of different farmer groups based on their peculiar socio-economic and agro-ecological needs. Since farmers had indicated their willingness to be part of plant

breeding development process, their indigenous knowledge will empower breeders' scientists' knowledge for designing target specific varieties.

CHAPTER FOUR

4.0 Evaluation of cowpea genotypes for tolerance to seedling and terminal drought

4.1 Introduction

Cowpea (*Vigna unguiculata* L. Walp.) is one of the most important legumes cultivated for pulse and forage production in arid and semi-arid regions in sub-Saharan Africa (SSA) (Singh and Awika, 2010; Hall, 2012). The crop is grown under rain-fed conditions but the recent pattern of rainfall in the sub-region which either comes late, sparse at the beginning of the season or stops earlier than usual requires that efforts be made to enhance the level of drought tolerance in the currently available improved varieties (Fatokun et al., 2012; Kutama et al., 2014).

Drought is the most important constraint threatening food security in the world. It has been reported that change in temperature and rainfall will have dramatic effects on agricultural production in Africa because only 7% of the total agricultural land in Africa (barely 3.7% for SSA) is irrigated, given that 40% of the total irrigated area is in North Africa (<http://www.fao.org/docrep/005/y6831e/y6831e-03.htm> accessed 19/10/2015 at 11.31am). Studies have reported that the yield of cowpea obtained in the West African sub-region is lower than that in the USA and in Australia (Quin, 1997) and very often inconsistent (Krasova-Wade et al., 2006). The low productivity has been attributed to drought, among other factors. Although, cowpea is said to be relatively drought tolerant, it still suffers from considerable yield loss when exposed to severe drought during seedling, flowering and pod-filling stages. Drought affects anatomical, morphological, physiological and biochemical aspects (Pimentel, 2004; Ewansiha and Singh, 2006; Costa et al., 2008) of

plant development. Drought severity on the crop is directly related to the duration, intensity and stage of crop development (Lobato et al., 2008; Bastos et al., 2011; Fatokun et al., 2012).

Water stress occurring at the early stage of plant development can have negative impact on final crop yield by causing delay in plant development through inhibition of growth during the water deficit period and slow or incomplete photosynthetic recovery which affects growth and development of sink size and source supply when the plant resumes growth after early drought (Blum, 1996, 2011; Chaves et al., 2011; Vadez et al., 2014). For instance in rice (*Oryza sativa*), it was discovered that the retention of green leaf area and the number of leaves surviving at the end of drought stress occurring at the seedling stage affects the ability of rice seedlings to recover and tiller (Kamoshita et al., 2008). In soybean (*Glycine max*), seedling stage drought stress reduced the number of nodes, internode length, overall biomass and the number of flowers produced, yield and yield components (Desclaux et al., 2000; Passioura, 2012). Drought stress during flowering and pod filling is particularly important since it impacts directly and negatively on flower development, pollination (Boyer and McPherson, 1975), reduction in leaf area (Akyeampong, 1986), pod setting and grain filling leading to reduced number of pods per plant and seed weight, and consequently low seed yield (Suliman and Ahmed, 2010; Mustapha et al., 2014).

Studies have shown that root and shoot growth are closely coordinated (Jackson, 1993; Palta et al., 2011), and that abscisic acid (ABA) likely plays a major role in their regulation for drought tolerance (Munns and Cramer, 1996). In cowpea, drought tolerance has been attributed to several mechanisms that include deep rooting, stomatal sensitivity, reduced growth rate, leaf area reduction (Turk and Hall, 1980a,b; Lawn, 1983; Mai-Kodomi et al.,

1999a; Singh et al., 1999a), delayed leaf senescence, hastened or delayed reproductive cycle (Gwathmey and Hall, 1992c), osmotic adjustment (Mai-Kodomi et al., 1999b; Chiulele and Agenbag, 2004) and selective moisture remobilization with major dedication to the upper leaves and growing tips (Mai-Kodomi et al., 1999b).

Genetic variability existing in germplasm can only be identified and selected only when they are screened for the phenotypic expression of the genes controlling the trait of importance (Vigouroux et al., 2002). Selection of lines to serve as parents to produce the next generation is important in breeding and good parents must be selected from genetically variable populations. The present levels of drought tolerance in commonly grown cowpea varieties could be further enhanced through genetic improvement. It is conceivable that genes that could contribute to these higher levels of drought tolerance exist in some of the unexploited cowpea germplasm lines maintained in the genetic resources unit at the International Institute of Tropical Agriculture (IITA). The aim of this study was to screen different cowpea germplasm sources for tolerance to drought and select parents for genetic studies and for use in developing drought tolerant improved cowpea lines.

4.2 Materials and Methods

4.2.1 Plant material

A collection of ninety-one cowpea genotypes comprising of advanced breeding lines, tropical *Vigna unguiculata* (TVu) tvuaccessions, improved cowpea varieties and landraces (highly inbred) were chosen to represent a wide range of cowpea genotypic diversity (Table 4.1). Some of these lines were previously reported to be tolerant to water stress (Danlla, TVu 11986) and susceptible to water stress (TVu 7778) (Agbicodo et al., 2009). However, a larger evaluation was necessary to assess the wide diversity of cowpea for additional sources of drought tolerance genes.

4.2.2 Phenotyping cowpea genotypes for shoot drought tolerance

A simple “wooden box screening technique” (Figure 4.1) described by Singh et al. (1999) was used to screen the seedlings of the ninety test genotypes plus one susceptible check in the glass house in two splits because of availability of wooden boxes. The dimension of each wooden box was 42 cm x 57 cm. Each wooden box was filled with a 34 kg mixture of sand and top soil in the ratio of 3: 1 (Plate 4.1). In split 1, each wooden box consisted of four test plants and a susceptible check arranged in an 10 x 5 alpha (0, 1) lattice design while a 10 x 4 alpha (0, 1) lattice design was used for split 2; each box serving as an incomplete block with three replications. Each box was watered thoroughly to field capacity and allowed to drain for 2 days before planting. Four / five hills were later marked out for each genotype, 9.5 cm between rows and 8.2 cm between holes, 1.5 cm deep and one seed per hill (Plate 4.2). After planting, boxes were watered to field capacity and thereafter watering was completely stopped for 4WAP (weeks after planting). Stress was

measured by observing that all the plants for the susceptible check in each box were dead (Plate 4.3) and thereafter watering was resumed every two days for two weeks. After resumption of watering, variable numbers of recovered seedlings were rated for recovery (Plate 4.4). Daily temperature and humidity of the glasshouse were logged on hourly basis using [Tinytag Ultra 2 TGU-4500](#). Mean readings were computed for the months. Rainfall data was collected by the automated weather station of the Geographic Information System (GIS) unit of IITA, Ibadan.

The surviving seedlings that exhibited significant genetic variation to drought during the seedling stage was transferred to plastic pots in the screen house in order to separate the plant root systems and to eliminate competition among the genotypes for water. They were watered till maturity (Muchero et al., 2008).

4.2.3 Field screening of cowpea genotypes for tolerance to terminal drought

The experiment was conducted at IITA experimental station in Ibadan (07°03'N, 3°9'E, 212 m above sea level (asl) during the dry season of 2013 under irrigation. The experimental design was 13 x 7 alpha (0, 1) lattice with three replications. Experiments were planted in two adjacent blocks that received different irrigation regimes. Block 1 was the drought stressed (DS) block and block 2 was the well-watered (WW) block. Irrigation water was supplied to both blocks with an overhead sprinkler irrigation system designed to dispense 17 mm of water twice a week until 35 DAP (days after planting) for the DS block while WW block continued receiving water twice a week until physiological maturity. DS block was separated from WW block by an alley that was 20 m wide to restrict lateral movement of water from the fully irrigated block to the drought stressed block. DS blocks

did not receive water from 35 DAP (days after planting) until harvesting while the WW block received water twice a week until physiological maturity. Except for the different irrigation treatments, all field management practices were uniform for both the well-watered and water-stressed blocks.

No data could however be obtained from the field screening owing to the interference of rain during the critical stage of imposition of terminal drought stress. Therefore, parental selection for genetic studies was only based on the response of the genotypes to seedling stage drought.



Plate 4. 1: Mixing sand and top soil in ratio 3:1 Plate 4. 2 Marking out the wooden boxes for planting



Plate 4. 3 Cowpea seedlings 14 DAP (A) and at 4 weeks after planting (B) during drought stress.



Plate 4. 4 Cowpea seedlings recovery after 4 weeks of drought stress followed by 2 weeks every other day watering. The susceptible parent, TVU7778 had 0% recovery rate while tolerant genotypes showed variable percentage survival rates.

4.2.3 Data collection

Data collection

i. Temperature and humidity conditions of the glasshouse

Daily minimum and maximum temperature and humidity of the glasshouse were captured using the [Tinytag Ultra 2 TGU-4500](#) temperature loggers hung in the glasshouse. The logger was placed in the glasshouse and was set to log temperature and humidity daily on an hourly interval for the whole period of the experiment in the glasshouse. Logged data were stored in the device memory following the manufacturer's instruction for set-up. On completion of the experiment, the logger was removed and connected to the computer to transfer logged data. Rainfall data for the period of experiment was collected from the IITA, Ibadan weather station unit.

ii. Agronomic traits

During drought stress, data were collected on number of days to seedling emergence, stem greenness and wilting at 14, 21 and 30 days after planting (DAP) on a scale of 0-4 (Muchero et al., 2008) and on plant height at 14 and 21DAP.

Data taken during drought stress:

Stem greenness

0 = leaves and stem completely yellow

1 = 75% of the leaves yellow, brown either from the base or tip of stem

2 = 50% yellow or pale green, stem not turgid

3 = 25% yellow, 75% green but less turgid

4 = completely green and stem turgid

Wilting

0 = no sign of wilting

1 = 25% of wilting

2 = moderate wilting, 50%

3 = yellow and brown leaves with 75% wilting

4 = completely wilted

After re-watering, data were collected on:

Survival count (SC): number of surviving plants per genotype

Recovery type: was rated on a score of 0-5

0 = no recovery

0.5 = recovery from basal meristem

1 = recovery from the apical meristem

Recovery rate (RR) was computed as:
$$\frac{\text{No of dead plants}}{\text{Total no of emerged plants}} \times 100$$

(Fatokun, 2014 *pers. Comm.*)

4.2.4 Data Analysis

All variables were analyzed using SAS (Version 9.3; SAS Institute, Cary, NC). Phenotypic correlation and regression analyses were performed with PROC CORR and PROC REG. Significant means were separated using the least significant difference at 5% probability level ($LSD_{0.05}$). Cluster analysis was performed to group observations together using the Euclidean distance method using three discriminant phenotypic characters. A dendrogram was computed from the cluster to show relationships among the genotypes.

Table 4. 1: Status and designation of lines screened for seedling stage and terminal drought tolerance

S/N	Lines	Status	Designation	S/N	Lines	Status	Designation
1	13-309	Advanced Breeding Line	ABL01	51	IT99K-573-1-1	Improved variety	IMV17
2	14-62	Advanced Breeding Line	ABL02	52	Tvu1007	Tropical <i>Vigna unguiculata</i>	TVu01
3	15-145	Advanced Breeding Line	ABL03	53	Tvu10100	Tropical <i>Vigna unguiculata</i>	TVu02
4	16-109	Advanced Breeding Line	ABL04	54	Tvu11800	Tropical <i>Vigna unguiculata</i>	TVu03
5	19B-35	Advanced Breeding Line	ABL05	55	Tvu11982	Tropical <i>Vigna unguiculata</i>	TVu04
6	19C-8	Advanced Breeding Line	ABL06	56	Tvu11984	Tropical <i>Vigna unguiculata</i>	TVu05
7	21A-40	Advanced Breeding Line	ABL07	57	Tvu11986	Tropical <i>Vigna unguiculata</i>	TVu06
8	21A-54	Advanced Breeding Line	ABL08	58	Tvu12791	Tropical <i>Vigna unguiculata</i>	TVu07
9	22A-85	Advanced Breeding Line	ABL09	59	Tvu1436	Tropical <i>Vigna unguiculata</i>	TVu08
10	23B-136	Advanced Breeding Line	ABL10	60	Tvu1438	Tropical <i>Vigna unguiculata</i>	TVu09
11	24A-23	Advanced Breeding Line	ABL11	61	Tvu14539	Tropical <i>Vigna unguiculata</i>	TVu10
12	28-25A	Advanced Breeding Line	ABL12	62	Tvu14553	Tropical <i>Vigna unguiculata</i>	TVu11
13	31-181	Advanced Breeding Line	ABL13	63	Tvu14632	Tropical <i>Vigna unguiculata</i>	TVu12
14	40-210	Advanced Breeding Line	ABL14	64	Tvu14676	Tropical <i>Vigna unguiculata</i>	TVu13
15	45-111	Advanced Breeding Line	ABL15	65	Tvu148	Tropical <i>Vigna unguiculata</i>	TVu14
16	52-13A	Advanced Breeding Line	ABL16	66	Tvu15055	Tropical <i>Vigna unguiculata</i>	TVu15
17	55-261	Advanced Breeding Line	ABL17	67	Tvu15058	Tropical <i>Vigna unguiculata</i>	TVu16
18	55-71	Advanced Breeding Line	ABL18	68	Tvu15450	Tropical <i>Vigna unguiculata</i>	TVu17
19	57-109	Advanced Breeding Line	ABL19	69	Tvu15866	Tropical <i>Vigna unguiculata</i>	TVu18
20	58-246	Advanced Breeding Line	ABL20	70	Tvu16646	Tropical <i>Vigna unguiculata</i>	TVu19
21	58-60	Advanced Breeding Line	ABL21	71	Tvu2672	Tropical <i>Vigna unguiculata</i>	TVu20
22	58-66	Advanced Breeding Line	ABL22	72	Tvu2722	Tropical <i>Vigna unguiculata</i>	TVu21
23	5A-55	Advanced Breeding Line	ABL23	73	Tvu2731	Tropical <i>Vigna unguiculata</i>	TVu22
24	60-321	Advanced Breeding Line	ABL24	74	TVu2736	Tropical <i>Vigna unguiculata</i>	TVu23
25	60-374	Advanced Breeding Line	ABL25	75	Tvu294	Tropical <i>Vigna unguiculata</i>	TVu24
26	61-317	Advanced Breeding Line	ABL26	76	Tvu3562	Tropical <i>Vigna unguiculata</i>	TVu25
27	61-88	Advanced Breeding Line	ABL27	77	Tvu441	Tropical <i>Vigna unguiculata</i>	TVu26
28	64-25	Advanced Breeding Line	ABL28	78	Tvu4574	Tropical <i>Vigna unguiculata</i>	TVu27

Table 4.1 continued

29	64-68	Advanced Breeding Line	ABL29	79	Tvu522	Tropical <i>Vigna unguiculata</i>	TVu28
30	6-67	Advanced Breeding Line	ABL30	80	Tvu5415	Tropical <i>Vigna unguiculata</i>	TVu29
31	7-11	Advanced Breeding Line	ABL31	81	Tvu557	Tropical <i>Vigna unguiculata</i>	TVu30
32	71-10	Advanced Breeding Line	ABL32	82	Tvu6333	Tropical <i>Vigna unguiculata</i>	TVu31
33	8A-131	Advanced Breeding Line	ABL33	83	Tvu6443	Tropical <i>Vigna unguiculata</i>	TVu32
34	8B-46	Advanced Breeding Line	ABL34	84	Tvu6707	Tropical <i>Vigna unguiculata</i>	TVu33
35	CB27	Improved variety	IMV01	85	Tvu7778	Tropical <i>Vigna unguiculata</i>	TVu34
36	Ife Brown	Improved variety	IMV02	86	Tvu79	Tropical <i>Vigna unguiculata</i>	TVu35
37	IT81D-985	Improved variety	IMV03	87	Tvu8670	Tropical <i>Vigna unguiculata</i>	TVu36
38	IT81D-994	Improved variety	IMV04	88	Tvu9693	Tropical <i>Vigna unguiculata</i>	TVu37
39	IT84S-2246-4	Improved variety	IMV05	89	Tvu9797	Tropical <i>Vigna unguiculata</i>	TVu38
40	IT85F-3139	Improved variety	IMV06	90	Sanzi	Landrace	LDR01
41	IT89D-288	Improved variety	IMV07	91	Danila	Landrace	LDR02
42	IT90K-277-2	Improved variety	IMV08				
43	IT90K-76	Improved variety	IMV09				
44	IT93K-452-1	Improved variety	IMV10				
45	IT96D-610	Improved variety	IMV11				
46	IT97K-207-15	Improved variety	IMV12				
47	IT97K-499-35	Improved variety	IMV13				
48	IT97K-573-2-1	Improved variety	IMV14				
49	IT97K-819-132	Improved variety	IMV15				
50	IT98K-1111-1	Improved variety	IMV16				

‡All genotypes are true-breeding; SC = susceptible check

4.3 Results

4.3.1 Climatic conditions

On the average, temperature varied between 22.8°C and 39.8°C and relative humidity ranged between 43.89% and 94.35%. Average rainfall during the screening experiment was 131 mm (Figure 4.1).

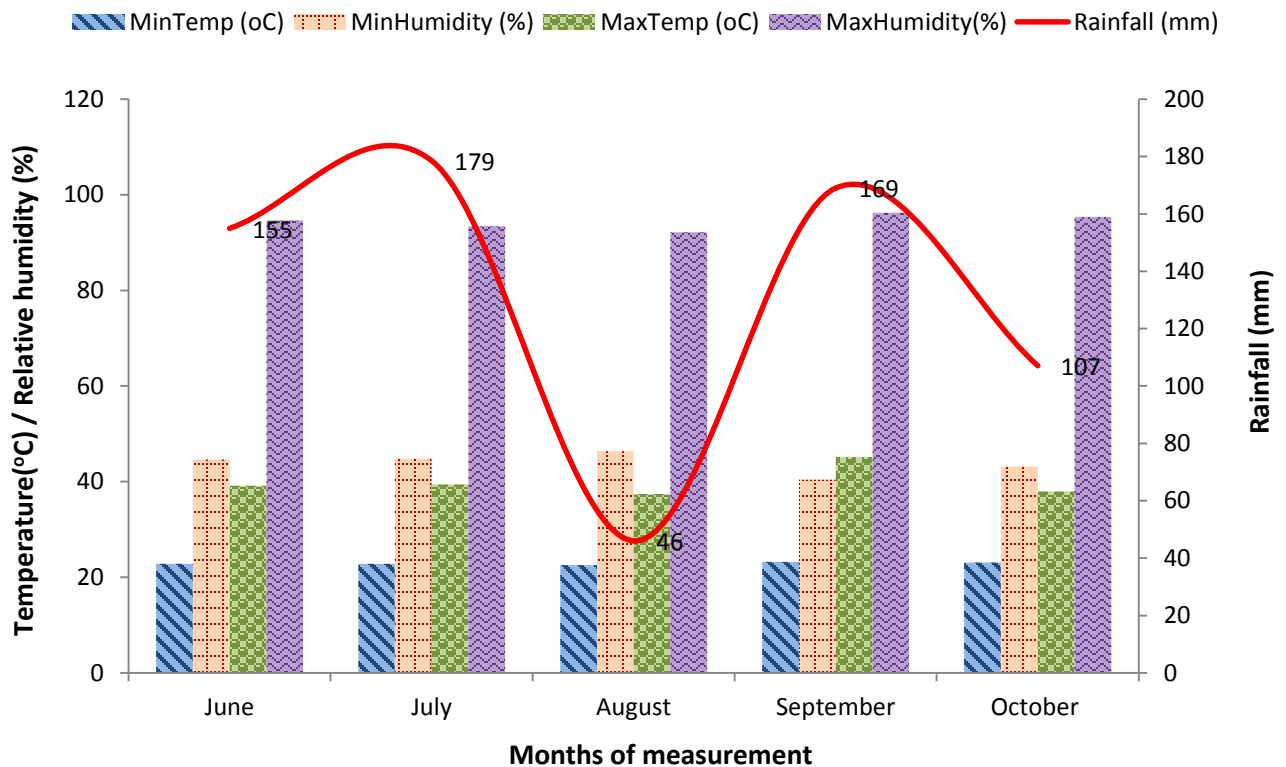


Figure 4. 1: Means of monthly temperature, relative humidity of the glass house and rainfall during screening experiment

4.3.2 Screening experiment

Results for the screening experiment for tolerance of cowpea germplasm to drought at seedling stage are presented in Tables 4.2 – 4.4. There were highly significant differences among the genotypes screened for tolerance to drought for all the parameters studied ($p < 0.0001$) (Table 4.2).

Stem greenness was reduced over time during the stress period and average stem greenness scores were 3.93, 2.79 and 1.66 at days 14, 21 and 30 days after planting respectively (Table 4.4). Stem greenness at 30 DAP was negatively correlated with wilting at days 21 and 30 after planting ($r = -0.19$, -0.54 respectively) but positively correlated with recovery ($r = 0.66$) (Table 4.3a). Stem greenness at 21 days after planting showed significant negative correlation with wilting at days 21 and 30 after planting ($r = -0.84$ and $r = -0.57$ respectively). The range of stem greenness scores differed among the different categories of cowpea germplasm screened. In the advanced breeding lines, stem greenness ranged from 3.87 – 2.17 for genotypes 15-145 and 58-60, respectively. Among the improved varieties, stem greenness score ranged from 3.81 – 2.3 for Ife Brown and IT97K-573-1-1. Among the TVu lines, it ranged from 3.72 – 1.82 for TVu11982 and TVu14632 respectively. Stem greenness scores for the landraces, Danila and Sanzi were 3.36 and 1.63 respectively.

Table 4. 2: Mean squares of measured traits for cowpea genotypes evaluated in the greenhouse for tolerance to drought at seedling stage.

Source of variation	Df	¹ DTE	PHT14	PHT21	SG14 DAP	SG21 DAP	SG30 DAP	W14 DAP	W21 DAP	W30 DAP	Recovery
Rep	2	0.28ns	12.28**	10.04*	0.49**	7.79***	5.39**	1.21***	2.19**	4.67**	0.01ns
Wooden box(Rep)	45	0.63*	9.59***	9.71***	0.29***	2.78***	3.88***	0.44***	2.55***	2.37***	0.1**
Genotypes	89	2.81***	29.77***	13.15***	0.19***	8.13***	5.62***	1.01***	17.02***	2.94***	0.22***
Error	888	0.46	2.3	2.42	0.06	0.72	0.95	0.07	0.45	0.73	0.05

*, **, ***, Significant at $P < 0.05$, 0.01 and 0.0001 respectively, ns=non-significant. ¹DTE = Days to seedling emergence, PHT14, PHT21= plant height at 14 and 21 days after planting, SG14DAP and SG30DAP = Stem greenness(0-4) at 14, 21 and 30 days after planting, W14DAP, W21DAP and W30DAP= Wilting (0-4) at 14, 21 and 30 days after planting

Wilting: significant differences in wilting existed among the evaluated genotypes and measurement periods ($P < 0.0001$). Wilting increased over time for the period of the drought stress. Average wilting scores were 0.25, 1.97 and 2.83 at days 14, 21 and 30 after planting, respectively (Table 4.4). Wilting showed a significant negative correlation with recovery at days 14 and 30 after planting. The wilting scores ranged from 0.37 – 2.23 in the advanced breeding lines for 7-11 and 19B-35. Among the improved varieties, the range was 2.17 – 1.04 for IT81KD-985 and IT93K-452-1; among the TVu lines, it ranged from 2.67 – 1.31 for TVu14553 and TVu8670 respectively. The landraces Danila and Sanzi had wilting scores of 1.78 and 2.5 respectively.

Plant height measured at 14 DAP was significant and positively correlated with height measured at 21 DAP ($r = 0.97$). There was a non-significant negative correlation between plant height and wilting ($r = 0.0004$) while it had a positive and significant relationship with stem greenness and recovery ($r = 0.21$, $r = 0.28$) respectively (Table 4.3b).

Recovery from drought: Genotypes showed highly significant differences for recovery from drought at seedling stage ($P < 0.0001$). Correlation analysis done on the average of the measurement days for wilting, plant height and stem greenness revealed a significant negative relationship between recovery and wilting ($r = -0.26$) but positive significant relationship for stem greenness ($r = 0.53$). Stem greenness showed a strong negative significant correlation with wilting ($r = -0.74$) (Table 4.3b). Because recovery from drought stress is important for survival and subsequent growth and reproduction, stepwise regression analysis of recovery on wilting, plant height and stem greenness was used to

determine which shoot variables could be used to predict seedling recovery from drought. Only stem greenness and wilting fitted into the model that explained 30.9% of variation to recovery. Stem greenness alone contributed 24.5% while wilting accounted for 6.4% of the variation in recovery (Figure 4.2).

Recovery ratings illustrated the ability of some genotypes to recover from early drought stress while others succumbed to the stress. Those genotypes with high percentage recovery may be of interest because they might possess mechanisms that sustained them through the early drought stress. In this study, Ife Brown had the highest recovery percentage of 83.33% (Table 4.4).

Table 4. 3: Spearman correlation among plant height, stem greenness, wilting and recovery for cowpea genotypes evaluated in the glass house for tolerance to drought at seedling stage.

a	¹DTE	PHT14	PHT21	SG14 DAP	SG21 DAP	SG30 DAP	W14 DAP	W21 DAP	W30 DAP	Recovery
DTE	1	-0.20*	-0.15ns	0.06ns	-0.15ns	-0.02ns	-0.15ns	0.17ns	0.17ns	0.06ns
PHT14		1	0.97***	0.12ns	-0.12ns	0.17ns	-0.25ns	0.19ns	0.18ns	0.28**
PHT21			1	0.21*	-0.24*	0.16ns	-0.38**	0.34**	0.27**	0.26*
SG14DAP				1	-0.18ns	0.18ns	-0.67***	0.24*	0.08ns	0.15ns
SG21DAP					1	0.37**	0.41***	-0.84***	-0.57***	0.23*
SG30DAP						1	-0.37*	-0.19ns	-0.54***	0.66***
W14DAP							1	-0.46***	-0.1ns	-0.24*
W21DAP								1	0.68***	-0.12ns
W30DAP									1	-0.25*
										1
b	PHT	SG	W	Recovery						
PHT	1	-0.0004ns	0.21*	0.28**						
SG		1	-0.74***	0.53***						
W			1	-0.26*						

¹DTE = Days to seedling emergence, PHT14, PHT21= plant height at 14and 21 days after planting, SG14DAP and SG30DAP = Stem greenness(0-4) at 14, 21 and 30days after planting, W14DAP, W21DAP and W30DAP= Wilting (0-4) at 14, 21 and 30 days after planting

*, **, ***, Significant at P < 0.05, 0.01 and 0.0001 respectively, ns=non-significant

Table 4. 4: Performance of best 20 and 10 worst cowpea lines screened for drought tolerance at seedling stage based on percentage rate of recovery.

Genotypes	*DTE	Plant height		Stem greenness (0-4)			Wilting (0-4)			¥RR(%)
		14DAP	21DAP	14DAP	21DAP	30DAP	14DAP	21DAP	30DAP	
Ife Brown	3.4	11.9	12.3	4.0	4.0	3.4	0.0	1.3	3.2	83.3
IT99K-573-1-1	3.4	10.2	10.6	4.0	3.0	1.9	0.0	2.1	3.1	57.1
5A55	3.3	7.8	7.3	4.0	3.8	2.7	0.3	0.7	1.9	50.0
IT90K-76	3.1	12.1	12.7	4.0	2.7	2.3	0.0	2.2	2.4	50.0
15-145	3.4	8.7	7.5	4.0	4.0	3.6	0.0	0.2	1.7	45.5
CB27	4.1	8.2	8.2	3.6	3.3	2.5	0.7	0.8	1.7	40.0
IT84S-2246-4	3.5	9.3	9.9	4.0	2.9	2.7	0.0	1.9	3.1	36.4
IT90K-277-2	3.3	13.0	13.7	4.0	2.4	3.1	0.0	2.9	3.1	36.4
19B-35	3.3	8.5	7.7	4.0	4.0	3.5	0.0	0.1	1.0	33.3
IT97K207-15	4.0	11.4	11.1	3.8	3.3	1.8	0.3	0.9	2.5	25.0
TVu15055	3.5	7.1	7.4	4.0	2.5	2.5	0.0	3.0	3.0	25.0
Tvu11984	3.8	9.6	10.1	4.0	1.8	1.8	0.0	3.1	3.0	25.0
IT89D-288	3.2	14.9	15.2	4.0	2.2	2.1	0.0	2.8	3.2	22.2
IT97K-819-132	3.9	8.4	8.3	3.9	3.9	2.3	0.2	0.6	2.3	20.0
IT81KD-985	3.0	9.6	10.3	4.0	3.5	2.2	0.0	2.4	3.0	18.2
IT93K-452-1	3.7	14.8	15.5	4.0	1.9	1.3	0.0	3.0	3.0	18.2
19C-8	3.0	8.1	8.7	4.0	3.9	3.3	0.1	0.2	1.3	16.7
64-25	3.1	9.6	9.2	4.0	3.5	1.9	1.0	1.3	2.3	16.7
6-67	3.0	7.4	7.9	3.9	3.8	2.0	0.3	0.5	2.1	16.7

Table 4.4 continued

Genotypes	*DTE	Plant height		Stem greenness (0-4)			Wilting (0-4)			‡RR(%)
		14DAP	21DAP	14DAP	21DAP	30DAP	14DAP	21DAP	30DAP	
Danila	3.0	9.7	10.3	4.0	3.3	2.8	0.0	2.2	3.2	16.7
TVu79	3.0	9.6	10.2	4.0	1.5	1.5	0.0	2.9	3.0	0.0
TVu8670	3.5	9.0	9.6	4.0	2.2	1.7	0.0	3.1	3.3	0.0
TVu9797	3.4	8.4	8.8	4.0	1.2	0.6	0.0	2.8	3.1	0.0
Tvu1007	3.7	10.1	10.5	4.0	2.7	1.8	0.0	2.4	3.0	0.0
Tvu14553	3.1	9.2	9.5	4.0	2.0	1.3	0.0	2.8	3.0	0.0
Tvu15450	3.2	9.5	10.2	4.0	2.6	1.2	0.0	2.2	2.8	0.0
Tvu15866	3.1	9.3	9.6	4.0	2.4	2.0	0.0	2.3	2.9	0.0
Tvu2736	3.6	6.1	6.5	4.0	1.4	1.4	0.0	2.7	2.2	0.0
Tvu9693	3.9	7.0	7.5	4.0	1.6	1.3	0.0	2.8	2.9	0.0
TVu7778 (SC)	3.1	7.7	8.3	4.0	1.3	0.9	0.0	3.1	3.4	0.0
*Mean	3.36	8.96	9.22	3.93	2.79	1.66	0.25	1.97	2.83	0.08
SE	0.03	0.07	0.08	0.01	0.04	0.04	0.01	0.04	0.03	0.08
LSD (0.05)	0.62	1.37	1.42	0.23	0.78	0.89	0.24	0.62	0.78	0.21

*Values derived from both wooden box screening; LSD = Least significant difference; SC= susceptible check; DTE=days to emergence; ‡RR = Recovery rate = no of dead / no of survival *100

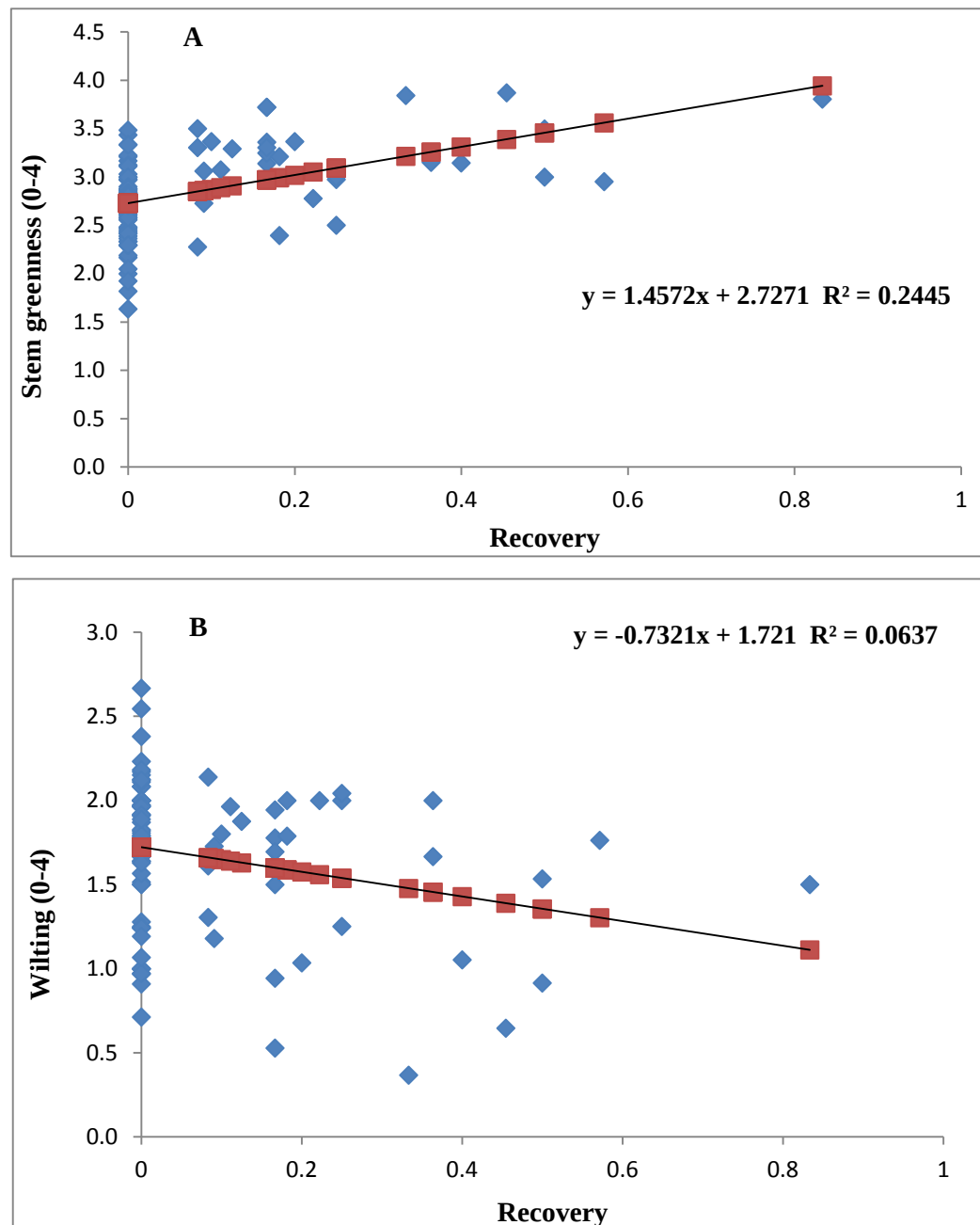


Figure 4. 2: Relationship between recovery rate and wilting (A) and stem greenness (B) for cowpea genotypes evaluated under seedling drought stress in the glass house. Measurement for stem greenness and wilting were means of all the measurement periods during stress while recovery (0-1) was recorded 2 weeks after resuming water. Square symbols are the predicted values based on the regression model and the diamonds are the observed values. Each point represents average of four plants per genotype replicated thrice.

4.3.3 Cluster analysis

Cowpea genotypes screened were grouped into three clusters. Stem greenness, wilting and recovery rate with sufficient discriminative power were used to cluster the genotypes into three main cluster groups. Cluster I consisted of 14 genotypes, cluster II had 48 and cluster III had 28. The largest cluster (II) comprised of all the lines from all the germplasm sources used in this study. Cluster I comprised mainly of the improved and the advanced breeding lines (Figure 4.3). The main clusters were further subdivided into smaller clusters that were closer in relationship.

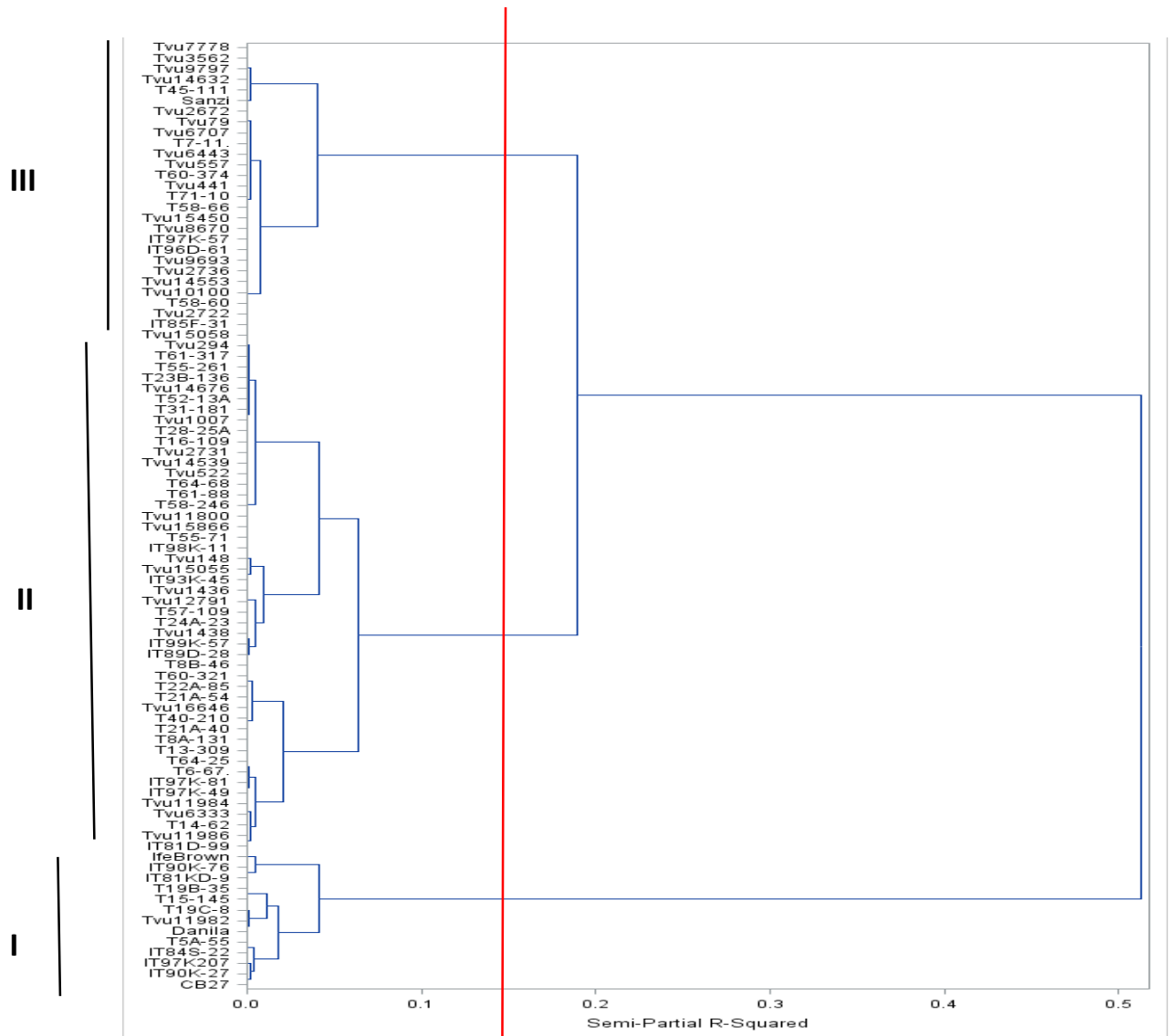


Figure 4. 3: Dendrogram of 90 cowpea germplasm revealed by average linkage cluster analysis based on 3 discriminant phenotypic characters.

4.4 Discussion

The objective of this study was to identify parents that are tolerant to drought that can serve as parental sources of favourable alleles for development of pure cowpea lines tolerant to drought. Results of the seedling screening could only be used for selection in this study owing to the interference of rain during the field trial. The use of wooden boxes or pots for screening for drought tolerance in the screen or glass house have however been reported to help quickly in identifying cowpea plants that would show drought tolerance especially at the vegetative stage. Studies by Watanabe et al. (1997) and Ewansiha and Singh (2006) have shown positive and significant correlation between drought tolerance in the seedling stage as observed using wooden boxes in a screen house and drought tolerance screening on the field. They therefore concluded that cowpea lines found to be drought tolerant at the seedling stage using wooden box should also perform well under drought in the field.

The results of this experiment confirmed that despite the inherent comparative tolerance to drought, cowpea exhibits significant genetic variation in response to drought stress. The drought-stress responses were manifested in a range of discrete physiological and morphological characteristics apparently related to the ability of the cowpea plants to tolerate and recover from seedling stage drought stress. It was observed that within genotypes, individual plants expressed varying levels of survival and ultimate recovery in response to drought stress. A similar result was reported by Watanabe et al. (1997).

In this study, genotypes like Ife Brown, 15-145 and Danila that wilted slowly and maintained green stems till the resumption of watering were able to conserve water in leaves and stem tissues, survive the dry period and resume growth, transferred into pots till maturity. These genotypes may have a mechanism to slow their transpiration rate and not

deplete their soil moisture reserve as quickly as genotypes that have high wilting score. However, genotypes such as IT93K-452-1 and TVu 1505 that wilted fast had relatively lower recovery rate. Similar findings were observed in soybean (Ries et al., 2012), common bean (*Phaseolus vulgaris*) (Mukeshimana et al., 2014). The slow wilting observed in this experiment was not associated with deep-water extraction by the root because the genotypes were planted in boxes with shallow soil profiles; it therefore meant that this trait is associated with water saving mechanism in the shoot. In grain legumes such as peanut (*Arachis hypogaea*), chickpea (*Cicer arietinum*), soybean and cowpea, traits such as lower transpiration rate under lower vapour pressure deficits (VPD) has been recognized as soil water-saving strategy in tolerant genotypes (Sinclair et al., 2008; Devi et al., 2010; Zaman-Allah et al., 2011; Belko et al., 2012).

Stem greenness was found to be an important seedling trait associated with drought tolerance in cowpea. From this study, stem greenness was positively correlated to recovery and genotypes such as Ife Brown that maintained high stem greenness scores during the drought stress period had higher recovery rates. Similar observations were made in sorghum (*Sorghum bicolor* (L.) Moench); where maintenance of stem greenness was found to be highly correlated with leaf chlorophyll content and drought tolerance (Xu et al., 2000). In other crops, various shoot characteristics have been used to evaluate drought tolerance at the seedling stage. In cotton, seedling recovery after stress was used as a criterion to assess drought tolerance in cotton (*Gossypium hirsutum*) (Longenberger et al., 2006; Rauf, 2008). Tolerance to seedling leaf death and recovery was used in rice (Mitchell et al., 1998; De Datta et al., 1988). In soybean, slow wilting was reported to be associated with seedling drought tolerance (Sadok et al., 2012). In cowpea, significant correlations

were reported between stem greenness, survival and recovery dry weight (Thomas and Howart, 2000). The fundamental method to develop variation for selection is crossing genotypes where selecting the parents may be very important and existing genetic differences between the crossing parents be required. Grouping the genotypes can give breeder the opportunity to select appropriate parents for crossing. Cluster analysis was used to group white beans accessions (Koiij and Saba, 2015) and common bean (Kahraman et al., 2015). Genotypes screened for seedling stage drought tolerance were grouped into three main clusters from where the lines for genetic studies were selected.

4.5 Conclusion

This study was conducted to determine the shoot traits associated with drought tolerance at an early development stage and select parents for genetic studies. The significant genotypic variation observed among the genotypes for all the traits measured indicated that significant progress can be made in selecting for drought tolerance using the wooden boxes. Shoot traits such as stem greenness, wilting and recovery from drought were identified from this study to be associated with drought tolerance at seedling stage in cowpea. Plant growth and productivity after drought stress are dependent on the degree of recovery from stress. Stem greenness and wilting were found to be positively and negatively correlated with recovery respectively. The assay that allows for a separation of root and shoot traits functional in drought tolerance study in cowpea would provide breeders a faster means to combine these traits into new cultivars to enhance performance under a broad range of soil moisture conditions. Twenty genotypes were selected as parental lines for genetic studies using the result obtained from the cluster analysis.

CHAPTER FIVE

5.0 Combining ability study of selected cowpea lines and performance of their first filial generation under managed stress.

5.1 Introduction

In African countries, agriculture remains the most important sector of the economy given its multiple roles in food security, employment and contribution to national Gross Domestic Products (GDPs). Despite this, however, agriculture in Sub-Saharan Africa (SSA) is almost 80% dependent on rainfall which has become less reliable resulting in shorter growing seasons in many regions (Kandji et al., 2006). Some of the most important impacts of global climate change including reduced or inconsistent rainfall are predicted to occur more frequently in the tropical regions and the impact will be more among “subsistence” or “smallholder” farmers in developing countries, thus threatening food security in the region (Morton 2007; Cavalieri et al., 2011).

Drought is defined in agricultural terms as a condition of insufficient moisture caused by a deficit of precipitation over a given period. It is the most important environmental factor, which induces significant alterations in plant physiology and biochemistry leading to reduction in crop productivity (McClean et al., 2011; Lauer et al., 2012). Research directed at improving crop resistance to production stresses, especially drought, is needed to complement other efforts under way to alleviate crop failure and malnutrition problems in the developing countries.

The cowpea crop plays a critical role in providing nutritional security to millions of people in Africa and other parts of the developing world, since it is one of the few available food sources that combines essential minerals and high quality protein (~ 26%) that nutritionally

complements staple low-protein cereal crops and tuber crops predominant in the region (Santos and Boiteux, 2015; Santos et al., 2015; Yewande and Thomas, 2015). It is also a valuable component of cropping systems in the drier regions because of its ability to fix atmospheric nitrogen (Sinclair et al., 2015). Although, cowpea is considered to be more drought tolerant compared with other legume crops grown in the semi-arid tropics, its productivity is adversely affected by drought particularly because production areas are subject to water deficits causing substantial yield losses. This necessitates more effort to enhance its resilience to water deficits (Agbicodo et al., 2009; Belko et al., 2012). Availability and adoption of such cowpea varieties by farmers will contribute positively to ensuring food security and improving human nutrition in the SSA region.

Efforts made in the past to develop drought-tolerant cowpea varieties have met with limited success. This limitation has been attributed to the complexity of factors at play in the determination of drought tolerance and high yield in the crops and limited information on the genetic basis for drought tolerance in cowpea (Fatokun et al., 2012). Extensive research has been carried out on the screening for mid- and late-season drought tolerance in cowpea focusing on morphological, biochemical and physiological responses of cowpea to drought (Singh and Matsui 2002; Ogbonnaya et al., 2003; Hamidou et al., 2007; Belko et al., 2012; Muchero et al., 2013). Nevertheless, only very few studies have used the resultant indices from these studies to select parental genotypes for further genetic studies.

It has been reported that genes that could contribute to higher levels of drought tolerance exist in some of the under-exploited cowpea germplasm maintained in the genetic resources unit at the International Institute of Tropical Agriculture (IITA) (Watanabe et al., 1997; Fatokun et al., 2012). In order to be able to efficiently utilize these lines as parental

lines to enhance the level of drought tolerance in the improved cowpea varieties, information on their performance in cross combinations to produce superior progenies that will combine desirable agronomic traits and the drought tolerance genes in the segregating generations is pertinent in addition to the study of nature of gene action controlling yield and other related traits under drought stress. Alidu et al. (2013) reported the importance of GCA for seed weight, number of pods per plant and grain yield under moisture stress in a diallel mating analysis of improved and adapted cowpea varieties.

However, there is limited information on the combining abilities of the cowpea germplasm that can guide efficient choice of tolerant lines that will combine well to produce desirable segregants on which selection can be applied for the development of novel drought tolerant varieties. The objectives of this study therefore were to (i) determine good general combiners among the cowpea lines for high yield and drought tolerance (ii) determine the gene action controlling grain yield and drought tolerance in the cowpea germplasm under managed stress conditions (iii) identify potential F_1 hybrids that can be advanced through selection towards the development of novel cowpea varieties with enhanced drought tolerance and high yield.

5.2. Materials and Methods

5.2.1 Development of F₁ crosses

i. Genetic materials

Twenty lines out of the 91 screened for drought tolerance were selected based on how they clustered on the dendrogram (Chapter 4). The 20 lines made up of seven improved lines, hereafter referred to as improved, released lines (IMR), two landraces (LDR) and eleven Tropical *Vigna unguiculata* lines (TVu) were assigned into four groups of five lines each (Table 5.1). Using the modified North Carolina design II mating scheme, inter-group crosses were made in four sets and each line from one group was mated with all the five lines in another group to generate twenty-five single F₁ crosses from each set and a total of 100 single F₁ hybrids (Comstock and Robinso, 1948; Dhliwayo et al., 2009). Each line was used as a male or female once in different sets.

The mating scheme for the four sets is as follows:

SET 1: GROUP I X GROUP II

SET 2: GROUPII X GROUP IV

SET 3: GROUP III X GROUP I

SET 4: GROUP IV X GROUP III

Table 5. 1: Line code, group and maturity period of 20 cowpea inbred lines selected for NCD II hybrid.

S/N	Line	Line code	Group	Pedigree	Maturity
1	Ife Brown	IMR01	1	TVu59 x TVu53	Medium
2	IT90K-76	IMR03	1	(IT84S-2246-4 X B301) X IT84S-2246-4	Medium
3	IT81KD-985	IMR02	1	[(TVu1190 x TVu76) x TVu2027] x TVu625	Medium
4	IT90K-277-2	IMR04	1	(IT87F-1777-2 X IT84S-2246-4) x TVx3236	Medium
5	DANILA	LDR01	1	Farmers' local landrace selection	Late
6	IT89KD-288	IMR09	2	(IT87F-1777-2 X IT84S-2246-4) X IT87F-1777-2	Medium
7	IT99K-573-1-1	IMR07	2	IT93K-596-9-12 X IT86D-880	Early
8	CB27	IMR16	2	Selection	Early
9	TVu11986	TVu07	2	Tropical <i>Vigna unguiculata</i> population	Medium
10	TVu6333	TVu06	2	Tropical <i>Vigna unguiculata</i> population	Medium
11	TVu7778	TVu34	3	Tropical <i>Vigna unguiculata</i> population	Medium
12	Sanzi	LDR02	3	Farmers' landrace	Medium
13	TVu3562	TVu26	3	Tropical <i>Vigna unguiculata</i> population	Medium
14	TVu9797	TVu38	3	Tropical <i>Vigna unguiculata</i> population	Medium
15	TVu79	TVu35	3	Tropical <i>Vigna unguiculata</i> population	Medium
16	TVu6707	TVu33	4	Tropical <i>Vigna unguiculata</i> population	Medium
17	TVu9693	TVu37	4	Tropical <i>Vigna unguiculata</i> population	Medium
18	TVu2736	TVu11	4	Tropical <i>Vigna unguiculata</i> population	Medium
19	TVu8670	TVu36	4	Tropical <i>Vigna unguiculata</i> population	Medium
20	TVu10100	TVu13	4	Tropical <i>Vigna unguiculata</i> population	Medium

ii Crossing nursery

The nursery was set up in the screen house of the International Institute of Tropical Agriculture, Ibadan. Five 25 cm diameter pots were arranged in a row. Three rows were planted for each parent for a cross and arranged by sets. Six seeds were planted per pot and were later thinned to three seedlings after two weeks of planting. Cultural practices such as manual weeding were regularly done and spraying of λ -Cyathothrin (Karate) 120 ml in 20L of water to control insect pests was done a month after planting and later as the need arose. Hand pollination commenced from April 15 2014 and lasted eight months. To ensure continuous availability of flowers so as to be able to develop enough F_1 seeds for evaluation; two steps were taken: (i) cowpea plants already flowering were propagated vegetatively through the vine. This was fast as flowering resumed soon after the vine established roots and (ii) at 1 month interval, new sets of pots were planted to ensure continuous availability of fresh flowers throughout the pollination period. The flowers were prepared for pollination by cutting two-thirds of the petals of unopened mature flower buds of the female parent opposite the stylar and staminal section with the aid of forceps to expose the pistil and stigma. The anthers were also carefully removed with the aid of the forceps. Pollination was done by gently rubbing the anther from freshly opened male parent on the exposed stigma of the female parent and labeled appropriately (Plate 5.1a – c). Harvesting pods of the F_1 was done as they matured and later bulked, dried to 13% moisture content and shelled (Yakubu et al., 2012).

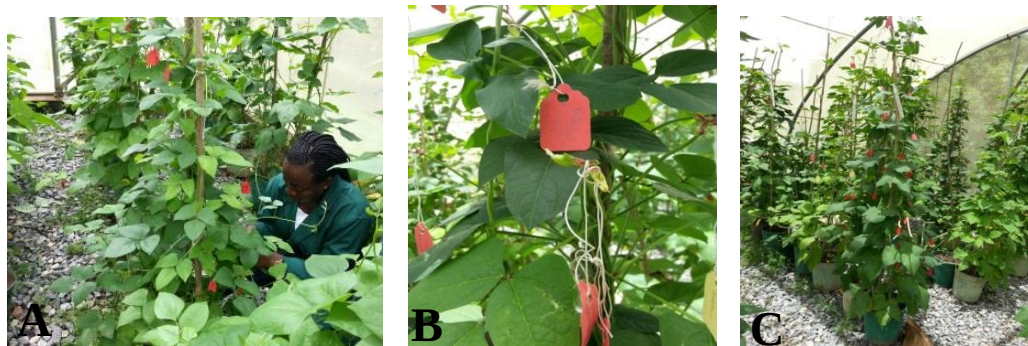


Plate 5. 1 (a-c): Hand emasculation, pollination of cowpea and resulting crosses

iii. Location and climate

The evaluation experiments were planted in IITA experimental stations as follows: in Ibadan, Oyo State on the 2nd December 2014 during the dry season and Minjibir, Kano State on the 19th February 2015 during the dry season following the climatic peculiarity of each location. The experimental field at Ibadan (derived savanna) is located at an altitude of 212 m above sea level (asl), latitude of 07°03'N and longitude of 3°9'E with annual rainfall of 1,400 mm. Ibadan experiences rain-free or sparing rainfall from the end of November to March annually. This makes it suitable for drought screening experiments during these months. More importantly, there was no rain interference especially during the critical periods of stress imposition in the years of study (2014-2015) (Figure 5.1). Minjibir (Sahel savanna) has an altitude of 431 m asl, latitude of 12° 13'N and longitude 3°55'E. Minijbir, Kano State falls in the Sahel region, characterized by a long and dry season between October and June with short erratic rainy season between July and September and a total annual rainfall between 400-600 mmyr⁻¹. Rainfall, maximum and minimum, and relative humidity readings of Minjibir and Ibadan for the period of experiments were recorded daily by an automated weather station situated at each location. Means of monthly weather readings for both locations are presented in Figure 5.1.

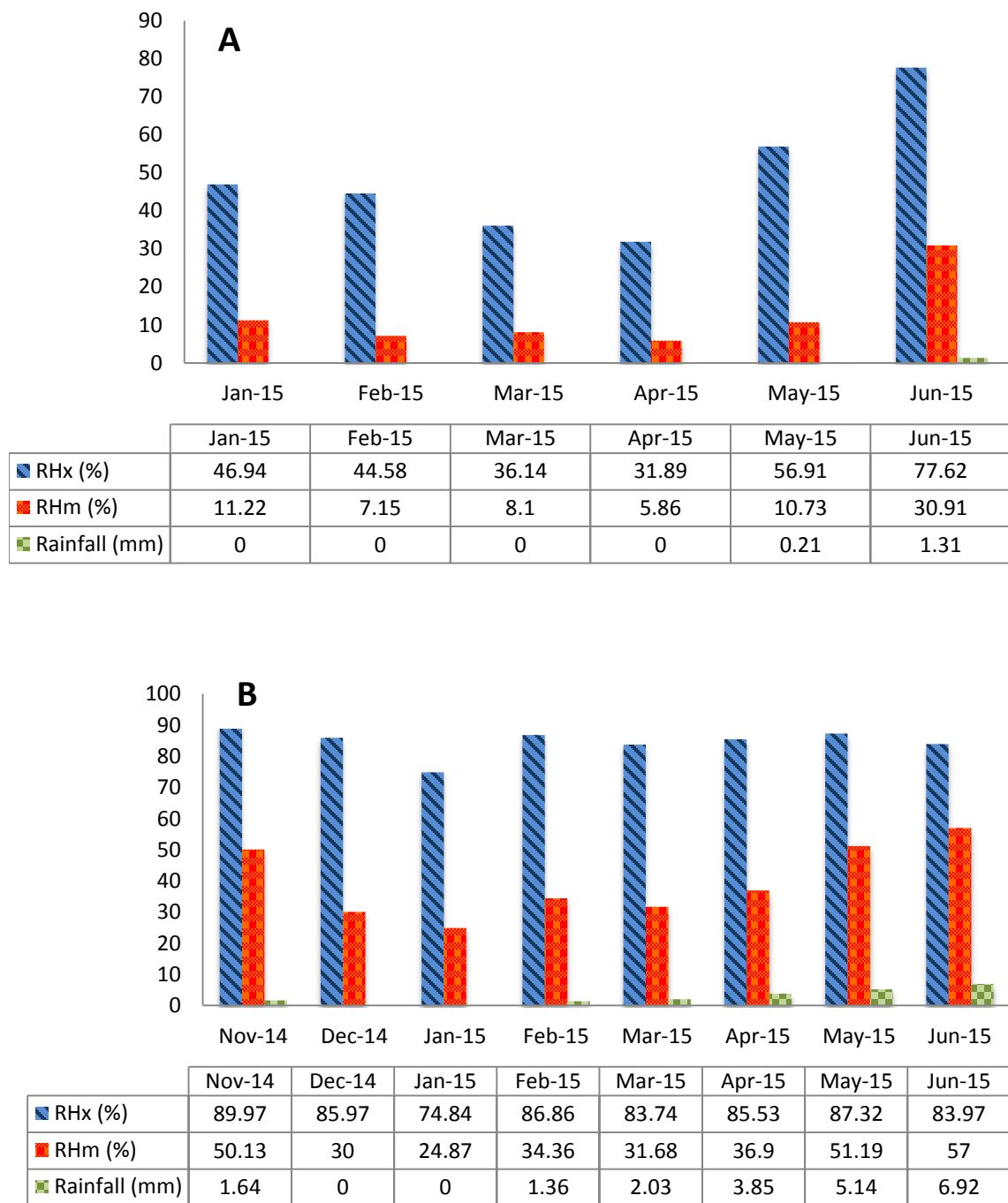


Figure 5. 1: Means of monthly rainfall (mm), maximum and relative humidity readings for Minjibr (A) and Ibadan (B) for the period of experiment in each location.

5.2.2 Evaluation of F₁ crosses and parents for yield and drought tolerance under managed stress conditions

The 100 F₁ crosses and the 20 parental lines were evaluated in two locations during the season of 2014 in Ibadan and 2015 in Minjibir under irrigation. The test materials were arranged in a 12 x 10 alpha (0, 1) lattice with three replications. Each experimental plot consisted of 1 m single row with test materials spaced at 0.20 m within rows and 0.75 m between rows. Three cowpea plants were planted per hills which were later thinned to 2 plants per hill two weeks after planting (WAP) giving a plant population density of 133,333 plants per hectare at each location.

Experiments were planted in two adjacent blocks that received different irrigation regimes. Block 1 is the drought stress (DS) block while block 2 is the well-watered (WW) block. The blocks were separated by an alley that was 20 m wide to restrict lateral movement of water from the fully irrigated block to the drought stressed block. Irrigation water was supplied to both blocks with an overhead sprinkler irrigation system designed to dispense 17 mm of water twice a week until 35 DAP (days after planting). Thereafter, DS blocks did not receive water until harvesting while the WW blocks received water twice a week until physiological maturity. Except for the different irrigation treatments, all field management practices were uniform for both the well-watered and water-stressed experiments. Insect pests were controlled at when due using 60-80 ml of λ -cyhalothrin (Karate 5EC) in 20 L of water.

The experiment was therefore conducted under four environments:

- i. IITA, Ibadan experimental station + drought stress = environment 1 (E1)
- ii. IITA, Ibadan experimental station + well-water = environment 2 (E2)
- iii. IITA, Minjibir experimental station + drought stress = environment 3 (E3)
- iv. IITA, Minjibir experimental station + well –water = environment 4 (E4)

5.2.3 Data collection

i. Soil moisture content

Access tubes were installed in both well-watered and moisture stressed blocks to monitor volumetric soil moisture content during the crop growth period, particularly during the critical periods of moisture stress. Six soil profiles were dug diagonally across each block for each water regime using an auger hammer. The length for the soil probes were different for both locations owing to the peculiarities in the soil profile for the two locations. For Ibadan, probe length of 0.6 m long was hammered into the soil while probe length of 1.2 m long was hammered into the soil at Minjibir using the specialized installation kits that came with the instrument (HH2 moisture meter by Delta Devices). The procedures for installation and moisture reading as explained in the installation guide were followed.

ii. Agronomic data

Data were recorded on plot basis on both water-stressed and fully irrigated plots at both locations. Days to 50% flowering and to maturity were recorded as number of days from flowering to when 50% of the plants in the plot had opened their flowers and had matured pods respectively. At harvest, numbers of pods per plant, number of seeds per pod and

hundred-seed weight were taken as average of five randomly selected plants within the plot excluding the border plants. Delayed leaf senescence (DLSC) was scored on a scale of 1-9, where 1 = almost all leaves are green and 9= almost all leaves are dead (Muchero et al., 2013).

Data on grain yield were recorded on plot basis (five plants per plot) in grams and later converted to kg ha^{-1} using the following formula:

$$\text{Grain yield (Kg ha}^{-1}\text{)} = \left[\frac{10,000 \times \text{total grain weight per plot}}{\text{plot area harvested} \times 1000} \right]$$

Data on Normalized Difference Vegetation Index (NDVI) was taken using the handheld Greenseeker® crop sensor which evaluates traits such as early vigour and stay green which are important for adaptation to drought stress. NDVI measurements were taken at different growth stages: vegetative (1), flowering (2) and pod-filling (3). The device computed the NDVI according to this formula:

$$NDVI = \left[\frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \right]$$

where R_{NIR} = the fraction of emitted NIR radiation returned from the sensed area (reflectance), and R_{RED} = the fraction of the emitted red radiation returned from the sensed area (reflectance) (Cabrera-Bosquet et al., 2011; Islam et al., 2011). Upon pulling the trigger, the sensor turns on, emits brief bursts of red and infrared light, and then measures the amount of each type of light that is reflected back at the sensor. The strength of the detected light is a direct indicator of the vigor or health - of the crop. The sensor displays the measured value in terms of an NDVI reading on its LCD display screen (Plate 5.2 and

5.3) NDVI readings range from 0.00 to 0.99; the higher the reading, the healthier the plant under stress.



Plate 5. 2: Schematic representation of how data was captured using the Greenseeker® handheld sensor



Plate 5. 3: Taking NDVI measurements on cowpea plants using greenseeker® handheld crop sensor.

5.2.4 Data Analyses

Analysis of Variance (ANOVA) was performed separately for drought stress and well-watered environments for the crosses and their parents to generate entry means adjusted for block effects according to the lattice design (Cochran and Cox, 1960; Menkir et al., 2003). The pooled error mean square was calculated for each block ANOVA by dividing the sum of the error sums of square by the corresponding sum of the error degrees of freedom. Combined analysis of variance was then computed across environments using the adjusted means. In the combined analysis, environment, replications and blocks were treated as random effects while crosses were considered as fixed effects. All analyses were

carried out using PROC GLM in SAS (SAS Institute, 2009) using a RANDOM statement with TEST option.

The ANOVA of NC II for each environment was performed on the entries using PROC GLM in SAS using a RANDOM statement with the TEST option (SAS, 2008). The crosses (sets) component of variation was divided into variation due to male (sets), female (sets), and female x male (sets) interaction. The main effects of male (sets) and female (sets) represent the general combining ability (GCA) while the female x male (sets) interaction represents specific combining ability (SCA) effect (Hallauer and Miranda, 1988). The F tests for male (sets), female (sets), and female x male (sets) mean squares were computed using the mean squares for their respective interaction with environment. The mean square attributable to environment x female x male (sets) was tested using the pooled error mean squares.

The general linear model for NC II mating design with set is:

$$X_{ijklm} = \mu + g_i(S_l) + g_j(S_l) + h_{ij}(S_l) + E_m + r_k (SE)_{lm} + (SE)_{lm} + (E_g)_{im}(S_l) \\ + (E_g)_{jm}(S_l) + (E_h)_{ijm}(S_l) + e_{ijklm}$$

Where;

X_{ijklm} = the observed value of the progeny of the i^{th} female, j^{th} male in the k^{th} replication with set l and in the m^{th} environment.

μ = population mean

S_l = average effect of the l^{th} set

$g_i(S_l)$ = GCA effect common to all crosses of the i^{th} female nested within l^{th} set

$g_j(S_l)$ = GCA effect common to all crosses of the j^{th} male nested within l^{th} set

$h_{ij}(S_l)$ = SCA effect of the cross from the i^{th} female and j^{th} male nested within l^{th} set

E_m = average effect of the m^{th} environment

$r_k (SE)_{lm}$ = the effect of the k^{th} replication nested within the l^{th} set and m^{th} environment

$(SE)_{lm}$ = Interaction between the set effect and the environment

$(E_g)_{im}(S_l)$ and $(E_g)_{jm}(S_l)$ = Interaction between environment and GCA nested within sets

$(E_h)_{ijm}(S_l)$ = Interaction between environment and SCA nested within sets

e_{ijklm} = Experimental error

General combining ability (GCA) was estimated as:

$$GCA_f = X_f - \mu, GCA_m = X_m - \mu$$

Where, GCA_f and GCA_m = General combining ability (GCA) of female and male parents respectively

X_f and X_m = Mean of female and male parents respectively

μ = Overall mean of crosses in the experiment

Specific combining ability (SCA) was estimated as:

$$SCA_X = X_X - E(X_X) = X_X - [GCA_f + GCA_m + \mu] \text{ Where,}$$

SCA_X = Specific combining ability of the cross X

X_X = Observed mean value of the cross

$E(X_X)$ = Expected mean value of the cross based on the GCA value of both parents.

The yield data was further subjected to genotype main effects plus genotype x environment interaction (GGE) bi-plot analysis to evaluate the G x E interaction of each experiment

using the GGE bi-plot application (Yan et al., 2000; Yan, 2001). The bi-plot model equation is:

$$Y_{ij} - Y_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{j2} \eta_{j2} + \Sigma_{ij}$$

Where, Y_{ij} = average yield of genotype i in environment j

Y_j = average yield of all genotypes in all environments j

λ_1 and λ_2 = singular values for principal component PC1 and PC2 respectively

ξ_{i1} and ξ_{j2} = PC1 and PC2 scores for genotype i

η_{j1} and η_{j2} = PC1 and PC2 scores for environment j

Σ_{ij} = residual of the model associated with the genotype i in environment j

The data was not transformed (Transform = 0), not standardized (Scale = 0) and environment centered (Centering = 2).

Drought tolerance index (DTI) or yield reduction was calculated as the percentage of grain yield loss due to drought stress on the yield realized under well-watered conditions (Ogbonaya et al., 2003; Derera et al., 2008) was calculated as:

$$DTI(\%) = \left[\frac{(\text{Yield under wellwatered} - \text{yield under drought})}{\text{Yield under wellwatered}} \right] \times 100$$

5.3. Results

5.3.2 Soil moisture content

Results of the measured soil moisture content taken at one week intervals between 10/1/2015 to 7/2/2015 for Ibadan and between 10/4/2015 to 8/5/2015 for Minjibir respectively during the flowering periods of cowpea under drought stress and well-watered conditions are shown in Figure 5.2. The measuring tubes were marked at interval of 100

cm. The 100 cm marking corresponds to the volumetric water reading closest to the base of the access tube in the soil while the 400 cm or 1 m marking corresponds to the soil reading close to the soil surface. At every 100 cm interval, volumetric water content at the well-watered blocks was higher than that of the drought stressed blocks (Figure 5.2).

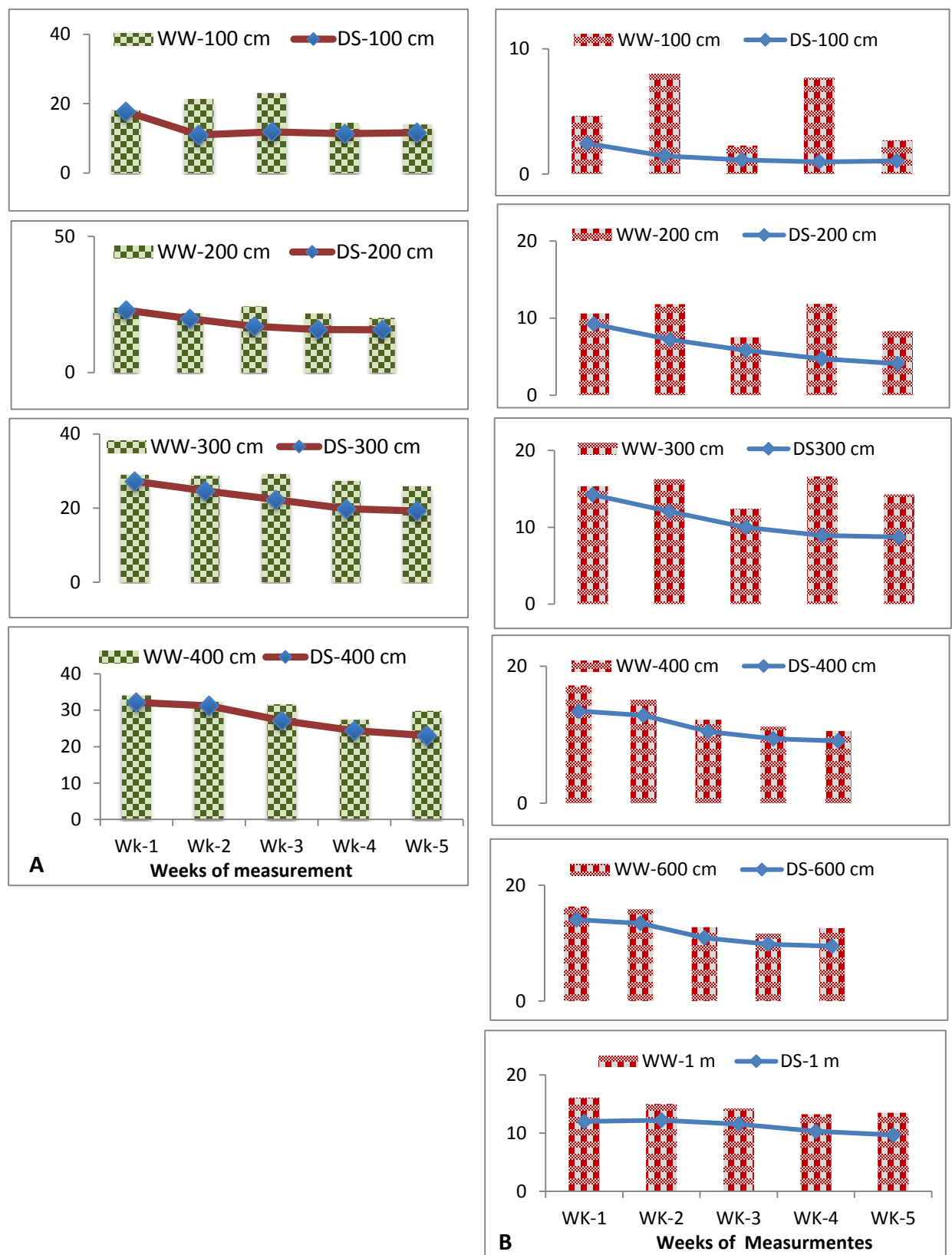


Figure 5. 2: Volumetric water contents measured under well-watered (WW) and drought stress (DS) in Ibadan (A) and Minjibir (B), Nigeria

5.3.3 Performance of parental lines under drought and well-watered conditions

Significant differences were observed among the parental lines for grain yield and other measured traits across drought and well-watered conditions (Table 5.2). Genotype x environment interaction effects were significant for all traits except for hundred seed weight, number of seeds per plant and number of pods per plant under DS and for number of seeds per pod under WW (Table 5.2). Under DS, genotypes accounted for 68% of the total sum of squares while genotype x environment interactions accounted for 20% and environment contributed 12%. Same trend was observed under WW environment where genotypes contributed 51%, genotype x environment contributed 39% and environment 0.1%. Across research environments, genotype contributed 50%, genotype x environment interaction 42% and environment contributed 7% (Table 5.3).

Grain yield across drought environments ranged between 116 kg ha⁻¹ for TVu11986 and 1,788 kg ha⁻¹ for TVu6707 with a trial mean of 587 kg ha⁻¹. Across well-watered environments, the trial mean yield was 728 kg ha⁻¹ while grain yield among parental lines ranged between 191 kg ha⁻¹ for Ife Brown and 2,127 kg ha⁻¹ for TVu6707 (Table 5.4).

Table 5. 2: Mean square of 20 parents for grain yield and other measured traits under drought stress, well-watered conditions and across research environments.

‡Traits	ENTRY			ENV			ENTRY *ENV			SE ±		
	‡DS	WW	AC	DS	WW	AC	DS	WW	AC	DS	WW	AC
GY	550963***	815231***	78.42***	1799511**	26809ns	30.12***	162359ns	511869**	8.63***	48.08	55.88	37.07
SW100	23.77*	33.64**	1179844***	50.57***	60.55***	1087767***	7.2ns	10.98***	330928***	0.35	0.31	0.24
SDPOD	75.81**	25.96***	57.63***	33.79***	47.40***	44.48***	8.46ns	5.01ns	5.63**	0.32	0.27	0.21
DFL	35.48***	35.42***	50.89***	359.91***	670.89***	346.62***	19.65***	18.51***	19.93***	0.39	0.41	0.28
NDVI_1	0.06***	0.05***	0.06***	2.34***	2.46***	1.60***	0.03**	0.04***	0.04***	0.02	0.02	0.02
NDVI_2	0.04***	0.04***	0.07***	0.16***	0.18***	0.12***	0.02**	0.03***	0.02***	0.01	0.01	0.01
NDVI_3	0.03*	0.02***	0.03**	1.18***	2.35***	1.23***	0.04**	0.04***	0.03***	0.02	0.02	0.01
PODPLT	589.33*	1270.10**	1387.08***	615.08ns	1665.54ns	1766.78**	444.26ns	1102.35**	756.82***	1.85	2.46	1.55
SDPLT	169317*	196352***	235101***	91298ns	20210ns	140781*	92448*	130601**	100695***	23.03	28.15	18.25
DLSC(1-9)	2.61ns	-	-	2.12ns	-	-	2.41ns	-	-	0.14	-	-
df	19	19	19	1	1	3	19	19	57			
Error df	50	50	126	50	50	126	50	50	126			

*, **, *** = significant at $P < 0.05$, 0.01 and 0.0001 respectively, ns=not significant. ‡GY=grain yield, SW100=hundred seed weight, SDPOD= seed per pod, NDVI 1, 2, 3= normalized difference vegetation index measured at vegetative, flowering and pod-filling stages, PODPLT=pod per plant, SDPLT=seed per plant, DLSC=delayed leaf senescence (scale of 1-9).‡DS, WW, AC= drought stress, well-watered and across all environments respectively.

Table 5. 3: Proportion of sum of squares of genotypes, environment and genotype x environment interaction to variation for grain yield.

	Sum of squares		
	DS	WW	ACROSS
Genotypes	68.19	61.36	50.33
Environment	11.72	0.11	7.33
G x E	20.09	38.53	42.35

On the average, grain yield obtained under drought stress was 19% of the yield obtained under well-watered conditions. Yield reduction expressed as the percentage of yield under drought stress relative to well-watered conditions ranged from -94% to 76%. The negative sign indicated that the lines had higher grain yield under drought stress than under well-watered conditions. Some of the lines that suffered less yield penalty had almost similar yield under both water regime. TVu6707 which yielded highest under both DS and WW had a yield reduction of 16% (Table 5.4).

Table 5. 4: Mean grain yield of 20 parental lines used in design II crosses under drought and well-watered environments.

Cowpea parental lines	Grain yield (kg ha ⁻¹)		¹ Yield reduction (%)	Seed per plant	
	² DS	WW		DS	WW
TVu6707	1788.1	2127.4	15.9	852.8	954.8
TVu9693	890.4	861.4	-3.4	434.1	437.1
TVu8670	869.7	561.2	-55.0	443.4	378.5
IT89KD-288	826.0	682.5	-21.0	420.1	292.2
DANILA	778.2	904.7	14.0	427.5	372.7
TVu9797	769.5	1261.2	39.0	420.4	718.8
TVu10100	592.8	520.0	-14.0	389.0	371.7
IT81D-985	585.9	1433.5	59.1	364.4	840.4
IT99K-573-1-1	510.2	649.8	21.5	268.0	350.3
IT90K-76	495.9	571.1	13.2	385.8	403.4
TVu3562	461.3	473.7	2.6	398.6	417.2
IT90K-277-2	457.9	345.5	-32.5	277.7	215.6
TVu6333	450.0	232.3	-93.7	300.3	135.0
TVu79	433.3	845.7	48.8	304.4	557.5
SANZI	402.9	547.6	26.4	308.1	518.7
TVu7778	382.8	284.4	-34.6	324.3	350.4
CB-27	339.4	273.9	-23.9	161.2	94.2
TVu2736	219.8	903.8	75.7	268.1	223.0
IFEBROWN	201.8	190.7	-5.8	111.0	117.1
TVu11986	115.9	330.5	64.9	328.6	283.8
Mean	586.6	727.9		358.8	417.2
SE	48.1	55.9		23.0	28.1
Min	0.4	20.2		16.0	28.0
Max	2083.1	3003.5		988.6	1372.8

¹Drought stress relative to well-watered conditions, ²DS=drought stress, WW= well-watered

5.3.7 Performance of single F₁ crosses for yield and drought tolerance

The means of grain yield and selected agronomic and drought adaptive traits of top 20 and 10 bottom crosses under drought stress and well-watered environments are given in Tables 5.5 and 5.6 respectively. Under drought stress conditions, grain yield ranged between 2,533 kg ha⁻¹ to 18 kg ha⁻¹ for crosses between lines TVu6707 x TVU9797 and TVu11986 x TVu2736 respectively (Table 5.5). Negative sign in the drought tolerance index signified that the crosses had higher yield under stress than under well-watered conditions while

absence of negative sign indicated that the crosses had higher yield under well-watered environments than when evaluated under the stress. This is important for the identification of drought tolerant genotypes without compromising yield performance under well-watered environments. Out of the 100 single F_1 crosses evaluated, 86 had positive tolerance indices while 14 had negative indices. Among the best 20 F_1 crosses under drought stress, yield reduction relative to their performance under well-watered condition ranged from -90.4% to 57.5% and from 30% to 470% among the 10 worst F_1 crosses. The trial mean yield of 738 kg ha⁻¹ under drought stress is about 42% of the trial mean of 1279 kg ha⁻¹ under well-watered conditions. Under well-watered conditions, grain yield ranged between 3786.22 kg ha⁻¹ and 45 kg ha⁻¹ for crosses between TVu6707 x TVu9797 and TVu6333 x TVu2736 respectively (Table 5.6). Overall, drought stress reduced grain yield by 49% (Table 5.5 and 5.6).

Table 5. 5: Means of grain yield and secondary traits of top 20 and bottom 10 crosses under drought stress environment.

Crosses	Grain yield			Secondary traits under DS			
	DS	Rank (WW)	[†] DTI (%)	DFL (days)	Pod per plant (no)	Seed per plant (no)	Seed per pod (no)
Top 20							
TVu6707 x TVu9797	2532.9	1	33.10	51.72	78.28	1144.49	13.17
TVu79 x DANILA	1914.1	18	-6.75	48.10	78.09	1051.13	12.85
TVu79 x IT90K-277-2	1685.9	72	-90.37	49.10	46.18	670.95	12.15
TVu9693 x TVu9797	1522.1	2	53.24	49.39	58.80	961.63	15.81
IT99K-573-1-1 x TVu9693	1417.2	10	37.64	46.59	53.77	771.16	14.28
TVu9693 x TVu79	1403.6	12	36.29	49.10	42.66	698.70	14.04
TVu79 x IT81D-985	1343.6	25	18.16	48.08	45.83	642.25	12.60
IT89D-288 x TVu6707	1312.1	51	-15.34	46.58	64.34	688.53	10.11
TVu79 x IT90K-76	1256.3	26	21.63	50.22	42.46	601.38	14.28
TVu6707 x TVu7778	1234.9	38	9.25	57.33	48.24	629.40	10.86
TVu8670 x TVu3562	1225.4	17	33.99	45.26	51.72	622.54	11.95
TVu3562 x IT81D-985	1217.3	14	42.92	50.58	42.69	605.34	12.86
TVu6707 x TVu3562	1203.5	4	57.53	50.74	52.59	727.81	12.58
TVu3562 x IFEBROWN	1192.2	67	-25.96	48.11	88.57	1214.96	13.37
CB-27 x TVu6707	1188.6	39	11.36	44.36	53.94	568.45	8.82
IT89D-288 x TVu8670	1181.5	19	33.17	46.88	43.69	527.97	11.10
TVu9693 x TVu7778	1139.0	20	34.34	52.67	36.81	570.32	10.36
TVu8670 x TVu79	1119.4	30	25.91	48.00	44.70	677.40	14.49
CB-27 x TVu9693	1115.7	21	34.92	47.44	57.26	704.07	12.36
CB-27 x TVu8670	1111.7	8	53.95	46.70	47.22	564.46	10.48
Bottom 10							
TVu6333 x TVu9693	263.1	89	49.71	52.88	12.03	126.28	11.81
Sanzi x IT90K-76	260.4	60	75.17	48.33	22.51	201.69	8.73
IT81D-985 x TVu11986	246.7	63	75.28	48.13	18.11	149.67	7.77
TVu7778 x IT81D-985	243.9	86	62.56	52.96	21.02	190.68	9.38
IT90K-76 x TVu6333	201.2	97	30.21	52.12	11.01	92.94	9.04
TVu6333 x TVu6707	177.5	92	62.32	51.76	17.42	183.99	10.94
TVu6333 x TVu2736	168.2	99	470.64	55.75	12.23	128.54	10.69
TVu6333 x TVu8670	60.2	91	87.28	52.03	3.72	5.58	9.71
TVu11986 x TVu10100	25.8	94	93.62	53.54	-1.22	-37.00	8.33
TVu11986 x TVu2736	17.6	66	98.14	51.16	11.58	103.16	9.41
Mean	738.2		48.57	49.58	35.70	426.53	10.73
LSD _(0.05)	810.0			3.97	29.47	421.92	2.81

[†]DTI=Drought tolerance index in % = [(Yield in well-watered - yield under drought)/yield in well-watered]*100. DLSC= delayed leaf senescence

Table 5. 6: Means of grain yield and secondary traits of top 20 and bottom 10 crosses under well-watered condition.

Crosses	Grain yield			Secondary traits under WW			
	WW	Rank (DS)	[†] DTI (%)	DFL (days)	Pod per plant (no)	Seed per plant (no)	Seed per pod (no)
<u>Top</u>							
TVu6707 x TVu9797	3786.2	1	33.10	49.23	124.73	1944.23	14.64
TVu9693 x TVu9797	3255.3	4	53.24	52.77	80.54	1393.71	17.86
TVu8670 x TVu9797	2892.3	39	72.26	49.37	75.71	1249.05	16.37
TVu6707 x TVu3562	2833.9	13	57.53	50.02	109.16	1694.38	15.57
TVu6707 x TVu79	2692.2	35	68.59	48.75	71.93	1115.19	14.97
TVu9693 x TVu3562	2602.0	21	58.01	48.47	108.33	1434.87	13.02
TVu9693 x Sanzi	2427.0	22	55.46	48.74	121.86	1533.82	13.29
CB-27 x TVu8670	2414.3	20	53.95	44.50	95.43	1192.55	11.34
IT99K-573-1-1 x TVu6707	2330.9	26	56.47	50.19	77.63	1015.05	13.17
IT99K-573-1-1 x TVu9693	2272.7	5	37.64	50.54	59.00	852.14	13.20
TVu3562 x IT90K-277-2	2215.4	44	65.66	51.73	109.05	1437.99	13.11
TVu9693 x TVu79	2203.1	6	36.29	48.79	75.21	1205.22	15.48
TVu9797 x IT90K-277-2	2148.8	30	56.16	48.62	69.71	963.47	13.51
TVu3562 x IT81D-985	2132.8	12	42.92	49.79	68.21	861.23	12.43
TVu3562 x DANILA	1929.4	28	51.02	47.60	90.45	1092.09	12.16
IT89D-288 x TVu9693	1904.5	59	69.14	50.79	61.35	838.75	13.02
TVu8670 x TVu3562	1856.4	11	33.99	51.03	69.55	964.82	13.82
TVu79 x DANILA	1793.1	2	-6.75	49.71	64.19	758.88	10.82
IT89D-288 x TVu8670	1767.8	16	33.17	47.79	68.04	820.85	11.79
TVu9693 x TVu7778	1734.8	17	34.34	50.77	69.54	938.03	11.89
<u>Bottom</u>							
TVu6333 x TVu8670	473.5	98	87.28	53.11	31.39	413.29	11.65
TVu6333 x TVu6707	471.1	96	62.32	59.61	40.18	415.09	9.80
IT90K-277-2 x CB-27	413.7	37	-99.01	50.85	28.32	193.34	7.32
TVu11986 x TVu10100	403.9	100	106.38	54.61	19.03	220.52	9.21
Sanzi x IT90K-277-2	380.0	76	-3.43	48.27	30.47	315.36	9.86
TVu7778 x DANILA	329.6	83	7.20	50.16	27.43	348.16	12.52
IT90K-76 x TVu6333	288.3	95	30.21	55.61	17.88	178.59	9.41
TVu7778 x IFEBROWN	101.3	69	-369.08	56.78	19.65	154.27	5.88
IT81D-985 x IT89D-288	81.4	52	-741.34	49.27	10.67	66.61	7.38
TVu6333 x TVu2736	45.4	97	-270.64	54.86	3.55	12.50	13.27
Mean	1278.8		48.57	50.20	54.71	666.60	11.62
LSD _(0.05)	1135			3.75	34.89	489.05	2.43

[†]DTI=Drought tolerance index in % = [(Yield in well-watered - yield under drought)/yield in well-watered]*

5.3.4 Genetic analysis of the performance of cowpea F₁ crosses under contrasting environments

The F₁ crosses showed highly significant differences for all measured traits ($P < 0.0001$) under both irrigation regimes (Tables 5.7 and 5.8). Under drought stress, effect due to environment ($P < 0.0001$) and environment x crosses interaction ($P < 0.01$) were highly significant for all traits. Similar trend were observed under well-watered environments for the crosses ($P < 0.0001$) and environment x crosses interaction ($P < 0.05$) was also significant. Although, the effect due to environment was found to be highly significant for all traits under stress (Table 5.7), it was not significant for number of pods per plant under well-watered conditions (Table 5.8). Similarly, the effect due to sets which was significant for all traits under drought stress was not significant for NDVI_1 and NDVI_2 under well-watered conditions. Negative drought tolerance indices (DTI) indicated that the crosses had higher yield under drought stress than the yield under well-watered condition. The cross between TVu6707 x TVu9797 had the highest grain yield under both DS and WW with 33% yield reduction.

Combined analysis of variance over all the research environments showed significant differences for all the measured traits except for the effect due to set for NDVI_1 and environment x set interaction for number of pods per plant (Table 5.9).

Table 5. 7: Mean squares of grain yield and other traits of F₁ crosses measured across drought stress environments.

Drought stress		‡GY Kgha ⁻¹	SW100 g	SDPPOD no	DFL days	PODPLT no	SDPLT no	Normalized Difference Vegetation Index (NDVI)			DLSC (1-9)
Source	df							1	2	3	
Env	1	77586454***	356.61***	2181.6***	4793.41***	11528.52***	6760612.08***	31.53***	1.40***	22.86***	588.13***
Sets	3	7443193**	602.23***	204.11ns	78.94***	6690.36***	2418045.58***	0.02*	0.19***	0.11***	57.76***
Env x Sets	3	4028355*	21.72***	14.79ns	117.32***	1586.16***	173006.99ns	0.01ns	0.05**	0.02*	19.36**
Crosses/sets	96	84891447***	15.70***	13.92***	36.89***	1198.69***	240309.39***	0.01***	0.03***	0.02***	12.47***
Env x crosses	96	68683390**	7.89***	8.28**	20.47***	1154.71***	227648.19***	0.01**	0.02***	0.02***	8.15***
GCA _f /sets	16	52764638***	40.65***	30.20***	96.32***	3262.50***	700742.42***	0.03***	0.07***	0.05***	28.14***
GCA _m /sets	16	9525449ns	20.86***	22.95***	57.64***	1471.50**	181103.6ns	0.01ns	0.03***	0.02***	24.89***
SCA/sets	64	25547510ns	7.18***	7.42ns	16.69**	648.86ns	144046.96ns	0.01*	0.02***	0.01***	4.67*
Env x GCA _f /sets	16	31628934***	13.55***	8.42ns	38.56***	1749.98***	339237.15***	0.02**	0.04***	0.03***	16.98***
Env x GCA _m /sets	16	8710419ns	6.48**	9.16ns	22.70**	1078.76*	230138.28*	0.01*	0.02**	0.02***	10.94***
Env x SCA/sets	64	31604828ns	6.91***	7.86*	14.53**	1025.58***	204007.66**	0.01ns	0.02***	0.01*	5.31**
Pooled error	342	444069	2.47	5.46	8.97	529.45	112603.90	0.01	0.01	0.01	3.35

*, **, ***, = significant at $P < 0.05$, 0.01 , 0.0001 respectively and ns= not-significant. ‡GY= grain yield, SW100=hundred seed weight, SDPPOD= no of seed per pod, PODPLT, no of pods per plant, SDPLT=no of seeds per plant, NDVI 1-3= measured at vegetative, flowering and pod filling stages respectively, DLSC=delayed leaf senescence where 1= almost all leaves are green, 9 virtually all leaves are dead

Table 5. 8: Mean squares of grain yield and other traits measured across well-watered environments.

Well-watered		‡GY	SW100	SDPPOD	DFL	PODPLT	SDPLT	Normalized Difference Vegetation Index		
Source	df	Kgha ⁻¹	g	no	days	no	no	1	2	3
Env	1	102494605***	262.31***	645.59***	2626.26***	73.32ns	2233981.5**	10.80***	4.57***	0.11**
Sets	3	15002232***	596.80***	275.15***	38.36**	14740.49***	5900877.39***	0.01ns	0.01ns	0.08***
Env x Sets	3	5814338***	29.77***	0.71ns	65.78***	298.83ns	171315.62ns	0.07**	0.03*	0.05**
Crosses/sets	96	2329462***	16.75***	14.99***	45.61***	2501.31***	501975.83***	0.03***	0.03***	0.02***
Env x Crosses	96	1734211***	6.35***	6.61**	19.00***	1350.94**	242943.85*	0.03***	0.02***	0.02**
GCA _f /sets	16	6358426***	44.95***	15.25***	113.69***	6896.84***	1167580.15***	0.04***	0.04***	0.03***
GCA _m /sets	16	2711384***	31.31***	29.01***	57.66***	2379.49**	645940.47***	0.02*	0.04***	0.05***
SCA/sets	64	1111636*	5.35***	11.62***	23.63***	1331.68**	281818.92**	0.02***	0.02***	0.01*
Env x GCA _f /sets	16	3915481***	10.89***	9.04**	22.48**	2253.24**	489999.12**	0.03**	0.03***	0.02**
Env x GCA _m /sets	16	1826835**	6.5***	6.11ns	22.67**	1304.76ns	191110.33ns	0.03**	0.03***	0.02**
Env x SCA/sets	64	1149591**	4.98***	6.27ns	18.37***	1178.24*	196177.95ns	0.02***	0.02***	0.01ns
Pooled error	342	748554	2.09	4.08	8.19	836.00	169697.40	0.01	0.01	0.01

*, **, *** = significant at $P < 0.05$, 0.01 , 0.0001 respectively and ns= not-significant. ‡GY= grain yield, SW100=hundred seed weight, SDPPOD= no of seed per pod, PODPLT, no of pods per plant, SDPLT=no of seeds per plant, NDVI 1-3= measured at vegetative, flowering and pod filling stages respectively.

Partitioning the sources of variation observed among the crosses into its genetic components, GCA_f was highly significant for all traits ($P < 0.0001$) under both irrigation regimes (Tables 5.7 and 5.8). The interaction effect of $GCA_f \times Env$ was also significant ($P < 0.01$) under both regimes for all traits except for number of seeds per pod under drought stress. Effect due to GCA_m was significant for all traits under well-watered and drought stress but not for grain yield, number of seed per plant and NDVI_1 under drought stress. Under well-watered conditions, GCA_f , GCA_m , SCA and interaction effect of $GCA_f \times$ environment were significant for all traits. On the other hand, the interaction of $GCA_m \times$ environment was not significant for number of seeds per pod, pods per plant and number of seeds per plant under well-watered conditions (Table 5.8). Interaction effect of SCA $\times$ environment was found to be significant for all traits except for grain yield and NDVI_1 under drought stress and number of seeds per pod, number of seed per plant and NDVI_3 under well watered conditions.

Across all the research environments, significant differences were observed for effects due to all the genetic effects of GCA_f , GCA_m , SCA and all interactions with the environment for all traits measured (Table 5.9). The GCA_f and GCA_m mean squares were observed to be larger than SCA effects for most of the measured traits.

Table 5. 9: Mean squares of grain yield and other traits measured across all research environments, Ibadan and Minjibir.

All environments										
		GY	SW100	SDPPOD	DFL	PODPLT	SDPLT	Normalized Difference Vegetation Index		
Source	df	Kgha⁻¹	g	no	days	no	no	1	2	3
Env	3	88237441***	364.34***	1015.01***	2514.61***	38735.09***	8533316.55***	14.26***	2.46***	11.65***
Sets	3	14189803***	1194.19***	449.61***	103.51***	20472.75***	7829746.68***	0.02ns	0.13***	0.18***
Env x Sets	9	3574691***	18.97***	15.79**	65.35***	1001.24ns	302046.67***	0.03**	0.05***	0.03**
Crosses/sets	96	2493519***	25.41***	21.06***	66.80***	2733.01***	540101.4***	0.02***	0.04***	0.03***
Env x Crosses	288	1039062***	6.86***	7.69***	17.93***	1143.42***	223446.8***	0.02***	0.02***	0.01***
GCA _f /sets	16	8891782***	73.83***	38.11***	198.27***	9340.74***	1730365.95***	0.04***	0.09***	0.06***
GCA _m /sets	16	2581033***	44.38***	44.82***	96.55***	2879.28***	578476.47***	0.02**	0.05***	0.06***
SCA/sets	64	864590*	7.81***	10.75***	25.60***	1048.48**	226762.44**	0.02**	0.02***	0.02***
Env x GCA _f /sets	48	2157248***	12.17***	8.57**	24.05***	1576.95***	315439.58***	0.03***	0.03***	0.03***
Env x GCA _m /sets	48	1010269**	6.85***	7.38*	21.26***	1106.75**	220052.25*	0.02***	0.02***	0.02***
Env x SCA/sets	192	767969*	5.44***	7.51***	15.79***	1052.20***	201625.28**	0.02***	0.02***	0.01*
Pooled error	684	596311	2.28	4.77	8.58	682.72	141150.60	0.01	0.01	0.01

*, **, ***, = significant at $P < 0.05, 0.01, 0.0001$ respectively and ns= not-significant. ‡GY= grain yield, SW100=hundred seed weight, SDPPOD= no of seed per pod, PODPLT, no of pods per plant, SDPLT=no of seeds per plant, NDVI 1-3= measured at vegetative, flowering and pod filling stages respectively.

5.3.5 Relative contributions of male and female general combining ability effects

The relative contributions of GCA and SCA were determined through the ratio of the sum of squares of the GCA or SCA to the total genetic effects. Under drought stress environment, the overall contributions of GCA (GCA_f and GCA_m) sum of squares to the total variation observed among the crosses ranged between 64% for number of seeds per pod to 74% for delayed leaf senescence (Figure 5.3). Contribution of SCA ranged between 26% for delayed leaf senescence to 40% for number of seeds per pod. For grain yield, contribution of GCA_f (60%) was larger than the GCA_m (11%) while SCA (29%) was larger than the GCA_m . This similar trend was observed for other traits except for delayed leaf senescence where both GCA_f (39%) and GCA_m (35%) were larger than the SCA (26%) sum of squares.

Under well-watered conditions, the contribution of GCA sum of squares ranged between 49% for number of seed per pod to 78% for hundred seed weight while SCA ranged from 22% for hundred seed weight to 51% for number of seed per pod (Figure 5.4). The contribution of GCA_f , GCA_m and SCA was 47%, 20% and 33% respectively for grain yield. The contribution of SCA was larger (51%) for number of seed per pod than GCA_f (17%) and GCA_m (32%).

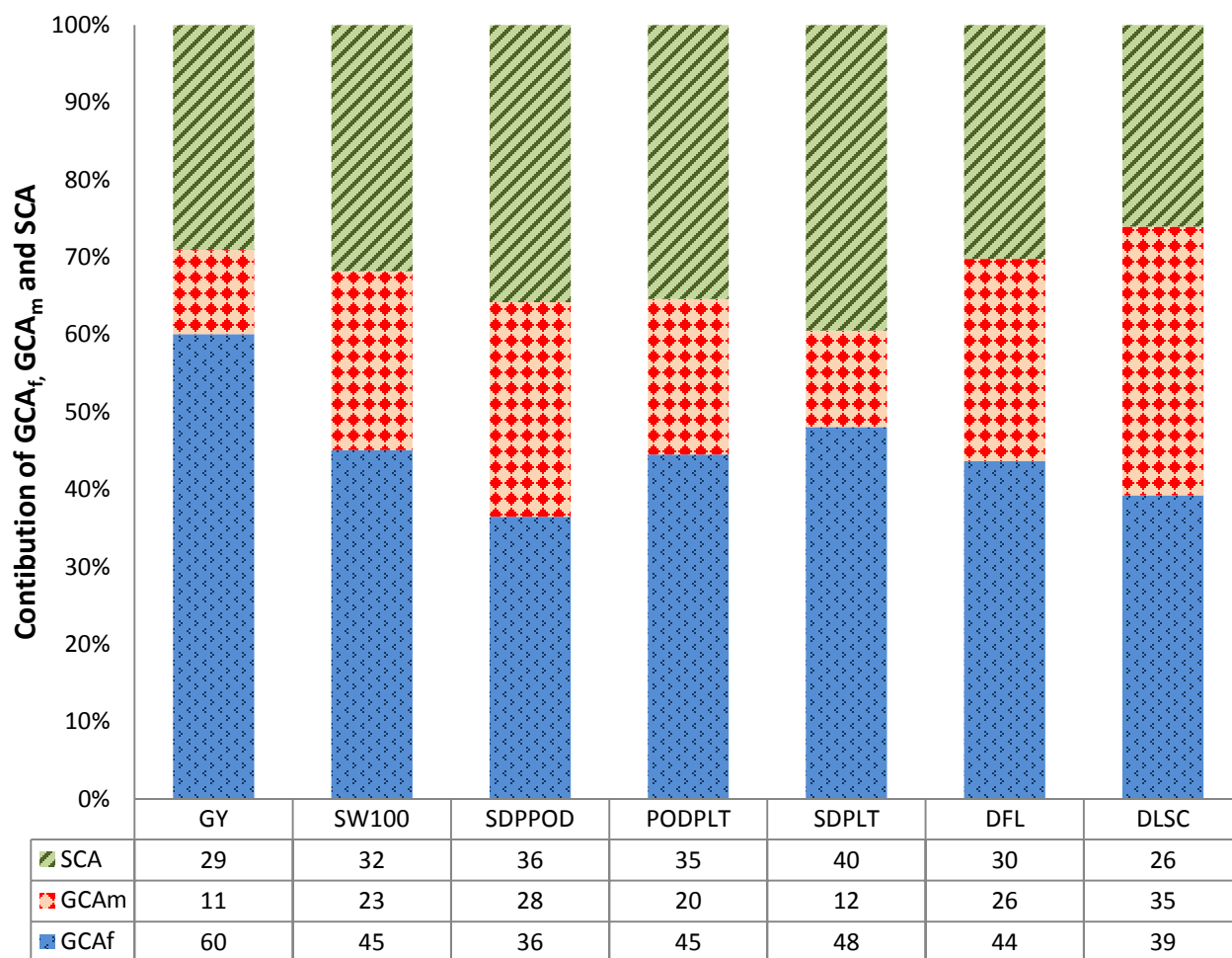


Figure 5. 3: Percentage contributions of GCA effects from GCA_f and GCA_m and their interactions for selected traits across drought stress environments.

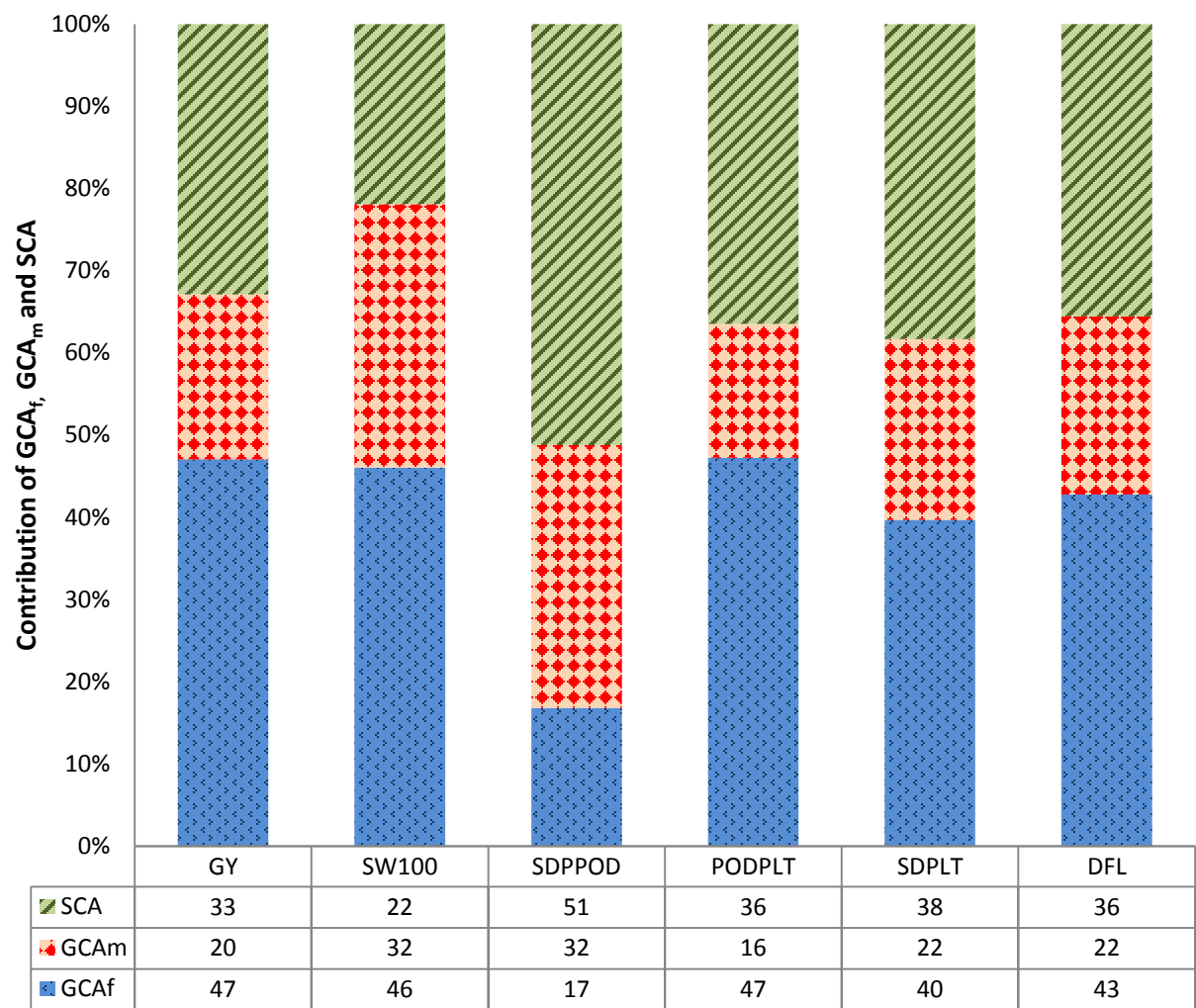


Figure 5. 4: Percentage contributions of GCA effects from GCA_f and GCA_m and their interaction for selected traits across well-watered environments.

Overall, GCA accounted for >60% of the total genotypic variation observed among the F_1 crosses across all research environments (Figure 5.5). Contribution of GCA_f was larger than GCA_m for all traits except for number of seeds per pod. GCA_f , GCA_m and SCA sum of squares were 60%, 17% and 23% respectively for grain yield. Contribution of SCA sum of squares was larger than GCA_m for grain yield, number of pods per plant and number of seeds per plant.

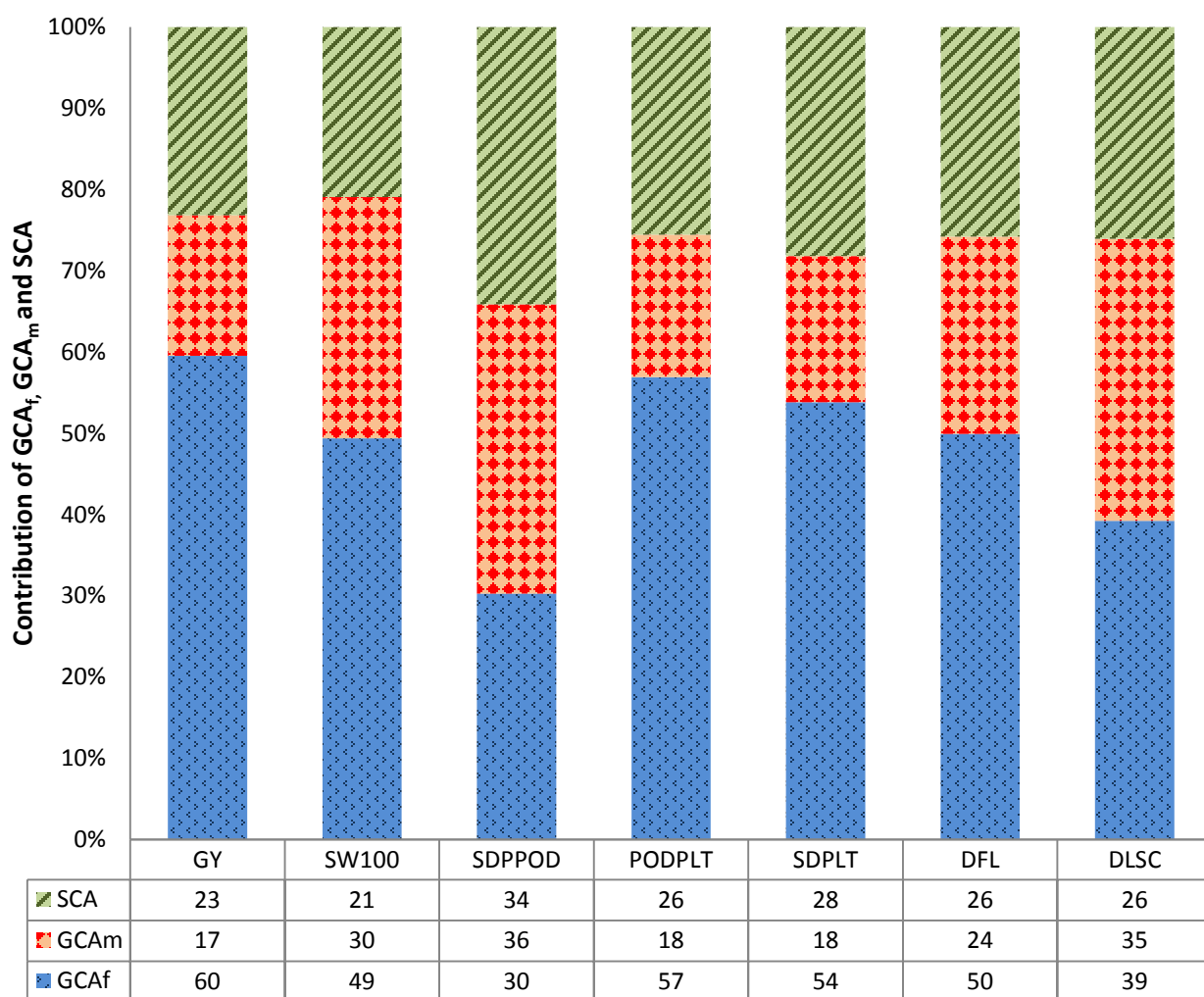


Figure 5. 5: Percentage contributions of GCA effects from GCA_f and GCA_m and SCA of selected traits across all research environments.

5.3.6 Estimate of general combining ability effects

Under drought stress environments, the GCA_f effect ranged from -569 for TVu6333 to 649 for TVu79 while GCA_m effect ranged from -402 for TVu10100 to 497 for TVu9797 for grain yield (Table 5.10). Out of the twenty parents, only ten of them had positive GCA_f and GCA_m effects for grain yield. Of the ten, TVu79, TVu6707 and TVu9693 had positive and significant GCA_f ; TVu6333 and TVu11986 had negative and significant GCA_f effects for grain yield. TVu9797 had significant positive GCA_m effect while TVu10100 had significant and negative GCA_m for grain yield. CB-27 and IT89KD-288 had superior positive GCA effects (significant GCA_f and GCA_m) for hundred-seed weight while IT81D-985, Danila and IT90K-277-2 had only GCA_f to be positive and significant for same trait. TVu6333 had superior negative GCA effects (negative GCA_f and GCA_m effects) for number of pods per plant and number of seeds per plant and delayed leaf senescence. TVu3562 had superior negative GCA effects for hundred-seed weight and superior positive GCA effects for number of seeds per pod, number of pods per plant and number of seeds per plant. TVu10100 had superior negative GCA effects for delayed leaf senescence. GCA_m and GCA_f effects for NDVI measured at flowering stage and pod-filling stages were significant and positive for TVu9693. TVu6707 had significant and positive GCA_f and GCA_m effects for NDVI measured at flowering stage but significant and positive GCA_m effects only for NDVI at pod-filling stage (Table 5.10b). CB-27, IT89KD-288, IT99K-573-1-1 and TVu11986 had significant negative GCA_m for NDVI measured at flowering stage. CB-27 had superior negative GCA effects (significant GCA_f and GCA_m) for number of days to 50% flowering.

Table 5. 10: Estimate of general combining effects of lines evaluated across drought stress environments.

Lines	GY		100-SW		SDPPOD		PODPLT		SDPLT	
	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m
TVu7778	-327.47	13.78	-1.28*	-1.21***	-1.76**	-0.9	-8.74	-2	-153.65	10.68
TVu10100	-286.14	-402.30**	-1.40*	0.13	0.37	-0.72	-4.44	-18.37**	-62.78	-237.18**
SANZI	-371.71	-6.75	-0.28	-2.88***	-1.22*	0.37	-3.62	16.76*	-105.1	227.44**
TVu3562	255.59	180.76	-1.31*	-2.56***	1.36**	1.34**	13.63*	13.83*	206.54*	205.00**
TVu9797	47.09	496.52***	-0.48	-2.31***	2.16***	2.41***	-4.5	12.73*	-4.81	260.27**
TVu79	648.80**	155.09	-0.05	-2.34***	1.50**	2.87***	15.23*	1.6	262.20**	130.48
TVu6707	567.66*	114.23	-1.52*	1.39**	1.47**	-0.32	16.80*	5.01	282.00**	3.96
TVu9693	513.79*	-46.44	-3.29***	-0.24	2.42***	1.06*	14.46*	-1.96	337.72**	-4.96
TVu2736	-186.18	-217.7	-2.87***	-1.24**	0.42	0.31	3.63	-8.64	84.25	-112.92
TVu8670	230.27	-51.39	-2.21**	0.17	1.40**	0.05	12.46	-7.18	192.68*	-96.93
IFEBROWN	56.48	18.76	2.31**	-0.45	-1.36**	0.13	3.96	11.14*	-19.15	151.07
TVu6333	-569.93*	-196.87	-2.49***	2.15***	0.36	-1.20*	-23.92**	-13.90**	-304.49**	-186.35*
IT90K-76	-184.49	26.85	2.09**	-0.56	-0.49	0.78	-5.67	1.4	-114.98	32.04
IT81D-985	-229.45	-15.9	3.73***	-0.98*	-2.33***	1	-10.27	-3.07	-196.63*	-9.95
DANILA	-30.5	124.35	4.29***	-1.04*	-2.30***	0.34	-4.6	2.26	-114.21	40.42
IT90K-277-2	-100.14	98.25	2.07**	-0.37	-2.04***	-0.2	-7.2	0.26	-146.07	-8.4
CB-27	226.49	-7.66	1.70**	4.37***	0.17	-1.71**	8.78	-0.4	96.67	-84.31
IT89KD-288	170.29	45.43	1.84**	3.59***	-0.08	-1.68**	5.46	1.87	62.51	-54.82
IT99K-573-1-1	45.45	-137.2	0.67	3.16***	0.44	-2.56***	-0.2	-4.2	-22.74	-141.11
TVu11986	-475.90*	-191.8	-1.51*	1.23**	-0.49	-1.37**	-21.25**	-7.14	-279.98**	-124.45
SE ±	229.60	120.49	0.60	0.42	0.47	0.49	6.83	5.36	95.11	78.34

GCA_f, GCA_m = GCA effects of the line used as a female and male parents respectively; *, **, ***, Significant at probability level of 0.05, 0.01 and 0.0001 probability levels, respectively, ns not significant

Table 5.10b: Estimates of general combining effects of lines evaluated across drought stress environments.

Lines	Normalized Difference Vegetation Index						DLSC	
	1		2		3			
	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m
TVu7778	0.050*	0.039*	-0.008	0.062**	-0.053	0.022	1.12	0.12
TVu10100	0.04	-0.014	0.032	0.003	0.049	0.021	-2.25**	-1.88**
SANZI	0.002	0.001	-0.046	0.041	-0.014	0.043	0.99	0.46
TVu3562	0.016	0.004	0.014	0.037	0.014	0.036	0.49	-0.51
TVu9797	-0.037	-0.012	-0.031	0.018	-0.027	0.003	0.86	-0.55
TVu79	0.03	0.002	0.054	0.008	0.015	-0.006	0.66	-0.55
TVu6707	0.007	-0.001	0.060*	0.060**	0.03	0.056*	0.09	-0.71
TVu9693	0.002	0.004	0.088**	0.063**	0.063*	0.047*	0.22	-0.71
TVu2736	-0.047	-0.025	-0.091**	-0.036	-0.070*	-0.034	-0.08	-0.58
TVu8670	0.031	0.019	0.076*	0.034	0.027	0.048*	0.99	-0.15
IFEBROWN	-0.003	0.038*	-0.024	0.004	-0.039	-0.011	1.12	1.32*
TVu6333	-0.03	0.021	0.03	-0.005	0.079**	0.036	-2.25**	-2.71***
IT90K-76	0.037	0.002	-0.014	-0.021	-0.004	-0.01	0.39	0.32
IT81D-985	-0.043	-0.016	-0.1	-0.026	-0.048	-0.021	-0.48	0.52
DANILA	-0.017	0.011	-0.092**	-0.003	-0.064*	-0.012	0.56	1.16*
IT90K-277-2	-0.053*	0.026	-0.043	0.028	-0.013	-0.01	-0.65	0.79
CB-27	-0.007	-0.033	-0.014	-0.083**	0.018	-0.04	-0.18	1.12*
IT89KD-288	-0.004	-0.019	-0.024	-0.066**	-0.04	-0.056*	0.26	1.59**
IT99K-573-1-1	0.04	-0.021	0.074*	-0.073**	0.012	-0.080**	0.76	1.39*
TVu11986	-0.016	-0.027	0.059	-0.046*	0.069*	-0.029	-2.61**	-0.45
SE ±	0.022	0.018	0.034	0.023	0.029	0.023	0.67	0.54

GCA_f, GCA_m=GCA effects of the line used as a female and male parents respectively; *, **, ***, Significant at probability level of 0.05, 0.01 and 0.0001 probability levels, respectively, ns not significant

GCA_f effect for grain yield under well-watered conditions ranged from -786 for TVu10100 to 1220 for TVu6707 and ranged from -548 for TVu10100 to 1241 for TVu9797 for GCA_m effect (Table 5.11). TVu6707 and TVu9693 had significant and positive GCA_f while TVu3562 and TVu9797 had significant positive GCA_m for grain yield.

TVu10100, TVu2736 and CB-27 had significant and negative GCA_m for grain yield. CB-27, IT89KD-288 and IT99K-573-1-1 had superior positive GCA (GCA_f and GCA_m) effects for hundred seed weight while Sanzi and TVu7778 had superior negative GCA effects for the same trait. TVu9693 had superior positive GCA (significant GCA_f and GCA_m) effects for number of seeds per pod and positive GCA_f for number of pods per plant and number of seeds per plant. TVu6333 had significant negative GCA_m effects for number of seeds per pod; significant negative GCA_f and significant positive GCA_m for hundred-seed weight (Table 5.11). TVu79 had superior GCA effects (GCA_m and GCA_f) for NDVI measured at pod-filling stage and a significant GCA_m for number of seeds per plant (Table 5.11b).

Table 5. 11: Estimates of general combining ability effects of lines evaluated across well-watered environments.

Lines	GY		100-SW		SDPPOD		PODPLT	
	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m
TVu7778	-598.06	-16.39	-1.30*	-2.74***	-1.69**	0.48	-10.81	-2.76
TVu10100	-168.88	-548.32*	-1.98**	1.09**	1.29**	-0.66	-2.16	-20.04**
SANZI	-476.72	227.2	-1.59**	-3.64***	-0.98*	0.64	-7.91	16.55**
TVu3562	257.22	799.96**	-0.61	-2.74***	0.3	2.11***	19.66*	32.22***
TVu9797	76.75	1241.61***	-0.01	-1.64***	0.43	3.76999	-9.59	27.89***
TVu79	263.76	291.77	0.8	-2.22***	-0.27	2.62***	9.86	1.81
TVu6707	1220.26**	-9.29	-1.65**	1.70***	1.84**	-0.82*	32.96***	0.41
TVu9693	1162.99**	166.86	-3.05***	-0.39	2.81***	1.62***	36.06***	-7.81
TVu2736	-220.42	-434.92*	-3.91***	-1.81***	1.23*	-0.32	-0.84	-12.09*
TVu8670	550.21	103.27	-2.40***	1.14**	2.44***	0.58	9.69	-0.41
IFEBROWN	-39.27	-114.66	2.83***	-0.84*	-1.23*	-1.19**	10.99	-3.38
TVu6333	-785.97	-349.24	-2.16***	1.71***	0.46	-0.86*	-29.21**	-9.36
IT90K-76	-393.63	-180.48	3.20***	-0.15	-1.02*	-0.32	-11.96	2.77
IT81D-985	-395.07	-28.49	1.47**	-0.86*	-1.27*	0.2	-20.44**	-1.13
DANILA	-138.75	-213.73	3.57***	-0.92*	-2.23***	-0.52	-5.01	-5.48
IT90K-277-2	-377.97	60.31	2.90***	0.05	-2.04***	-0.39	-10.54	8.41
CB-27	35.76	-471.09*	1.70**	2.99***	-0.99*	-2.20***	1.42	-17.21**
IT89KD-288	110.55	-357.13	2.14***	3.19***	-0.53	-2.44***	4.06	-5.74
IT99K-573-1-1	332.15	-190.38	1.61**	4.65***	0.55	-2.08***	4.39	-3.11
TVu11986	-414.9	23.14	-1.56**	1.44**	0.9	-0.2	-20.61**	-1.54
SE ±	323.13	220.72	0.54	0.42	0.49	0.40	7.75	5.90

GCA_f, GCA_m = GCA effects of the line used as a female and male parents respectively; *, **, ***, Significant at probability level of 0.05, 0.01 and 0.0001 probability levels, respectively, ns not significant

Table 5.11b: Estimates of general combining ability effects of lines evaluated across well-watered environments.

Lines	Normalized Difference Vegetation Index						SDPLT	
	1		2		3			
	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m	GCA _f	GCA _m
TVu7778	-0.002	0.003	-0.039	-0.012	0	-0.027	-197.57	2.66
TVu10100	-0.046	-0.001	-0.015	-0.01	-0.011	-0.01	14.26	-290.95***
SANZI	0.053	-0.007	-0.002	-0.029	-0.048	0	-157.97	240.57**
TVu3562	0.001	-0.013	0.042	0.016	0.023	0.018	239.87	528.67***
TVu9797	0.000	-0.011	-0.055*	0.008	0.01	-0.012	-61.01	619.20***
TVu79	-0.013	0.008	0.044	-0.004	0.072**	0.048*	90.7	177.67*
TVu6707	0.009	-0.018	0.029	0.038	0.009	0.053*	602.58***	-67.9
TVu9693	0.060*	-0.012	0.019	0.018	0.045	0.035	638.23***	-34.58
TVu2736	-0.062*	0.011	-0.080**	-0.044	-0.02	-0.016	44.1	-238.66**
TVu8670	0.019***	0.036	0.026	0.090**	0.004	0.052*	269.60*	-43.55
IFEBROWN	0.013	-0.018	0.003	-0.035	-0.062*	-0.016	57.91	-65.18
TVu6333	0.033	0.048	0.009	0.029	-0.004	0.068**	-383.77**	-159.02*
IT90K-76	0.005	0.032	-0.005	0.046	-0.005	0.01	-201.53	-19.68
IT81D-985	0.042	-0.029	0.025	-0.047	-0.087**	0.016	-291.37*	-20.09
DANILA	-0.023	0.034	-0.069*	0.025	-0.056*	0.028	-158.66	-76.56
IT90K-277-2	-0.071*	0.019	-0.017	0.002	0.017	0.016	-213.49	95.53
CB-27	0.000	-0.042	0.007	-0.033	0.02	-0.107***	-40.71	-293.15***
IT89KD-288	0.009	-0.064*	-0.01	-0.065*	-0.004	-0.079**	-1.19	-180.82*
IT99K-573-1-1	0.023	0.006	0.047	-0.043	0.019	-0.092***	-28.16	-161.85*
TVu11986	-0.049	0.019	0.039	0.049	0.082**	0.017	-221.81	-12.3
SE ±	0.030	0.029	0.027	0.026	0.025	0.023	114.31	71.39

GCA_f, GCA_m = GCA effects of the line used as a female and male parents respectively; *, **, ***, Significant at probability level of 0.05, 0.01 and 0.0001 probability levels, respectively, ns not significant

5.3.8 Inter-relationship among traits

Under drought stress, significant and negative correlation was observed between grain yield and number of days to 50% flowering and NDVI measured at pod-filling stage ($r = -0.43$) and ($r = -0.35$) (Table 5.12). The relationship between grain yield and number of pods per plant and number of seeds per plant was significant and positive under both drought stress and well-watered condition (Tables 5.12 and 5.13). Similarly, number of days to 50% flowering had significant and negative relationship with number of pods per plant and number of seeds per pod under both water regimes (Tables 5.12 and 5.13).

Table 5. 12: Correlation coefficients of traits under drought stress.

Traits	SDPOD	DFL	NDVI_1	NDVI_2	NDVI_3	PODPLT	SDPLT
GY	0.59**	-0.43**	0.49**	0.31**	-0.35**	0.77**	0.85**
DFL			0.60**	-0.29**	0.51***	-0.34**	-0.34**
NDVI_1				0.49**	-0.78**	0.27**	0.35**
NDVI_2					-0.03ns	0.32**	0.34**
NDVI_3						-0.05ns	-0.14*
PODPLT							0.96**

*, **, indicates significance at $P < 0.05$ and 0.01 respectively, ns=not significant

GY= grain yield, DFL=days to flowering, NDVI_1,NDV_2,NDVI_3 = normalized difference vegetation index taken at vegetative, flowering and pod-filling stages respectively, SDPLT=seed per plant, PODPLT=pod per plant, SDPOD=seed per pod

Table 5. 13: Correlation coefficients of traits under well watered condition.

Traits	SDPOD	DFL	NDVI_1	NDVI_2	NDVI_3	PODPLT	SDPLT
GY	0.56**	-0.32**	0.32**	0.31**	0.11*	0.74**	0.83**
DFL			-0.55**	-0.49**	0.09*	-0.18**	-0.22**
NDVI_1				0.74**	-0.02ns	0.05ns	0.15*
NDVI_2					0.21**	0.16ns	0.23**
NDVI_3						0.19**	0.19**
PODPLT							0.93**

5.3.9 GGE biplot analysis of grain yield of F₁ crosses

The GGE biplot analysis for grain yield of fifty crosses that had good yield across all the research environments revealed that both PC1 and PC2 together accounted for 86.3% of the total variation for grain yield with PC1 explaining 71.7% and PC2 explaining 14.6%.

The combined analysis of variance performed across all research environments revealed highly significant differences among the crosses and environment x crosses interaction for grain yield. In Figure 5.6 which showed the “which wins where” of the mean grain yield of the crosses plus the environment x crosses interaction, there are 8 vertices with entries 38, 37, 18, 13, 45, 8, 9 and 35 as the vertex cultivars. This shows that these vertex cultivars were most responsive in the environment (s) found within the same vector as the cultivar (s). From Figure 5.6, only TVu6707 x TVu3562 (38) fell within the same sector as environment IBWW (Ibadan well-watered conditions). Vertex cultivar TVu79 x Danila (35) fell within the sector where environments MJBWW (well-watered condition in Minjibr) and IBDS (drought stress condition in Ibadan) fell. Although, entries 37, 18, 13, 45, 8 and 9 were vertex cultivars, they did not fall within any sector with any test environments suggesting that they were not responsive at any of these environments.

Based on Figure 5.7, it is possible to assess both mean yield and stability performance through a biplot. An average tester coordinate (ATC) horizontal axis passes through the biplot origin and the average location and the oval shows the positive end of the ATC horizontal axis. The average yields of genotypes are estimated by projections of their markers on to the ATC horizontal axis. Thus TVu6707 x TVu9797 (38) had the highest average yield while TVu2736 x TVu79 (45) had the lowest average yield (Figure 5.7). Stability of each genotype is explored by its projection onto the ATC vertical axis. The

smaller the absolute length of projection of a genotype, the more stable it is. Thus, TVu6707 x TVu3562 (37), TVu6707 x TVu9797 (38), TVu9693 x TVu3562 (40) and TVu8670 x TVu9797 were high yielding but highly unstable while TVu8670 x Sanzi (47), IT89D-288 x TVu8670 (19), TVu6707 x TVu79 (39), TVu9693 x TVu79 (42) and TVu8670 x TVu79 (49) were the most stable (Figure 5.7). Considering both mean yield and stability performance, TVu8670 x Sanzi (47), IT89D-288 x TVu8670 (19), TVu6707 x TVu79 (39) and TVu8670 x TVu79 (49) are most favourable.

Code	Crosses	Code	Crosses	Code	Crosses
1	IFEBROWN x CB-27	21	IT99K-573-1-1 x TVu6707	41	TVu9693 x TVu9797
2	IFEBROWN x IT89D-288	22	IT99K-573-1-1 x TVu9693	42	TVu9693 x TVu79
3	IFEBROWN x IT99K-573-1-1	23	TVu11986 x TVu2736	43	TVu2736 x TVu3562
4	IFEBROWN x TVu11986	24	TVu7778 x IT90K-76	44	TVu2736 x TVu9797
5	IFEBROWN x TVu6333	25	Sanzi x IT90K-76	45	TVu2736 x TVu79
6	IT90K-76 x CB-27	26	TVu3562 x IFEBROWN	46	TVu8670 x TVu7778
7	IT90K-76 x IT89D-288	27	TVu3562 x IT90K-76	47	TVu8670 x Sanzi
8	IT90K-76 x IT99K-573-1-1	28	TVu3562 x IT81D-985	48	TVu8670 x TVu9797
9	IT90K-76 x TVu11986	29	TVu3562 x DANILA	49	TVu8670 x TVu79
10	DANIILA x CB-27	30	TVu9797 x IFEBROWN	50	TVu10100 x TVu9797
11	DANIILA x IT89D-288	31	TVu9797 x IT81D-985		
12	DANIILA x IT99K-573-1-1	32	TVu79 x IFEBROWN	Code	Environment
13	IT90K-277-2 x IT99K-573-1-1	33	TVu79 x IT90K-76	MJBDS	Minjibir drought stress
14	CB-27 x TVu2736	34	TVu79 x IT81D-985	MJBWW	Minjibir well-watered
15	CB-27 x TVu8670	35	TVu79 x DANILA	IBDS	Ibadan drought stress
16	CB-27 x TVu10100	36	TVu79 x IT90K-277-2	IBWW	Ibadan well-watered
17	IT89D-288 x TVu6707	37	TVu6707 x TVu3562		
18	IT89D-288 x TVu9693	38	TVu6707 x TVu9797		
19	IT89D-288 x TVu8670	39	TVu6707 x TVu79		
20	IT89D-288 x TVu10100	40	TVu9693 x TVu3562		

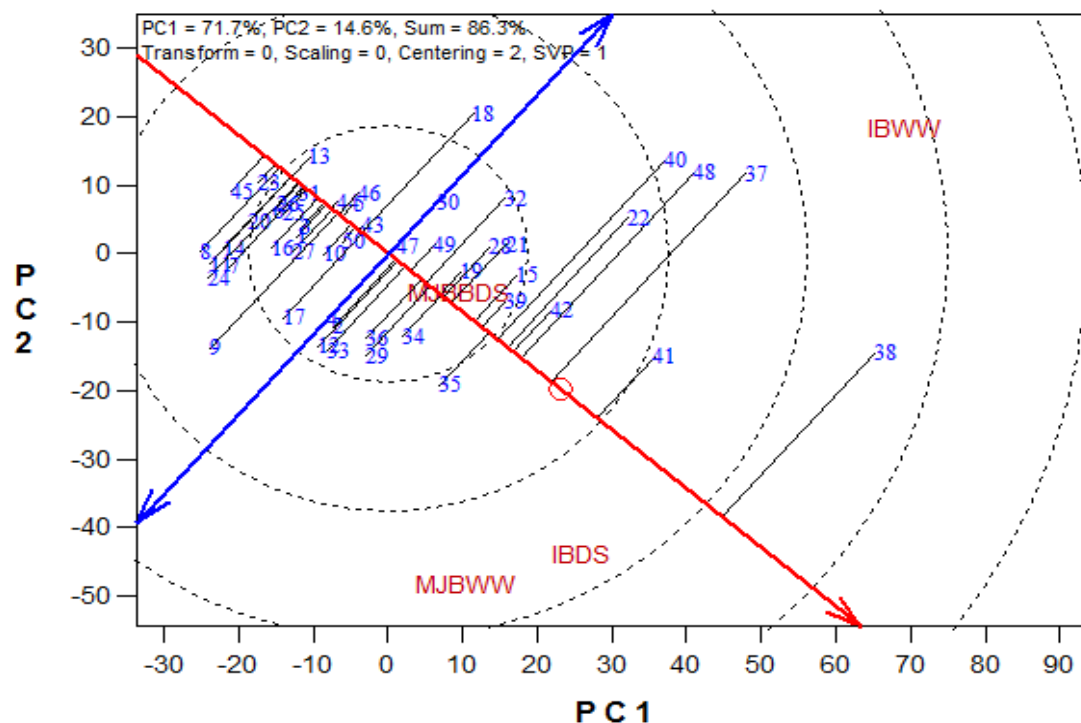


Figure 5. 7: An entry/tester view of genotype main effect plus genotype x environment biplot of 50 F₁ crosses across drought and well-watered environments in Ibadan and Minjibir.

5.4 Discussion

Soil moisture content measured for both drought and well-watered blocks showed that the volumetric water content within the root zone between 100 cm to 300 cm in the well-watered block was higher than that in the drought stress block. Yield reduction under drought stress has been reported to be between 42% (Abayomi et al., 2001) and 67% (Fatokun et al., 2012). The average yield reduction obtained for the hybrids under drought in this study was 48% of that under well-watered conditions.

Genetic variation is a basic criterion for measuring germplasm genetic diversity on which selection acts (Ferriol et al., 2003). The significant variation among the parental lines and their F_1 crosses under drought and well-watered conditions indicated that adequate genetic variation existed among the cowpea germplasm and their crosses. This implies that significant progress can be made from selection for development of productive novel drought tolerant cowpea varieties. The significant environmental variation observed for all traits under drought and well-watered conditions indicates that the environments were unique and variable which emphasizes testing of genotypes in multi-environments. The significant genotype x environment interaction effect observed for all the traits across the research environments indicates that the F_1 crosses varied in their responses to the different environment. This is in agreement with findings of Akande et al. (2009) and Ddamulira et al. (2015).

Combining ability analysis is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits. The success of the hybridization programme depends on the ability of the parents used in hybridization to produce superior segregants / recombinants (Hallauer and Miranda 1981). Combining ability studies help to define the pattern of gene effects in the expression of quantitative traits by identifying potentially superior parents and hybrids (Goyal and Kumar 1991; Ahuja and Dhayal 2007). In the combining ability study, females within sets (GCA_f) was significant for grain yield and other measured traits under both watering regimes. Under drought stress, males within sets (GCA_m) was not significant for grain yield, number of seeds per plant and NDVI_1. The male x female within set interaction (SCA) was not significant for grain yield, number of seeds per pod, number of

Pods per plant and number of seeds per plant. The significant GCA_f , GCA_m and SCA for traits under stress indicated that there were differences in the performance of the lines used as parents. The percentage sum of squares due to GCA effects for grain yield, flowering traits, number of seeds and pods per plant and delayed leaf senescence under drought stress was larger than that due to SCA effects indicating the preponderance of additive gene effects controlling the inheritance of these traits. This result indicates that genetic gains can be achieved through selection for grain yield under drought stress. This agrees with the findings of Jatasra, 1980; Hallauer et al., 2010; Rashwan et al., 2015. The GCA_f and GCA_m mean squares for grain yield were two times larger than those of SCA under drought stress further confirming the importance of additive gene effects over non-additive gene effects in the inheritance of grain yield in the parental lines used. The result of this study contradicts the findings of Alidu et al. (2013) who reported that non-additive gene action was more preponderant for the control of grain yield under drought stress. This disparity may be due to the different set of cowpea germplasm used in the two studies.

None of the parental lines had superior GCA (both significant GCA_f and GCA_m estimates) effects for grain yield under drought stress; however lines TVu6707, TVu79, TVu8670 and TVu9693 had positive GCA_f effect while TVu9797, TVu6707, TVu79 and TVu3562 had positive GCA_m effect for grain yield under drought stress. The results suggest that these lines contribute positively to the grain yield of their crosses either as female or male parents, respectively, under drought stress. It is not surprising that these lines produced the best 20 hybrids under drought and well-watered conditions. TVu3562 had superior GCA effects (GCA_f and GCA_m) for number of seeds per pod and number of pods per plant under drought stress. This suggests that this TVu3562 will contribute favourable alleles for this

trait to its progeny. This is in agreement with findings of Ayo-Vaughan, (2013) who reported predominance of additive genetic variance for number of pods per plant in cowpea.

NDVI readings taken with the Greenseeker® handheld crop sensor device which measures leaf greenness (chlorophyll content) is considered to be correlated with crop productivity under moisture stress. Although this device has gained wide acceptance in maize and wheat breeding for precision phenotyping under water stress (Hazratkulova et al., 2012; Lu et al., 2012), this study appeared to be the first to employ the use of the device for phenotyping cowpea under water stress. The device was used to measure the vegetation index of the parental lines and their crosses at vegetative, flowering and pod-filling stages. From the result of this study, TVu9693 had a superior GCA (GCA_f and GCA_m) effects for NDVI at flowering and grain filling stages under drought stress. TVu6707 had superior GCA (GCA_f and GCA_m) for NDVI_2. This indicates that these lines contributed positively to NDVI values of their crosses during these stages of cowpea growth thus enhancing their increased productivity under drought stress.

Under well-watered conditions, TVu9693 and TVu6707 had significant positive GCA_f for grain yield indicating that they contributed positively to the grain yield of their crosses as female parents. TVu3562 and TVu9797 had significant positive GCA_m for grain yield indicating positive allelic contribution for grain yield as male parent. This indicates that hybrids from the crosses of these lines will produce high yield under well-watered conditions. From this study, the hybrids produced from TVu6707, TVu9693, TVu3562 and TVu8670 were among the best 20 under both watering regimes indicating that these

lines are good combiners for grain yield under both watering regimes and will be good sources of drought tolerance genes to develop new cowpea varieties that are high yielding and tolerant to drought.

Correlation analysis was used to determine the degree of association between the measured traits under both watering regimes. Under the watering regimes, number of pods and seeds per plant showed high and significant positive relationships with grain yield ($r = 0.77$, $r = 0.85$ and $r = 0.74$, $r = 0.83$). This is in agreement with findings of Ayo-Vaughan, (2013). It has been suggested that NDVI could be used to predict grain yield in cereals (Wang et al., 2010). The result from this study showed a significant and positive correlation between grain yield and NDVI measured at vegetative and flowering stages under drought stress ($r = 0.49$, $r = 0.31$) and under well-watered conditions ($r = 0.32$, $r = 0.31$ respectively). This is in agreement with results of other workers (Islam et al., 2011; Lu et al., 2011) who reported positive but weak correlation between NDVI and grain yield in maize ($r = 0.38 - 0.49$). This indicates that a high NDVI value which translates to maintaining green photosynthetic surface during flowering stage will allow cowpea varieties to survive mid-season drought stress. Accumulation of abundant biomass at vegetative stage under drought stress has been reported to be correlated with increase in grain yield at harvest (Adebayo et al., 2014). In cowpea, varieties that combine water saving traits at vegetative stage with delayed leaf senescence will be able to withstand mid-season and terminal drought stress (Belko et al., 2012; Fatokun et al., 2012). Negative and significant correlations were observed between number of days to 50% flowering and grain yield under drought stress as well as under well-watered conditions. This is in agreement with findings of Alidu et al. (2013). This shows that to increase grain yield under both watering regimes, in cowpea, earliness will

be a good direction to exploit but Muchero et al. (2013) reported that early maturing genotypes do not give good yield when exposed to intermittent mid-season drought.

The evaluation of G and GE interaction is an important component of the cultivar selection process in multi-environment trials (METs). The yield of each cultivar in each test environment is a mixture of environment main effect (E), genotype main effect (G) and genotype $\times$ environment interaction (GEI) (Pourdad and Moghaddam, 2013). GGE biplot analysis is an effective method which is based on the principal component analysis (PCA) in order to fully explore METs. For this reason, instead of trying to separate G and GE, Yan et al. (2000) combined G and GE and referred to the mixture as GGE. The GGE biplot is thus a powerful tool for identifying best performing genotypes in a given environment and the most suitable environment for each genotype, average yield of the genotype and the stability of the genotypes in given environments. The PC1 and PC2 of the GGE biplot captured 86.3% of the total variability observed in grain yield with PC1 and PC2 explaining 71.7% and 14.6%, respectively. TVu8670 $\times$ Sanzi, IT89D-288 $\times$ TVu8670, and TVu6707 $\times$ TVu79 were thus identified by the GGE biplot analysis as the most stable crosses across all environments. Although, the GGE biplot identified crosses between TVu6707 $\times$ TVu3562 and TVu6707 $\times$ TVu9797 as high yielding, they were unstable across environments. The findings from this study confirmed the report by Fatokun et al. (2012) that the under-exploited cowpea germplasm (TVu lines) possesses favourable alleles for drought tolerance.

5.5 Conclusion

The ultimate aim in cowpea breeding is to produce pure lines that are highly productive under the ever changing climate conditions. Choosing parents that will contribute favourable alleles for these traits of interest and the knowledge of the mode of gene action controlling the traits are important prerequisites that will ensure efficient utilization of available genetic resources.

In this study, F_1 crosses were evaluated under drought stress and well-watered conditions in two locations in order to examine the combining ability of parents covering diverse array of cowpea germplasm (landrace, advanced breeding lines and tropical *Vigna unguiculata* accession) for drought tolerance; to identify the mode of gene action conditioning drought tolerance and to identify putative parents with good combining ability that will give good hybrids that can further be advanced through appropriate breeding methodology for cowpea to develop high yielding pure lines for drought prone production areas. The findings of this study are summarized below:

The drought and well-watered environments at both experimental locations were unique. High variability exists among the parents and their F_1 progenies to allow selection of F_1 crosses tolerant to drought stress. Additive gene action played a predominant role in the inheritance of grain yield and most traits measured under drought stress. TVu6707, TVu79, TVu96963 and TVu9797 are good general combiners identified from this study. Lines TVu6707 and TVu9693 had significant GCA_f effect for grain yield under drought stress and well-watered conditions while TVu79 had significant GCA_m effect under drought stress. TVu3562 and TVu9797 had significant GCA_m effects for grain yield under the contrasting environments. Advanced progenies resulting from crosses involving these

parents will contribute favourable alleles for drought tolerance and high yield when used as male and female parents in cowpea hybridization programme. These high yielding crosses: TVu6707 x TVu9797, TVu9693 x TVu9797 and TVu79 x DANILA found to be more productive under both watering regimes identified from this study resulted from cross combinations of these lines.

The result on GGE identified cross between TVu6707 x TVu9797 and TVu6707 x TVu3562 were high yielding but were unstable across contrasting environments. TVu8670 x Sanzi, IT89D-288 x TVu8670, TVu6707 x TVu79 and TVu8670 x TVu79 were however high yielding and stable across all the environments. Advancing these crosses could provide new drought tolerant varieties that are high yielding

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

West African countries (Nigeria and Niger) account for over 68% of world's cowpea grain production. However, information from the Food and Agricultural Organization (FAO) database revealed that the production realized per hectare of land in the United States of America surpasses what is realized in SSA. This indicates that increased production quantity in SSA is mainly as a result of increase of land under cultivation and not from the actual yield potential of the crop.

Drought stress is the single most important abiotic factor that reduces cowpea production in semi-arid regions where it is mainly cultivated. With the ever changing global climate, productivity may continue to decline in these regions. The development of high yielding drought tolerant cowpea varieties through breeding will be more rewarding for smallholder cowpea farmers in SSA. In order to achieve this, it is important that cowpea breeders exploit existing variability in cowpea germplasm and identify superior parental lines with good combining ability for pure line development.

Although several studies have reported cowpea to be more tolerant to drought when compared to other grain legumes, in this study, the hypothesis that drought stress reduces cowpea production was tested. From the PRA conducted, the tested hypothesis was accepted. The result of this study confirmed the set out hypothesis and revealed that drought was still ranked as the major abiotic stress limiting cowpea productivity. Farmers interviewed in this study indicated that the unreliable and erratic pattern of rainfall they witness during cropping seasons reduce cowpea productivity through reduction in leaf

production, flower abscission, poor pod-filling and increase in the incidence of some devastating pests and diseases.

The PRA was able to identify reasons why at times new varieties are never adopted by farmers. They indicated that sometimes many of the high yielding varieties they get don't meet consumer preferences which drive their farming business. It was identified in this study that consumer-based traits such as large seeds, short cooking time and high market acceptability were of importance to the farmers as well as the biotic and abiotic constraints and so should be incorporated in breeding programmes.

In order to identify lines with tolerance to vegetative and terminal drought, ninety-one cowpea lines comprising of advanced breeding lines, improved released lines and tropical *Vigna unguiculata* accessions belonging to the primary gene pool of cowpea were screened for seedling and terminal drought tolerance. The objective of this study was to identify parental lines that will combine well to produce superior progenies. The result from the field screening could not be used for selection because of rain interference on the field during the year of evaluation. In the wooden box study for seedling stage tolerance, maintenance of stem greenness was found to be an important trait for tolerance to drought at seedling stage. The genotypes showed significant differences in their responses to drought imposed at seedling stage. The result therefore confirms that the genotypes possess desirable genes for tolerance to drought at seedling stage and that there will be gain in selection for this trait in cowpea using these germplasm. From this study, cowpea was successfully propagated like vegetative crops using the vines of already flowering plants. This success enabled continuous production of flowers for hybridization, thus the number of F₁ seeds needed for evaluation at two locations was possible.

Significant genotype, environment and genotype x environment variation observed among the crosses and the parents for grain yield and in this study confirmed that variability in the germplasm for drought tolerance and the need for multi-environment testing. The significant GCA_f and GCA_m for grain yield and other traits under drought stress indicated that the performance of the parents in cross combinations was influenced by additive gene action under drought stress. The larger proportion of GCA sum of squares over SCA for grain yield, number of pod per plant and delayed leaf senescence indicates that additive gene action played a major role in the inheritance of these traits under drought stress. Some lines showed positive GCA effects for grain yield under drought stress (TVu6707 and TVu79) and (TVu9797 and TVu9693) under well-watered conditions. These lines could be used to develop new varieties that will be highly productive under diverse environmental conditions.

Among the one hundred crosses evaluated under drought and well-watered conditions, eight out of the top 20 yielders under both irrigation regimes were crosses involving lines from TVu accessions while others were crosses involving either a landrace or an improved line. This confirmed that these accessions are repository of favourable alleles for drought tolerance and grain yield. These favourable genes can be exploited for improvement of adapted lines and development of novel varieties.

6.1 Recommendations

- ✓ Climate change is a global phenomenon that needs coordinated measures by government, breeders and farmers in order to provide food and nutrition for the ever increasing population in the SSA.

- ✓ Farmers' preferences are driven by consumers; therefore, breeders have to incorporate these preferences in newly developed climate-smart cowpea varieties so as to increase adoption.
- ✓ The crosses that showed positive GCA effects for grain yield under both irrigation regimes can be advanced for the development of pure lines.
- ✓ Multi-environment testing should be done for the new varieties from the identified parents for stability and grain yield before release.
- ✓ The use of crop sensors for precision cowpea phenotyping under water stress would enhance selection efficiency for drought tolerant cowpea varieties.
- ✓ Pyramiding of drought tolerant QTL for vegetative and terminal drought stress in new cowpea varieties would be a major breakthrough in developing drought tolerant cowpea varieties.

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APPENDICES

APPENDIX 3.1 SURVEY GUIDE QUESTIONS FOR FOCUS GROUP DISCUSSION

General questions

1. Geographic boundaries of the district
2. Major towns and villages
3. Major crops grown
4. Minor crops grown
5. The ranking of cowpea among other crops in the area
6. Other economic activities of the area

Questions on cowpea

1. Varieties of cowpea grown
2. Sources of seeds
3. Preferred seed colour
4. Sources of information on new cowpea technologies
5. Number of times cowpea seeds are used for planting before discarding
6. Seed treatment for storage
7. Storage receptacles (i.e. sacks)
8. Criteria for selecting cowpea for home consumption
9. Criteria for selecting cowpea for marketing
10. Farmers recommended traits into future cowpea varieties
 - a. Yield related
 - b. Preference and quality related
 - c. Labour related
11. Farmers involvement in cowpea research
 - a. Goal setting and objective formulation
 - b. Variety selection
 - c. On-farm evaluation
 - d. Variety release
 - e. Seed multiplication and promotion
 - f. No involvement
12. Production constraints (list and rank)

Questions of drought impact on yield

1. Sources of information on climate change and mitigation techniques (drought)
2. Are varieties grown drought tolerant?
3. Symptoms of drought on cowpea
4. Realized yield of cowpea under normal growing conditions
5. Yield as a result of pre flowering drought
6. Yield as a result of post flowering drought
7. Which stage of cowpea is drought very devastating?
8. Causes of drought
9. Controlled options employed
10. Access to drought tolerant cowpea varieties?

APPENDIX 3.2. PRA Semi-structured questionnaire for individual farmer

State..... Local Government Area

Village Community

Latitude Longitude

Interviewed by Date

A. Background information

1. What is your name?
.....
2. What is your relationship to the household? (a) Household head (b) Spouse (c) Son/daughter aged 15 and above, (d) Others
3. What is the gender of the household head? (a) Male (b) Female
4. What is age of the household head? _____
5. Marital Status 1= Single[] 2= Married[] 3= Separated [] 4=widow/widower []
6. What is the highest schooling years attained by any member of the household?

7. How many household members do you have? _____
8. In the last agricultural year (2013/14), how many household members engaged in agricultural activities? _____
9. Primary occupation (Tick as many as applicable)

1= Farming [] 2= Trading [] 3=Civil service [] 4= Artisan [] 5=others
(specify)

10. Are you a member of any farmer group? 1= Yes [] 0=No []

11. If yes please specify If No, why not?
.....

B. General information on farming practices

12. Years of farming experience. _____

13. Total farm size (ha) _____

14. What was the total cowpea area planted in the last agricultural season? _____

15. What was the area planted to improved cowpea varieties in 2013/14 agricultural season? _____

16. In 2013/14, did you apply chemical fertilizer to cowpea? _____

17. Land ownership. 1= rent [] 2= inherited through family [] 3= bought []

18. How many times do you cultivate cowpea in a year? 1=once [] 2=twice [] 3=thrice []

19. What type of cropping system do you use? 1=mono-cropping [] 2= mixed cropping []

If answer in 12 above is 2, list crops-----

20. What kind of labour do you use for cowpea farming? (Tick as many as applicable)
1= immediate family [] 2=hired [] 3=others (specify)

21. Do you use any motor-powered equipment for cowpea farming? 1= Yes
0= N

22. If yes, which machines do you use? 1= plough[] 2= seed planter[]
3= combine harvester [] 4=other (specify)_____

23. Does your household currently own any of the following? (a) Cattle, Donkey, or horses (b) Goats or sheep (c) Poultry
(b) If yes, How many? (a) Cattle, Donkey or horses _____ (b) Goats or Sheep _____ (c) Poultry _____

22. Please provide the following information on labor and other power inputs for other crops

Farm operation	Labour input in person day		Oxen inputs in days		Tractor	
	No. of persons	No. of days	No of Oxen pairs	No of days	No. of days	Amount paid/day
Land clearing						
1 st ploughing/ Hoeing						
2 nd ploughing/ Harrowing						
Furrowing/ ridging						
Planting						
1 st weeding						
2 nd weeding						

Remolding						
Herbicide/insecticide application						
Farm operation	Labour input in person day		Oxen inputs in days		Tractor	
	No. of persons	No. of days	No of Oxen pairs	No of days	No of days	Amount paid/day
Manure application						
Inorganic fertilizer application						
Harvesting						

*State the number of oxen used _____

C. Varietal preferences

24. Cowpea varieties grown and their yield estimates

Variety	Seed colour 1=white, 2=brown, 3=red 4=black	Seed size 1=small, 2=medium, 3=large	Yield under normal condition (kg/ha)	Yield under drought(kg/ha)

25. Type of cowpea seeds grown 1= local landrace [] 2= improved seeds from research []

26. Sources of seeds 1= open market [] 2= Seed company/ agro-dealer [] 3= farmer friend/relative [] 4=own saved local seed [] 5= own saved improved seed [] 6= Government /NGO []

D. Climate change (drought) and impact on cowpea production

27. Prominent climatic factors that affect cowpea production 1= rainfall [] 2= temperature [] 3=wind [] 4= relative humidity []

28. Sources of information on climate change 1 = Extension agent [] 2=Friends[]Relatives [] 3= Co-farmers [] 4= Mass Media [] 5=Other sources[]

29. Have you ever experienced drought during cowpea growing seasons 1= Yes [] 2=No []

30. If yes, how devastating was the effect on grain yield? 1=very severe [] 2=moderately severe [] 3=not severe []

31. If yes in 29, how devastating was the effect on fodder yield? 1=very severe [] 2=moderately severe [] 3=not severe []

32. At which stage of cowpea growth can drought be devastating? 1= vegetative stage []
2= flowering stage [] 3= pod setting [] 4=all growth stages []
33. **Effects of drought on cowpea growth and yield:** Tick one option for one effect under both

Effects	Pre-flowering drought				Post- flowering drought			
	Great extent	Some extent	Little extent	No extent	Great extent	Some extent	Little extent	No extent
Late emergence of seed								
Plant wilting								
Flower abortion								
Poor pod formation								
Poor pod filling/seed set								
Increase in Incidence of pests and diseases								
Stunted growth								
Yellowing of leaves								
Low grain yield								
Low fodder yield								

headings.

34. Realized yield (kg/ha) as a result of drought at different growth stages of cowpea.

Varieties	Pre-flowering drought		Post-flowering drought	
	grain	fodder	grain	fodder

E. Adaptation measures employed

Adaptation measures	Yes	No
Use of irrigation		
Planting improved varieties tolerant to drought		
Manipulation of planting times and harvesting dates		
Other measures (specify)		

35. Production constraints

Constraints	Great extent	Some extent	Little extent	No extent
Lack of improved varieties				
Drought				

Problems of diseases				
Problems of pests				
High cost of land preparation and maintenance				
Inadequate marketing channels				
Floods				
High cost of land rent				
Gender in respect of land ownership				
Religion				
Educational level				
Poor soil fertility				
Land size				

F. Improved cowpea varieties

36. Do you have easy access to improved cowpea varieties that are tolerant to drought?

0=No [] 1= Yes []

37. How do you get information on these improved seeds? NGOs [] Radio [] Television [] farmer field school [] Agric. Extension [] other farmers [] friends [] other sources []

38. Have you ever grown these improved varieties? 0= No [] 1=Yes []

39. If yes, give reasons for your adoption of the improved varieties. -----

40. Factors limiting adoption of improved varieties

Limiting factors	Great extent	Some extent	Little extent	No extent
Expensive seeds				
Information dissemination				
Lack of demonstration/field days				
Steady source of seeds/access to seeds				
Educational status				
Age				
Perception				
Gap between technology and adoption				
Threshing quality				
Cooking time				
Market and consumer acceptability				
Others				

41. Do the improved varieties yield more than local varieties in times of drought? 0=No []

1= Yes []

42. If yes, please give comparison

Variety name	Type: (local =1; improved = 2)	Yield (kg/ha)

43. How do you get information on improved seeds? NGOs [] Radio [] Television []
farmer field school days [] Agric. Extension [] other farmers [] other sources []
44. What do you think farmers' involvement in cowpea research should be? Please tick
all that apply.

	Farmers' involvement in research	Yes	No
a)	Objective formulation		
b)	On-farm trials, evaluations and selection		
c)	No involvement		

45. Please rank these traits in order of preference.

Preferred traits	Rank
High yielding	
Pest and disease resistance	
High palatability	
Early maturing	
High storability	
Large seeds	
Drought resistance	
Dual-purpose	
Short cooking time	
High market acceptability	
Late maturing	

G. Marketing of cowpea

46. Do you cultivate cowpea for home consumption or for selling?
1= selling 2= home consumption 3=both
47. If both, what percentage of cowpea do you sell in a growing season?
48. Who buys your cowpea? 1= market women [] 2= government agency /NGO [] 3=
Others
49. Is it difficult to sell the cowpea you produce 0= No [] 1=Yes []
50. If Yes, what is the major reason for lack of market for the cowpea you produce? 1=
Bad road [] 2=high cost of transportation [] 3=Glut [] 4=poor storage [] 5=other
(specify)
51. Do you make profits from growing cowpea? 0=No 1=Yes

APPENDIX 4.1 Pedigree and maturity of lines screened for drought tolerance

S/N	Lines	Pedigree	Maturity	S/N	Lines	Pedigree	Maturity
1	13-309	IT97K-499-35 x (TVu522 x TVu557)	Medium	47	IT97K-499-35	IT93K-596-12 x IT93K-2046-1	Medium
2	14-62	IT97K-499-35 x (TVu522 x DANILA)	Medium	48	IT97K-573-2-1	IT93K-596-9-12 x IT86D-880	Medium
3	15-145	IT97K-499-35 x (TVu1438 x TVu557)	Medium	49	IT97K-819-132	IT90K-592 x IT88DM-867-11	Medium
4	16-109	IT97K-499-35 x (TVu4574 x TVu522)	Medium	50	IT98K-1111-1	IT93K-452-1 x TVU 11426	Early
5	19B-35	TVu522 x IT99K-494-6	Medium	51	IT99K-573-1-1	IT93K-596-9-12 x IT86D-880	Early
6	19C-8	IT97K-499-35 x (TVu4574 x TVu6443)	Medium	52	Tvu1007	TVu accession	Medium
7	21A-40	TVu1438 x TVu2731	Late	53	Tvu10100	TVu accession	Medium
8	21A-54	TVu1438 x TVu2731	Medium	54	Tvu11800	TVu accession	Medium
9	22A-85	TVu1438 x TVu522	Medium	55	Tvu11982	TVu accession	Medium
10	23B-136	IT99K-494-6 x TVu522	Medium	56	Tvu11984	TVu accession	Medium
11	24A-23	IT99K-494-6 x TVu6443	Medium	57	Tvu11986	TVu accession	Medium
12	28-25A	IT98K-205-8 x (TVu522 x TVu4574)	Medium	58	Tvu12791	TVu accession	Medium
13	31-181	IT98K-205-8 x (IT99K-494-6 x TVu522)	Medium	59	Tvu1436	TVu accession	Medium
14	40-210	IT89KD-374-57 x (TVu6443 x IT99K-494-6)	Medium	60	Tvu1438	TVu accession	Medium
15	45-111	IT97K-499-38 x (IT99K-494-6 x TVu522)	Medium	61	Tvu14539	TVu accession	Medium
16	52-13A	IT90K-372-1-2 x (TVu4574 x DANILA)	Medium	62	Tvu14553	TVu accession	Medium
17	55-261	IT97K-1069-6 x (TVu522 x TVu557)	Medium	63	Tvu14632	TVu accession	Medium
18	55-71	IT97K-1069-6 x (TVu522 x TVu557)	Medium	64	Tvu14676	TVu accession	Medium
19	57-109	IT00K-1263 x (IT99K-494-6 x TVu522)	Medium	65	Tvu148	TVu accession	Medium
20	58-246	IT00K-1263 x (TVU522 x TVu557)	Medium	66	Tvu15055	TVu accession	Medium
21	58-60	IT00K-1263 x (TVU522 x TVu557)	Medium	67	Tvu15058	TVu accession	Medium
22	58-66	IT00K-1263 x (TVU522 x TVu557)	Medium	68	Tvu15450	TVu accession	Medium
23	5A-55	TVU 6443 x IT 99K-494-6	Medium	69	Tvu15866	TVu accession	Medium
24	60-321	IT00K-1263 x (TVu4574 x TVu522)	Medium	70	Tvu16646	TVu accession	Medium
25	60-374	IT00K-1263 x (TVu4574 x TVu522)	Medium	71	Tvu2672	TVu accession	Medium
26	61-317	IT00K-1263 x (TVu6443 x TVu1438)	Late	72	Tvu2722	TVu accession	Medium
27	61-88	IT00K-1263 x (TVu6443 x TVu1438)	Medium	73	Tvu2731	TVu accession	Medium
28	64-25	IT00K-1263 x (TVu557 x TVu522)	Medium	74	TVu2736	TVu accession	Medium
29	64-68	IT00K-1263 x (TVu557 x TVu522)	Medium	75	Tvu294	TVu accession	Medium
30	6-67	TVU 6443 x TVU 1438	Medium	76	Tvu3562	TVu accession	Medium
31	7-11	IT98K-506-1 x (IT98K-506-1 x TVu6443)	Medium	77	Tvu441	TVu accession	Medium
32	71-10	IT96D-610 x (TVu557 x TVu522)	Medium	78	Tvu4574	TVu accession	Medium
33	8A-131	TVu557 x TVu522	Medium	79	Tvu522	TVu accession	Medium
34	8B-46	TVu557 x TVu523	Medium	80	Tvu5415	TVu accession	Medium
35	CB27	California Blackeye No. 27	Early	81	Tvu557	TVu accession	Medium

Appendix 4.1 continued							
36	Ife Brown	TVu59 x TVu53	Medium	82	Tvu6333	TVu accession	Medium
37	IT81D-985	[(TVu1190 x TVu76) x TVu2027] x TVu625	Medium	83	Tvu6443	TVu accession	Medium
38	IT81D-994	(IT87F-1777-2 x IT84S-2246-4) x TVx3236	Late	84	Tvu6707	TVu accession	Medium
39	IT84S-2246-4	IT82D-716 x IT81D-1020	Medium	85	Tvu7778	TVu accession	Medium
40	IT85F-3139	IT82D-716 x IT82D-889	Medium	86	Tvu79	TVu accession	Medium
41	IT89D-288	(IT87F-1777-2 x IT84S-2246-4) x IT87F-1777-2	Late	87	Tvu8670	TVu accession	Medium
42	IT90K-277-2	(IT87F-1777-2 x IT84S-2246-4) x TVx3236	Medium	88	Tvu9693	TVu accession	Medium
43	IT90K-76	(IT84S-2246-4 x B301) x IT84S-2246-4	Late	89	Tvu9797	TVu accession	Medium
44	IT93K-452-1	(IT87F-1777-2 x IT84S-2246-4) x TVx3236	Early	90	Sanzi	Selection	Medium
45	IT96D-610	IT90K-48-1 x IT89KD-288	Medium	91	Danila	Selection	Late
46	IT97K-207-15	IT90K-48-1 x IT86D-719	Medium				

APPENDIX 4.2 Performance of lines screened for drought tolerance at seedling stage.

Genotypes	*DT E	PHT1 4	PH T21	SG21 DAP	SG1 4DA P	SG30 DAP	LW 14D AP	LW 21D AP	LW3 0DAP	¥RR (%)
13-309	3.3	8.1	7.8	3.9	4.0	1.6	0.3	0.3	2.3	0.0
14-62	3.8	8.9	9.6	3.6	3.9	1.6	0.4	1.0	2.2	9.1
15-145	3.4	8.7	7.5	4.0	4.0	3.6	0.0	0.2	1.7	45.5
16-109	3.1	8.5	8.2	3.5	3.6	1.8	0.7	1.1	2.1	0.0
19B-35	3.3	8.5	7.7	4.0	4.0	3.5	0.0	0.1	1.0	33.3
19C-8	3.0	8.1	8.7	3.9	4.0	3.3	0.1	0.2	1.3	16.7
21A-40	3.0	6.9	7.3	4.0	4.0	1.6	0.4	0.5	2.0	0.0
21A-54	3.4	7.6	7.7	4.0	4.0	2.3	0.3	0.3	1.4	0.0
22A-85	3.0	7.4	7.3	4.0	3.8	2.6	0.5	1.0	1.3	0.0
23B-136	3.3	6.4	6.3	3.4	3.8	1.4	0.6	1.3	2.6	0.0
24A-23	3.0	8.0	7.8	3.5	4.0	1.1	0.5	1.5	3.0	9.1
28-25A	3.0	10.0	10.3	3.6	4.0	1.3	0.0	0.1	2.9	0.0
31-181	3.3	6.3	6.4	3.6	4.0	1.4	0.3	0.8	2.6	0.0
40-210	3.2	8.8	8.2	3.9	4.0	1.8	0.3	0.3	2.3	0.0
45-111	4.0	8.0	8.3	4.0	4.0	0.5	0.5	0.5	3.5	0.0
52-13A	3.2	7.8	7.7	3.7	4.0	1.4	0.5	0.9	2.3	0.0
55-71	3.2	8.2	7.7	3.6	3.6	1.0	0.7	1.4	3.1	0.0
55-261	3.1	9.7	9.8	3.5	3.9	1.2	0.7	0.9	2.9	0.0
57-109	3.5	7.1	7.4	3.8	4.0	0.4	0.8	0.8	3.5	0.0
58-246	3.3	10.4	9.5	3.3	3.9	0.8	1.1	1.8	3.1	0.0
58-60	3.2	8.6	8.9	2.4	3.5	0.6	0.9	2.1	3.3	0.0
58-66	3.3	9.0	8.5	3.0	3.7	1.0	1.0	2.0	3.0	0.0
5A55	3.3	7.8	7.3	3.8	4.0	2.7	0.3	0.7	1.9	50.0
60-321	3.3	9.8	9.6	3.7	3.7	2.4	0.6	0.9	2.2	0.0
60-374	3.1	9.7	9.8	3.1	3.3	0.8	1.0	1.5	3.1	0.0
61-317	3.2	9.0	8.7	3.4	3.9	1.3	1.1	2.0	2.9	0.0
61-88	3.3	7.3	7.8	3.3	3.3	1.3	1.0	1.3	2.8	0.0
64-25	3.1	9.6	9.2	3.5	4.0	1.9	1.0	1.3	2.3	16.7
64-68	3.0	7.9	7.6	3.2	3.6	1.3	1.0	1.6	2.7	0.0
6-67	3.0	7.4	7.9	3.8	3.9	2.0	0.3	0.5	2.1	16.7
7-11	3.5	5.9	6.7	2.7	4.0	0.6	1.0	2.2	3.5	0.0
71-10	3.4	9.9	10.3	3.1	4.0	0.6	0.7	1.3	3.2	0.0
8A-131	3.1	9.0	8.1	3.7	4.0	1.5	0.3	0.3	2.3	0.0
8B-46	3.0	7.6	7.4	3.8	4.0	2.2	0.5	1.0	1.7	0.0
CB27	4.1	8.2	8.2	3.3	3.6	2.5	0.7	0.8	1.7	40.0
Danila	3.0	9.7	10.3	3.3	4.0	2.8	0.0	2.2	3.2	16.7
IT81D-994	3.0	12.8	13.5	3.0	4.0	3.1	0.0	2.3	3.1	10.0
IT81KD-985	3.0	9.6	10.3	3.5	4.0	2.2	0.0	2.4	3.0	18.2
IT84S-2246-4	3.5	9.3	9.9	2.9	4.0	2.7	0.0	1.9	3.1	36.4
IT85F-3139	3.4	7.2	6.6	3.1	3.5	0.5	1.3	1.8	3.5	0.0

Appendix 4.2 continued

IT89D-288	3.2	14.9	15.2	2.2	4.0	2.1	0.0	2.8	3.2	22.2
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IT90K-277-2	3.3	13.0	13.7	2.4	4.0	3.1	0.0	2.9	3.1	36.4
IT90K-76	3.1	12.1	12.7	2.7	4.0	2.3	0.0	2.2	2.4	50.0
IT93K-452-1	3.7	14.8	15.5	1.9	4.0	1.3	0.0	3.0	3.0	18.2
IT96D-610	4.0	9.2	8.4	3.5	3.6	2.3	0.6	0.8	2.2	0.0
IT97K-499-35	3.3	9.7	10.2	3.3	4.0	2.6	0.0	3.0	2.6	12.5
IT97K-573-1-1	3.6	12.9	13.4	1.5	4.0	1.4	0.0	2.9	3.5	0.0
IT97K-573-2-1	3.3	13.1	13.2	2.4	4.0	1.5	0.0	2.9	3.5	0.0
IT97K-819-132	3.9	8.4	8.3	3.9	3.9	2.3	0.2	0.6	2.3	20.0
IT97K207-15	4.0	11.4	11.1	3.3	3.8	1.8	0.3	0.9	2.5	25.0
IT98K-1111-1	3.4	9.8	9.5	3.5	4.0	0.7	0.6	1.4	3.2	0.0
IT99K-573-1-1	3.4	10.2	10.6	3.0	4.0	1.9	0.0	2.1	3.1	57.1
Ife Brown	3.4	11.9	12.3	4.0	4.0	3.4	0.0	1.3	3.2	83.3
Sanzi	3.0	8.9	9.3	0.7	4.0	0.2	0.0	3.6	4.0	0.0
TVu10100	3.1	12.2	12.6	2.0	4.0	1.0	0.0	2.8	3.0	0.0
TVu11800	3.0	10.4	10.7	2.6	4.0	1.8	0.0	3.0	3.3	0.0
TVu11982	3.1	8.1	8.8	4.0	4.0	3.2	0.0	2.8	3.0	16.7
TVu12791	3.2	8.7	10.1	2.4	4.0	1.8	0.0	2.5	2.7	9.1
TVu1438	4.0	8.0	8.5	4.0	4.0	1.0	0.0	2.0	3.0	0.0
TVu14539	3.0	8.5	9.1	2.5	4.0	1.5	0.0	2.4	3.1	0.0
TVu14632	4.0	8.8	9.3	1.1	4.0	0.4	0.0	2.7	3.2	0.0
TVu14676	3.2	6.4	7.4	2.2	4.0	2.5	0.0	2.1	2.6	0.0
TVu148	3.1	8.0	8.4	1.5	4.0	1.3	0.0	3.2	3.3	8.3
TVu15055	3.5	7.1	7.4	2.5	4.0	2.5	0.0	3.0	3.0	25.0
TVu15058	3.0	10.2	11.0	3.0	4.0	1.6	0.0	2.4	3.4	0.0
TVu16646	3.2	12.0	12.9	3.7	4.0	2.8	0.0	1.5	2.4	8.3
TVu2672	3.4	10.0	10.5	1.6	4.0	1.6	0.0	3.3	3.0	0.0
TVu2722	5.3	7.7	8.0	1.1	4.0	1.4	0.0	3.6	3.6	0.0
TVu2731	4.9	7.6	8.7	2.6	4.0	1.9	0.0	2.9	3.1	0.0
TVu294	3.1	11.9	12.5	2.3	4.0	2.3	0.0	2.5	2.9	0.0
TVu3562	4.7	6.0	7.5	1.0	4.0	1.0	0.0	4.0	4.0	0.0
TVu522	3.3	8.4	9.1	2.0	4.0	1.9	0.0	3.1	2.9	0.0
TVu557	3.4	10.3	10.9	3.0	4.0	1.0	0.0	2.0	3.0	0.0
TVu6333	7.1	7.2	7.7	3.3	4.0	2.6	0.0	2.1	3.0	16.7
TVu6443	4.4	7.4	8.0	2.4	4.0	1.0	0.0	2.8	3.1	0.0
TVu6707	3.3	9.1	9.7	1.8	4.0	1.5	0.0	2.8	3.1	0.0
TVu79	3.0	9.6	10.2	1.5	4.0	1.5	0.0	2.9	3.0	0.0
TVu8670	3.5	9.0	9.6	2.2	4.0	1.7	0.0	3.1	3.3	0.0
TVu9797	3.4	8.4	8.8	1.2	4.0	0.6	0.0	2.8	3.1	0.0
Tvu1007	3.7	10.1	10.5	2.7	4.0	1.8	0.0	2.4	3.0	0.0
Tvu11984	3.8	9.6	10.1	1.8	4.0	1.8	0.0	3.1	3.0	25.0
Tvu11986	3.3	7.8	8.3	3.3	4.0	2.7	0.0	2.4	2.5	8.3
Tvu1436	3.6	9.4	9.6	2.9	4.0	2.3	0.0	2.7	3.2	11.1
Tvu14553	3.1	9.2	9.5	2.0	4.0	1.3	0.0	2.8	3.0	0.0
Tvu15450	3.2	9.5	10.2	2.6	4.0	1.2	0.0	2.2	2.8	0.0

Appendix 4.2 continued

Tvu15866	3.1	9.3	9.6	2.4	4.0	2.0	0.0	2.3	2.9	0.0
Tvu2736	3.6	6.1	6.5	1.4	4.0	1.4	0.0	2.7	2.2	0.0
Tvu441	3.8	8.0	8.4	2.5	4.0	1.6	0.0	2.4	3.0	0.0
Tvu9693	3.9	7.0	7.5	1.6	4.0	1.3	0.0	2.8	2.9	0.0
TVu7778 (SC)	3.1	7.7	8.3	1.3	4.0	0.9	0.0	3.1	3.4	0.0
[‡] Mean	3.36	8.96	9.22	2.79	3.93	1.66	0.25	1.97	2.83	0.08
SE	0.03	0.07	0.08	0.04	0.01	0.04	0.01	0.04	0.03	0.08
LSD (_{0.05})	0.62	1.37	1.42	0.78	0.23	0.89	0.24	0.62	0.78	0.21

[‡]Values derived from both wooden box screenings; SC= susceptible check; *DTE = Days to seedling emergence, PHT14, PHT21= plant height at 14 and 21 days after planting, SG14DAP and SG30DAP = Stem greenness (0-4) at 14, 21 and 30 days after planting, LW14DAP, LW21DAP and LW30DAP= Wilting (0-4) at 14, 21 and 30 days after planting. [‡]Each point represents four plants per genotype replicated thrice. %RR (recovered plants) = no of dead/ no of survived*100

APPENDIX 5.1: Means of grain yield and other agronomic traits of parental lines evaluated under drought stress at Ibadan and Minjibir.

Pedigree	GY	SW100	sdppod	D50fl	Ndvi_1	Ndvi_2	Ndvi_3	Podplt	Pdlt	sdplt	DLSC
CB-27	339.4	18.33	7.45	49.70	0.18	0.40	0.35	19.21	13.86	161.25	7.19
DANILA	778.2	16.07	9.97	48.71	-1.28	0.61	0.50	42.72	16.90	427.55	8.06
IFEBROWN	201.8	14.13	6.52	47.45	1.22	0.71	0.46	16.59	10.05	111.05	8.87
IT81D-985	585.9	13.14	9.15	47.75	2.12	0.65	0.41	38.86	15.51	364.41	6.71
IT89KD-288	826.0	16.93	10.28	48.61	0.69	0.48	0.38	38.55	13.83	420.09	7.55
IT90K-277-2	457.9	14.28	7.28	53.37	0.67	0.54	0.40	38.29	12.43	277.72	7.73
IT90K-76	495.9	11.49	11.15	51.90	-2.48	0.70	0.52	31.94	13.10	385.84	9.42
IT99K-573-1-1	510.2	12.30	6.34	56.08	0.86	0.70	0.45	33.27	14.57	268.00	7.89
SANZI	402.9	7.32	7.62	45.83	0.66	0.49	0.33	32.69	10.60	308.11	8.44
TVu10100	592.8	9.42	10.56	52.90	2.28	0.63	0.31	31.73	12.66	388.99	8.12
TVu11986	115.9	10.90	13.37	50.18	33.66	0.50	0.40	4.04	34.17	328.61	7.71
TVu2736	219.8	7.48	10.62	51.04	0.52	0.53	0.28	22.41	12.25	268.09	7.26
TVu3562	461.3	8.18	10.35	51.04	0.32	0.60	0.44	32.94	13.46	398.65	8.09
TVu6333	450.0	9.61	11.55	52.23	-0.59	0.68	0.48	26.15	14.59	300.32	7.82
TVu6707	1788.1	12.60	15.52	46.26	4.91	0.77	0.26	61.87	18.46	852.81	7.05
TVu7778	382.8	8.00	12.32	47.18	12.94	0.67	0.25	25.48	14.55	324.31	8.54
TVu79	433.3	8.37	12.00	47.45	-0.07	0.68	0.51	24.27	14.39	304.41	9.32
TVu8670	869.7	11.54	13.57	47.12	0.81	0.75	0.38	29.44	17.59	443.42	7.27
TVu9693	890.4	6.92	15.27	50.49	-2.45	0.75	0.41	25.17	15.82	434.14	7.76
TVu9797	769.5	9.68	13.28	46.82	-0.20	0.64	0.39	32.13	15.37	420.38	6.43
Mean	586.6	11.41	10.71	49.30	0.59	0.64	0.40	30.68	15.13	358.81	7.88
SE	48.1	0.35	0.32	0.39	0.02	0.01	0.02	1.85	0.62	23.03	0.14

APPENDIX 5.2: Means of grain yield and other agronomic traits of parental lines evaluated under well-watered conditions at Ibadan and Minjibir.

pedigree	GY	SW100	sdppod	D50fl	Ndvi_1	Ndvi_2	Ndvi_3	Podplt	Pdlt	sdplt
CB-27	273.9	14.05	7.54	47.91	0.66	0.45	0.38	13.96	14.06	94.19
DANILA	904.7	14.68	11.05	45.27	0.75	0.58	0.25	41.95	14.65	372.67
IFEBROWN	190.7	13.73	7.65	49.47	0.52	0.58	0.40	13.50	10.81	117.07
IT81D-985	1433.5	15.88	10.61	49.34	0.48	0.60	0.48	82.60	15.47	840.41
IT89KD-288	682.5	17.38	8.71	46.08	0.61	0.62	0.38	33.35	14.03	292.20
IT90K-277-2	345.5	15.04	8.07	51.40	0.55	0.58	0.44	30.69	12.61	215.63
IT90K-76	571.1	9.71	11.67	50.09	0.56	0.74	0.51	34.11	13.94	403.41
IT99K-573-1-1	649.8	13.66	7.07	51.53	0.55	0.71	0.44	42.79	14.89	350.33
SANZI	547.6	8.29	7.80	46.13	0.58	0.55	0.48	61.29	10.65	518.74
TVu10100	520.0	9.68	10.31	52.31	0.44	0.51	0.43	31.23	12.82	371.69
TVu11986	330.5	11.20	11.16	49.73	0.56	0.63	0.49	27.24	14.70	283.77
TVu2736	903.8	9.22	11.07	50.46	0.52	0.68	0.52	21.32	11.89	222.96
TVu3562	473.7	8.75	11.07	49.54	0.46	0.61	0.52	37.06	12.74	417.24
TVu6333	232.3	9.04	12.21	48.24	0.79	0.82	0.47	9.92	15.24	134.95
TVu6707	2127.4	11.51	14.97	47.48	0.77	0.79	0.32	62.46	17.93	954.82
TVu7778	284.4	8.58	11.62	53.62	0.54	0.54	0.40	32.17	14.41	350.45
TVu79	845.7	11.01	13.39	47.12	0.59	0.72	0.47	47.87	15.91	557.47
TVu8670	561.2	12.38	12.55	48.21	0.64	0.71	0.53	25.26	16.11	378.45
TVu9693	861.4	9.45	15.04	55.90	0.49	0.60	0.50	30.43	16.24	437.07
TVu9797	1261.2	11.27	14.25	51.18	0.49	0.69	0.51	50.12	15.88	718.77
Mean	727.9	11.70	11.03	49.83	0.58	0.64	0.45	37.25	14.33	417.15
SE	55.9	0.31	0.27	0.41	0.02	0.01	0.02	2.46	0.21	28.15

APPENDIX 5.3: Means of grain yield and other agronomic traits of 100 single F₁ crosses evaluated under drought stress at Ibadan and Minjibir.

Crosses	*GY	SW100	sdppod	D50fl	Ndvi_1	Ndvi_2	Ndvi_3	Podplt	Pdlt	sdplt	DLSC
IFEBROWN x TVu6333	668.7	16.06	9.32	50.85	0.56	0.74	0.51	20.62	14.51	257.16	3.82
IFEBROWN x CB-27	920.1	17.26	8.51	45.37	0.51	0.61	0.43	52.64	14.85	500.30	7.73
IFEBROWN x IT89D-288	1080.8	14.11	10.93	46.14	0.52	0.67	0.43	46.60	14.58	537.63	8.30
IFEBROWN x IT99K-573-1-1	610.6	12.71	7.99	48.03	0.54	0.69	0.41	40.42	15.27	326.85	8.37
IFEBROWN x TVu11986	716.4	11.60	10.93	50.93	0.46	0.51	0.36	40.68	14.42	446.32	6.62
IT90K-76 x TVu6333	201.2	13.34	9.04	52.12	0.63	0.61	0.47	11.01	13.29	92.94	2.84
IT90K-76 x CB-27	527.6	15.71	9.80	47.29	0.53	0.65	0.46	35.68	14.37	336.53	8.45
IT90K-76 x IT89D-288	270.3	13.77	10.38	48.20	0.50	0.67	0.49	35.24	14.40	353.57	7.61
IT90K-76 x IT99K-573-1-1	476.1	15.43	8.27	50.95	0.50	0.57	0.39	26.78	14.21	241.67	7.09
IT90K-76 x TVu11986	744.2	12.97	11.66	49.76	0.59	0.74	0.56	45.05	15.30	510.87	4.99
IT81D-985 x TVu6333	787.8	14.12	11.20	50.41	0.51	0.68	0.58	26.56	17.28	341.90	2.36
IT81D-985 x CB-27	296.7	15.53	9.08	44.39	0.46	0.54	0.38	23.15	15.71	218.66	6.47
IT81D-985 x IT89D-288	684.9	18.06	6.95	45.87	0.48	0.52	0.36	36.99	13.04	275.16	6.30
IT81D-985 x IT99K-573-1-1	692.1	17.11	7.51	46.51	0.46	0.51	0.41	28.59	14.20	266.79	6.09
IT81D-985 x TVu11986	246.7	14.47	7.77	48.13	0.43	0.57	0.37	18.11	13.61	149.67	5.14
DANILA x TVu6333	766.8	13.80	10.57	48.97	0.49	0.62	0.46	26.44	15.03	319.60	2.81
DANIILA x CB-27	924.2	17.19	8.33	42.81	0.52	0.54	0.37	36.24	13.51	377.12	8.05
DANILA x IT89D-288	571.6	19.15	8.23	46.20	0.48	0.52	0.37	24.55	12.89	237.45	8.64
DANILA x IT99K-573-1-1	686.9	17.67	7.98	49.21	0.49	0.56	0.37	37.51	15.32	327.47	6.92
DANILA x TVu11986	431.4	14.93	7.92	53.03	0.47	0.58	0.44	18.59	13.35	191.60	3.88
IT90K-277-2 x TVu6333	418.9	13.25	8.39	52.52	0.50	0.69	0.51	17.52	13.69	159.55	4.22
IT90K-277-2 x CB-27	823.4	16.17	9.51	46.72	0.40	0.58	0.52	37.04	14.18	386.98	4.23
IT90K-277-2 x IT89D-288	816.2	14.29	9.11	48.43	0.50	0.62	0.43	33.18	13.58	323.69	6.28
IT90K-277-2 x IT99K-573-1-1	562.3	14.37	8.10	49.02	0.44	0.56	0.38	23.15	14.49	205.16	5.44
IT90K-277-2 x TVu11986	441.9	13.02	8.63	50.41	0.51	0.65	0.45	19.14	12.26	194.25	4.95
TVu6333 x TVu10100	281.0	9.37	11.45	53.81	0.49	0.67	0.57	14.19	13.36	166.76	2.57
TVu6333 x TVu6707	177.5	10.23	10.94	51.76	0.45	0.70	0.59	17.42	14.92	183.99	2.33
TVu6333 x TVu9693	263.1	9.66	11.81	52.88	0.50	0.72	0.51	12.03	14.74	126.28	3.92
TVu6333 x TVu2736	168.2	8.89	10.69	55.75	0.49	0.69	0.53	12.23	12.82	128.54	4.45
TVu6333 x TVu8670	60.2	9.24	9.71	52.03	0.49	0.70	0.52	3.72	12.70	5.58	4.29

Appendix 5.3 continued											
CB-27 x TVu10100	737.8	15.04	11.32	45.19	0.52	0.64	0.51	33.31	15.30	381.72	4.83
CB-27 x TVu6707	1188.6	16.18	8.82	44.36	0.54	0.68	0.52	53.94	14.50	568.45	4.96
CB-27 x TVu9693	1115.7	13.66	12.36	47.44	0.52	0.70	0.52	57.26	16.88	704.07	6.29
CB-27 x TVu2736	799.0	10.93	11.53	46.82	0.47	0.58	0.43	35.69	12.82	464.60	6.18
CB-27 x TVu8670	1111.7	14.09	10.48	46.70	0.49	0.65	0.51	47.22	15.64	564.46	5.15
IT89D-288 x TVu10100	485.3	13.76	9.25	49.45	0.47	0.70	0.44	21.67	14.87	239.87	3.87
IT89D-288 x TVu6707	1312.1	15.39	10.11	46.58	0.59	0.76	0.47	64.34	15.59	688.53	8.14
IT89D-288 x TVu9693	587.8	14.09	10.70	48.05	0.53	0.67	0.52	30.94	16.36	408.89	4.79
IT89D-288 x TVu2736	965.2	11.67	12.15	49.38	0.41	0.39	0.22	37.83	14.32	499.83	5.27
IT89D-288 x TVu8670	1181.5	14.59	11.10	46.88	0.54	0.65	0.46	43.69	17.13	527.97	7.90
IT99K-573-1-1 x TVu10100	375.2	13.36	9.57	50.16	0.54	0.71	0.45	15.67	14.15	188.95	5.68
IT99K-573-1-1 x TVu6707	1014.6	14.76	10.27	48.28	0.51	0.69	0.52	45.78	16.84	443.76	6.50
IT99K-573-1-1 x TVu9693	1417.2	10.84	14.28	46.59	0.55	0.77	0.49	53.77	17.46	771.16	6.75
IT99K-573-1-1 x TVu2736	552.0	13.35	9.76	46.81	0.55	0.74	0.47	37.09	14.48	310.60	6.27
IT99K-573-1-1 x TVu8670	943.1	12.50	11.77	49.81	0.57	0.76	0.51	32.20	17.68	383.21	6.90
TVu11986 x TVu10100	-25.8	9.27	8.33	53.54	0.48	0.66	0.50	-1.22	13.03	-37.00	2.95
TVu11986 x TVu6707	368.4	11.72	11.69	53.05	0.47	0.77	0.56	19.05	15.99	220.19	3.61
TVu11986 x TVu9693	308.9	11.48	9.42	52.13	0.44	0.73	0.52	12.54	13.23	82.76	2.55
TVu11986 x TVu2736	17.6	9.89	9.41	51.16	0.51	0.70	0.53	11.58	13.42	103.16	2.59
TVu11986 x TVu8670	295.2	11.12	10.92	52.01	0.57	0.73	0.58	12.80	15.62	133.42	3.19
TVu7778 x IFEBROWN	475.2	11.16	9.01	48.94	0.60	0.69	0.37	32.82	12.13	356.27	7.82
TVu7778 x IT90K-76	446.2	11.90	9.55	49.58	0.54	0.66	0.46	28.60	13.02	285.65	6.21
TVu7778 x IT81D-985	243.9	11.31	9.38	52.96	0.55	0.64	0.46	21.02	12.93	190.68	6.11
TVu7778 x DANILA	305.9	9.68	9.28	49.72	0.65	0.68	0.39	22.02	13.88	224.09	7.90
TVu7778 x IT90K-277-2	609.0	10.14	8.41	55.79	0.52	0.65	0.41	39.23	12.41	465.10	6.26
Sanzi x IFEBROWN	456.8	12.19	10.54	47.67	0.52	0.59	0.47	42.49	12.22	465.90	6.66
Sanzi x IT90K-76	260.4	11.86	8.73	48.33	0.47	0.53	0.41	22.51	11.52	201.69	5.15
Sanzi x IT81D-985	290.8	11.22	9.92	47.54	0.48	0.53	0.46	31.41	13.92	313.17	6.15
Sanzi x DANILA	300.4	12.42	9.66	46.60	0.52	0.67	0.48	28.47	11.14	280.99	7.04
Sanzi x IT90K-277-2	393.1	12.99	7.86	49.37	0.57	0.67	0.45	36.00	10.34	292.90	6.38
TVu3562 x IFEBROWN	1192.2	11.05	13.37	48.11	0.60	0.75	0.52	88.57	15.28	1214.96	6.14
TVu3562 x IT90K-76	1065.3	10.31	11.89	49.36	0.56	0.67	0.43	54.23	13.77	701.14	6.84

Appendix 5.3 continued											
TVu3562 x IT81D-985	1217.3	11.91	12.86	50.58	0.45	0.63	0.42	42.69	16.48	605.34	6.34
TVu3562 x DANILA	945.1	9.66	11.92	47.28	0.47	0.64	0.47	37.13	15.65	458.77	6.43
TVu3562 x IT90K-277-2	760.8	11.27	11.65	54.97	0.58	0.71	0.54	26.98	13.33	272.13	5.34
TVu9797 x IFEBROWN	831.4	12.04	12.07	47.98	0.48	0.55	0.42	26.37	15.13	345.57	6.84
TVu9797 x IT90K-76	1028.5	12.10	13.42	53.69	0.47	0.59	0.43	42.60	14.76	572.99	6.49
TVu9797 x IT81D-985	673.9	10.88	14.06	51.83	0.48	0.62	0.42	26.92	14.62	379.77	5.04
TVu9797 x DANILA	784.6	11.83	12.72	53.38	0.44	0.61	0.45	31.81	15.34	411.11	6.50
TVu9797 x IT90K-277-2	942.1	10.99	12.72	47.89	0.50	0.73	0.49	34.84	15.66	465.70	7.39
TVu79 x IFEBROWN	704.2	12.01	10.35	49.62	0.51	0.70	0.51	35.08	14.08	421.48	6.13
TVu79 x IT90K-76	1256.3	11.54	14.28	50.22	0.54	0.74	0.53	42.46	17.45	601.38	6.06
TVu79 x IT81D-985	1343.6	10.62	12.60	48.08	0.57	0.76	0.50	45.83	16.49	642.25	6.67
TVu79 x DANILA	1914.1	11.51	12.85	48.10	0.58	0.71	0.47	78.09	19.29	1051.13	6.58
TVu79 x IT90K-277-2	1685.9	13.73	12.15	49.10	0.54	0.67	0.39	46.18	14.96	670.95	6.55
TVu10100 x TVu7778	275.2	12.31	8.01	49.82	0.69	0.75	0.55	18.06	12.65	190.47	4.87
TVu10100 x Sanzi	460.6	9.76	10.08	50.64	0.56	0.73	0.55	34.46	13.52	373.58	5.31
TVu10100 x TVu3562	356.2	10.39	10.66	53.64	0.47	0.64	0.48	37.60	13.52	353.50	2.67
TVu10100 x TVu9797	883.1	11.26	14.29	49.31	0.50	0.62	0.49	36.93	15.62	523.10	2.34
TVu10100 x TVu79	322.0	10.56	14.07	50.42	0.55	0.72	0.53	26.64	15.95	418.37	2.59
TVu6707 x TVu7778	1234.9	10.73	10.86	57.33	0.54	0.71	0.49	48.24	14.86	629.40	6.06
TVu6707 x SANZI	508.2	10.67	9.89	48.69	0.51	0.71	0.52	40.24	16.03	438.63	6.08
TVu6707 x TVu3562	1203.5	10.65	12.58	50.74	0.56	0.72	0.51	52.59	14.56	727.81	4.44
TVu6707 x TVu9797	2532.9	11.11	13.17	51.72	0.47	0.71	0.50	78.28	14.75	1144.49	4.43
TVu6707 x TVu79	845.7	10.17	13.26	49.22	0.52	0.67	0.50	36.98	18.62	493.21	5.55
TVu9693 x TVu7778	1139.0	8.21	10.36	52.67	0.52	0.77	0.55	36.81	15.65	570.32	6.23
TVu9693 x Sanzi	1081.1	8.53	12.37	49.43	0.51	0.79	0.58	70.30	15.16	917.86	4.51
TVu9693 x TVu3562	1092.5	9.33	13.58	49.49	0.52	0.75	0.57	60.69	16.09	897.44	5.85
TVu9693 x TVu9797	1522.1	8.22	15.81	49.39	0.53	0.79	0.52	58.80	16.84	961.63	7.09
TVu9693 x TVu79	1403.6	9.41	14.04	49.10	0.53	0.69	0.49	42.66	15.53	698.70	6.01
TVu2736 x TVu7778	381.0	13.54	8.80	52.67	0.44	0.60	0.33	25.83	11.08	328.51	5.30
TVu2736 x Sanzi	627.0	7.62	11.90	55.23	0.51	0.65	0.48	67.75	13.77	936.27	6.93
TVu2736 x TVu3562	680.1	8.04	11.67	50.15	0.47	0.55	0.50	38.79	13.03	443.85	5.60
TVu2736 x TVu9797	520.7	8.57	11.39	49.68	0.49	0.54	0.31	26.09	13.35	336.98	5.14

Appendix 5.3 continued											
TVu2736 x TVu79	532.2	8.68	12.06	51.34	0.46	0.57	0.37	31.07	15.75	451.38	6.10
TVu8670 x TVu7778	711.5	10.25	11.37	49.37	0.56	0.76	0.55	31.78	17.55	407.83	5.43
TVu8670 x Sanzi	919.7	9.20	11.91	47.34	0.53	0.67	0.46	64.68	15.24	830.18	8.22
TVu8670 x TVu3562	1225.4	9.15	11.95	45.26	0.58	0.80	0.49	51.72	15.47	622.54	6.85
TVu8670 x TVu9797	802.2	9.73	11.71	47.79	0.53	0.72	0.52	41.67	14.07	491.29	6.79
TVu8670 x TVu79	1119.4	10.79	14.49	48.00	0.52	0.68	0.48	44.70	16.75	677.40	5.31
Mean	738.2	12.14	10.73	49.58	0.52	0.66	0.47	35.70	14.61	426.53	5.65
SE	35.1	0.13	0.14	0.21	0.01	0.01	0.01	1.17	0.13	17.32	0.11

*GY=grain yield (kg/ha), SW100=100-seed weight, sdppod=no of seed/pod, DFL=days to 50% flower; NDVI_1-3=normalized difference vegetation indices at vegetative, flowering and pod-filling stages, podplt=no of pod/plant, pdlt=pod length, sdplt=no of seed/plant, DLSC=delayed leaf senescence

APPENDIX 5.4: Means of grain yield and other agronomic traits of 100 single F₁ crosses evaluated under well-watered conditions at Ibadan and Minjibir.

Crosses	*GY	SW100	sdppod	DFL	Ndvi_1	Ndvi_2	Ndvi_3	Podplt	Pdlt	sdplt
IFEBROWN x TVu6333	1382.7	14.81	11.04	48.82	0.54	0.76	0.80	84.32	15.94	962.01
IFEBROWN x CB-27	1198.9	18.41	7.99	45.40	0.51	0.72	0.63	50.68	13.96	424.58
IFEBROWN x IT89D-288	1254.1	16.46	10.17	47.84	0.60	0.73	0.62	67.46	15.22	702.95
IFEBROWN x IT99K-573-1-1	1173.3	17.31	8.67	49.17	0.65	0.78	0.57	63.58	16.53	590.30
IFEBROWN x TVu11986	1666.8	15.00	13.02	50.85	0.57	0.75	0.65	76.67	15.54	1047.45
IT90K-76 x TVu6333	288.3	14.88	9.41	55.61	0.67	0.70	0.69	17.88	14.33	178.59
IT90K-76 x CB-27	798.9	15.88	10.09	48.82	0.52	0.68	0.60	33.46	14.03	376.49
IT90K-76 x IT89D-288	1210.5	17.62	10.63	51.07	0.48	0.76	0.66	66.79	14.40	723.02
IT90K-76 x IT99K-573-1-1	820.4	19.49	11.40	49.61	0.54	0.70	0.58	32.97	18.26	355.47
IT90K-76 x TVu11986	1338.6	14.86	11.41	51.80	0.57	0.79	0.72	56.87	15.94	669.77
IT81D-985 x TVu6333	1204.0	14.95	10.30	52.43	0.59	0.77	0.72	47.81	16.78	553.89
IT81D-985 x CB-27	772.6	14.22	10.20	43.69	0.70	0.83	0.51	33.94	21.44	342.88
IT81D-985 x IT89D-288	-81.4	14.78	7.38	49.27	0.45	0.55	0.43	10.67	13.73	66.61
IT81D-985 x IT99K-573-1-1	1079.7	15.56	10.35	46.44	0.64	0.78	0.54	31.88	18.56	368.23

Appendix 5.4 continued										
IT81D-985 x TVu11986	998.0	14.27	13.22	47.01	0.65	0.85	0.66	31.75	17.92	439.06
DANIILA x TVu6333	1152.1	15.43	10.88	49.98	0.60	0.76	0.74	51.54	16.59	581.13
DANIILA x CB-27	1131.4	16.29	9.97	43.45	0.51	0.59	0.48	47.02	16.14	521.09
DANIILA x IT89D-288	956.8	19.00	8.60	47.42	0.46	0.69	0.67	39.56	14.46	339.20
DANIILA x IT99K-573-1-1	1340.8	19.34	9.05	48.24	0.49	0.56	0.52	57.93	15.55	551.95
DANIILA x TVu11986	1074.1	14.06	7.89	53.62	0.58	0.72	0.62	48.23	12.54	495.71
IT90K-277-2 x TVu6333	478.2	14.92	11.03	51.02	0.60	0.80	0.77	20.12	15.86	210.76
IT90K-277-2 x CB-27	413.7	17.20	7.32	50.85	0.36	0.66	0.64	28.32	13.60	193.34
IT90K-277-2 x IT89D-288	925.0	14.71	8.52	50.89	0.45	0.66	0.63	44.07	13.65	423.76
IT90K-277-2 x IT99K-573-1-1	974.5	18.27	9.16	50.81	0.51	0.63	0.65	59.87	15.78	576.66
IT90K-277-2 x TVu11986	1571.0	15.62	11.29	53.75	0.51	0.79	0.74	59.46	16.00	724.27
TVu6333 x TVu10100	686.7	11.37	13.58	51.67	0.71	0.80	0.72	19.98	14.31	259.04
TVu6333 x TVu6707	471.1	12.83	9.80	59.61	0.48	0.68	0.71	40.18	15.43	415.09
TVu6333 x TVu9693	523.3	10.86	13.37	52.02	0.59	0.75	0.63	17.90	15.56	250.01
TVu6333 x TVu2736	-45.4	10.12	13.27	54.86	0.50	0.67	0.62	3.55	15.24	12.50
TVu6333 x TVu8670	473.5	11.18	11.65	53.11	0.63	0.81	0.70	31.39	14.99	413.29
CB-27 x TVu10100	874.5	16.46	10.65	47.78	0.44	0.62	0.58	34.38	16.30	375.00
CB-27 x TVu6707	1341.0	16.93	9.09	47.11	0.52	0.74	0.69	63.57	15.42	564.46
CB-27 x TVu9693	1714.5	14.97	13.00	47.70	0.58	0.80	0.74	72.58	17.59	852.09
CB-27 x TVu2736	664.6	11.15	10.69	45.08	0.60	0.69	0.70	30.82	13.78	324.06
CB-27 x TVu8670	2414.3	16.45	11.34	44.50	0.58	0.79	0.69	95.43	16.71	1192.55
IT89D-288 x TVu10100	899.5	16.91	9.88	50.96	0.52	0.66	0.63	47.08	15.36	498.07
IT89D-288 x TVu6707	1137.6	17.12	9.75	49.70	0.62	0.78	0.67	62.77	16.57	603.25
IT89D-288 x TVu9693	1904.5	14.81	13.02	50.79	0.53	0.68	0.64	61.35	17.57	838.75
IT89D-288 x TVu2736	804.5	12.44	10.45	48.95	0.58	0.64	0.69	46.90	14.05	513.02
IT89D-288 x TVu8670	1767.8	16.53	11.79	47.79	0.61	0.82	0.75	68.04	16.64	820.85
IT99K-573-1-1 x TVu10100	1155.5	15.92	11.31	50.85	0.54	0.70	0.64	60.70	17.27	607.29
IT99K-573-1-1 x TVu6707	2330.9	16.40	13.17	50.19	0.55	0.79	0.71	77.63	17.77	1015.05
IT99K-573-1-1 x TVu9693	2272.7	13.16	13.20	50.54	0.50	0.76	0.73	59.00	18.19	852.14
IT99K-573-1-1 x TVu2736	1385.8	14.25	11.67	48.42	0.65	0.79	0.59	65.98	17.42	552.75
IT99K-573-1-1 x TVu8670	658.5	15.48	11.86	50.26	0.60	0.82	0.67	31.84	18.25	150.64

Table 5.4 continued										
TVu11986 x TVu10100	403.9	12.32	9.21	54.61	0.56	0.77	0.73	19.03	15.15	220.52
TVu11986 x TVu6707	1065.9	12.90	12.33	53.64	0.54	0.80	0.80	33.59	16.59	418.66
TVu11986 x TVu9693	1061.3	11.25	15.07	51.78	0.49	0.76	0.75	37.20	17.14	557.26
TVu11986 x TVu2736	949.9	10.27	12.12	53.30	0.47	0.67	0.70	41.89	16.31	559.40
TVu11986 x TVu8670	1110.7	13.20	14.41	51.41	0.49	0.85	0.79	38.86	17.46	478.82
TVu7778 x IFEBROWN	101.3	10.57	5.88	56.78	0.43	0.60	0.58	19.65	12.40	154.27
TVu7778 x IT90K-76	1040.5	12.96	10.29	48.50	0.59	0.74	0.65	64.65	14.25	723.91
TVu7778 x IT81D-985	651.5	12.24	10.76	57.02	0.58	0.75	0.72	45.45	16.35	524.63
TVu7778 x DANILA	329.6	10.45	12.52	50.16	0.52	0.68	0.67	27.43	15.97	348.16
TVu7778 x IT90K-277-2	1111.2	14.06	10.08	51.78	0.62	0.69	0.67	59.40	15.00	605.13
Sanzi x IFEBROWN	1128.9	12.55	10.54	46.64	0.65	0.77	0.66	61.43	12.96	650.03
Sanzi x IT90K-76	1048.6	12.46	10.24	47.34	0.53	0.72	0.63	52.01	12.54	546.51
Sanzi x IT81D-985	803.3	11.37	11.29	53.80	0.59	0.59	0.58	47.57	14.74	560.85
Sanzi x DANILA	643.2	10.33	10.92	45.48	0.64	0.82	0.68	45.11	13.40	500.13
Sanzi x IT90K-277-2	380.0	12.51	9.86	48.27	0.66	0.72	0.63	30.47	13.32	315.36
TVu3562 x IFEBROWN	946.4	12.63	9.73	49.63	0.56	0.75	0.65	51.70	13.45	499.26
TVu3562 x IT90K-76	847.3	12.85	11.14	49.42	0.59	0.80	0.72	57.23	13.58	639.31
TVu3562 x IT81D-985	2132.8	12.33	12.43	49.79	0.54	0.70	0.63	68.21	16.23	861.23
TVu3562 x DANILA	1929.4	12.83	12.16	47.60	0.55	0.80	0.65	90.45	15.37	1092.09
TVu3562 x IT90K-277-2	2215.4	12.78	13.11	51.73	0.54	0.84	0.83	109.05	15.86	1437.99
TVu9797 x IFEBROWN	1655.0	13.04	11.87	47.28	0.54	0.62	0.59	53.91	14.98	690.68
TVu9797 x IT90K-76	1410.0	13.63	12.90	46.27	0.68	0.81	0.65	49.26	16.13	628.77
TVu9797 x IT81D-985	1021.8	12.37	13.12	50.50	0.49	0.62	0.74	35.32	17.49	471.88
TVu9797 x DANILA	632.8	13.28	9.03	55.16	0.57	0.68	0.75	28.02	12.15	337.67
TVu9797 x IT90K-277-2	2148.8	14.44	13.51	48.62	0.52	0.70	0.70	69.71	16.08	963.47
TVu79 x IFEBROWN	1708.7	13.83	13.06	49.06	0.50	0.67	0.68	70.50	15.95	977.90
TVu79 x IT90K-76	1603.2	14.57	11.29	50.30	0.56	0.82	0.73	69.50	15.83	745.89
TVu79 x IT81D-985	1641.7	14.19	12.60	50.07	0.48	0.74	0.74	66.27	17.67	831.96
TVu79 x DANILA	1793.1	15.28	10.82	49.71	0.61	0.80	0.73	64.19	15.97	758.88
TVu79 x IT90K-277-2	885.6	13.90	9.64	50.60	0.53	0.80	0.75	54.06	14.36	524.55
TVu10100 x TVu7778	1235.9	12.43	13.36	52.49	0.52	0.78	0.70	40.91	16.47	609.68

Appendix 5.4 continued										
TVu10100 x Sanzi	891.7	9.38	10.84	49.49	0.46	0.62	0.65	36.46	14.96	426.33
TVu10100 x TVu3562	862.5	11.00	13.80	51.43	0.54	0.80	0.65	54.70	15.29	717.98
TVu10100 x TVu9797	1374.1	13.10	13.43	53.49	0.52	0.74	0.68	68.66	15.20	910.68
TVu10100 x TVu79	886.3	11.33	12.68	51.54	0.48	0.67	0.68	47.47	14.41	575.44
TVu6707 x TVu7778	1360.8	11.60	11.07	56.86	0.49	0.68	0.63	51.74	15.98	641.87
TVu6707 x SANZI	1424.0	11.65	11.00	52.15	0.56	0.68	0.59	67.81	14.10	762.45
TVu6707 x TVu3562	2833.9	11.80	15.57	50.02	0.55	0.84	0.77	109.16	17.37	1694.38
TVu6707 x TVU9797	3786.2	12.65	14.64	49.23	0.60	0.82	0.75	124.73	17.79	1944.23
TVu6707 x TVu79	2692.2	11.39	14.97	48.75	0.54	0.77	0.74	71.93	16.59	1115.19
TVu9693 x TVu7778	1734.8	9.57	11.89	50.77	0.74	0.82	0.73	69.54	15.02	938.03
TVu9693 x Sanzi	2427.0	9.86	13.29	48.74	0.58	0.76	0.75	121.86	14.36	1533.82
TVu9693 x TVu3562	2602.0	10.52	13.02	48.47	0.56	0.75	0.73	108.33	16.12	1434.87
TVu9693 x TVu9797	3255.3	11.41	17.86	52.77	0.50	0.62	0.64	80.54	17.81	1393.71
TVu9693 x TVu79	2203.1	10.40	15.48	48.79	0.67	0.81	0.76	75.21	16.89	1205.22
TVu2736 x TVu7778	659.1	9.21	12.08	52.96	0.40	0.56	0.67	37.89	14.48	462.70
TVu2736 x Sanzi	1248.2	7.95	13.39	50.65	0.49	0.68	0.70	67.07	13.83	867.29
TVu2736 x TVu3562	1574.1	8.31	12.86	49.93	0.50	0.66	0.63	71.06	14.63	918.14
TVu2736 x TVu9797	1420.1	10.01	14.95	50.18	0.54	0.75	0.62	69.31	14.46	987.53
TVu2736 x TVu79	693.0	12.44	11.27	51.47	0.51	0.59	0.67	36.28	15.09	461.09
TVu8670 x TVu7778	1538.6	11.60	12.05	49.14	0.62	0.77	0.70	56.95	16.49	669.34
TVu8670 x Sanzi	1449.5	10.25	13.46	48.41	0.59	0.75	0.67	63.87	16.76	922.27
TVu8670 x TVu3562	1856.4	11.50	13.82	51.03	0.48	0.67	0.69	69.55	16.91	964.82
TVu8670 x TVu9797	2892.3	12.01	16.37	49.37	0.54	0.80	0.69	75.71	16.27	1249.05
TVu8670 x TVu79	1510.9	10.30	15.20	49.03	0.64	0.76	0.66	53.50	17.47	863.41
Mean	1278.8	13.43	11.62	50.23	0.55	0.73	0.67	54.71	15.67	666.60
SE	50.2	0.13	0.12	0.19	0.01	0.01	0.01	1.52	0.12	21.79

*GY=grain yield (kg/ha), SW100=100-seed weight, sdppod=no of seed/pod, DFL=days to 50% flower; NDVI_1-3=normalized difference vegetation indices at vegetative, flowering and pod-filling stages, podplt=no of pod/plant, pdlt=pod length, sdplt=no of seed/plan

APPENDIX 5.5: Specific Combining Ability (SCA) effects of the crosses for grain yield

F₁ Crosses	DS	WW	AC
TVu7778 x IFEBROWN	-2.7	-363.8*	-183.3
TVu7778 x IT90K-76	-31.8	437.7**	202.9
TVu7778 x IT81D-985	-64.5	377.2*	156.4
TVu7778 x DANILA	-264.9*	-153.9	-209.4
TVu7778 x IT90K-277-2	111.6	179.9	145.7
TVu10100 x TVu7778	-234	284.3	25.2
TVu10100 x Sanzi	-134.4	-530.6**	-332.5*
TVu10100 x TVu3562	-155.3	-666.6**	-410.9**
TVu10100 x TVu9797	-101.7	-1161.8***	-631.8***
TVu10100 x TVu79	-214.1	-469.5*	-341.8*
Sanzi x IFEBROWN	99.8	296.2	198.0
Sanzi x IT90K-76	131.2	346.7*	238.9
Sanzi x IT81D-985	-56.5	-1.8	-29.1
Sanzi x DANILA	-280.2*	130.5	-74.9
Sanzi x IT90K-277-2	-146.6	-294.5	-220.6
TVu3562 x IFEBROWN	120.9	-393.5*	-136.3
TVu3562 x IT90K-76	-125.8	-526.3**	-326.0*
TVu3562 x IT81D-985	171.1	440.4*	305.8*
TVu3562 x DANILA	-103.3	494.5**	195.6
TVu3562 x IT90K-277-2	-315.2**	461.9**	73.3
TVu9797 x IFEBROWN	27.8	303.6	165.7
TVu9797 x IT90K-76	70.8	92.6	81.7
TVu9797 x IT81D-985	-214.1	-361.0*	-287.6*
TVu9797 x DANILA	-72.7	-385.2*	-228.9
TVu9797 x IT90K-277-2	-64.1	827.1***	381.5**
TVu79 x IFEBROWN	-498.2***	634.6**	68.2
TVu79 x IT90K-76	-296.6	126.3	-85.2
TVu79 x IT81D-985	-88.4	22.3	-33.1
TVu79 x DANILA	468.8***	391.2*	430.0**
TVu79 x IT90K-277-2	162.1	-697.3***	-267.6
TVu6707 x TVu7778	90.7	-1228.4***	-568.8***
TVu6707 x SANZI	-747.4***	-1224.5***	-986.0***
TVu6707 x TVu3562	-265.6*	-250.5	-258.1
TVu6707 x TVu9797	636.3***	279.2	457.7**
TVu6707 x TVu79	-553.4***	-119.9	-336.7*
TVu9693 x TVu7778	-149.8	-563.4**	-356.6*
TVu9693 x Sanzi	-142.5	-229.4	-186.0
TVu9693 x TVu3562	-344.4	-568.6**	-456.5**
TVu9693 x TVu9797	-274.3*	-510.8**	-392.6**
TVu9693 x TVu79	71.6	-671.9**	-300.1*
TVu2736 x TVu7778	-194.3	-521.1**	-357.7*
TVu2736 x Sanzi	163.3	-7.2	78.1
TVu2736 x TVu3562	-54.4	-229.8	-142.1

Appendix 5.5 continued

F1 Crosses	DS	WW	AC
TVu2736 x TVu9797	-614.9	-1020.0***	-817.5***
TVu2736 x TVu79	-139.1	-766.0***	-452.6**
TVu8670 x TVu7778	-352.0**	-515.6**	-433.8**
TVu8670 x Sanzi	21.6	-552.4**	-265.4
TVu8670 x TVu3562	-19.7	-828.6***	-424.2**
TVu8670 x TVu9797	-484.8***	-130.7	-307.7*
TVu8670 x TVu79	-4.5	-516.8**	-260.7
IFEBROWN x TVu6333	-44.5	286.7	121.1
IFEBROWN x CB-27	122.4	179.3	150.8
IFEBROWN x IT89D-288	425.4**	472.6*	449.0**
IFEBROWN x IT99K-573-1-1	-67.7	80.8	6.5
IFEBROWN x TVu11986	52.5	325.4	188.9
TVu6333 x TVu10100	448.3**	508.5**	478.4**
TVu6333 x TVu6707	-3.1	198.9	97.9
TVu6333 x TVu9693	-20.5	-283.8	-152.1
TVu6333 x TVu2736	189.1	346.6*	267.9
TVu6333 x TVu8670	-10.2	-47.9	-29.0
IT90K-76 x TVu6333	-43	-275.9	-159.5
IT90K-76 x CB-27	153.4	468.9**	311.2*
IT90K-76 x IT89D-288	-93.6	698.4***	302.4*
IT90K-76 x IT99K-573-1-1	28.4	56.4	42.4
IT90K-76 x TVu11986	442.9**	396.9*	419.9**
IT81D-985 x TVu6333	344.4**	958.6***	651.5***
IT81D-985 x CB-27	-281.3*	191.4	-45.0
IT81D-985 x IT89D-288	238.1*	-229.2	4.5
IT81D-985 x IT99K-573-1-1	155.4	235.6	195.5
IT81D-985 x TVu11986	31.5	188.2	109.9
DANILA x TVu6333	363.7**	486.5**	425.1**
DANIILA x CB-27	309.5**	375.7*	342.6*
DANILA x IT89D-288	-254.3*	-9.5	-131.9
DANILA x IT99K-573-1-1	181.3	758.5***	469.9**
DANILA x TVu11986	-112.2	-266.5	-189.3
IT90K-277-2 x TVu6333	-132.5	-111.2	-121.9
IT90K-277-2 x CB-27	184	129.3	156.7
IT90K-277-2 x IT89D-288	172.6	412.4*	292.5
IT90K-277-2 x IT99K-573-1-1	190.6	213.4	202.0
IT90K-277-2 x TVu11986	73.4	700.7***	387.1**
CB-27 x TVu10100	170.6	-15.5	77.6
CB-27 x TVu6707	22.5	48.6	35.5
CB-27 x TVu9693	240.4*	113.9	177.1
CB-27 x TVu2736	60.1	-360.3*	-150.1
CB-27 x TVu8670	110	935.7***	522.9**
IT89D-288 x TVu10100	-86.5	32.1	-27.2
IT89D-288 x TVu6707	338.9**	-256.1	41.4

Appendix 5.5 continued

F₁ Crosses	DS	WW	AC
IT89D-288 x TVu9693	-186	318.9	66.4
IT89D-288 x TVu2736	217.8	235	226.4
IT89D-288 x TVu8670	319.5**	392.4*	356.0*
IT99K-573-1-1 x TVu10100	-173.4	185.7	6.2
IT99K-573-1-1 x TVu6707	188.4	592.3**	390.3**
IT99K-573-1-1 x TVu9693	523.6***	552.4**	538.0**
IT99K-573-1-1 x TVu2736	-71.6	59.3	-6.1
IT99K-573-1-1 x TVu8670	136.5	-667.2**	-265.3
TVu11986 x TVu10100	244.5	11.6	128.1
TVu11986 x TVu6707	56.9	138.7	97.8
TVu11986 x TVu9693	46.2	20.9	33.6
TVu11986 x TVu2736	208.2	441.8*	325.0*
TVu11986 x TVu8670	47.8	109.4	78.6
SE $\pm$	114.8	175.1	143.1

SCA = SCA effects of the crosses; *, **, ***, Significant at probability level of 0.05, 0.01 and 0.0001 probability levels, respectively. SE = Standard Error of SCA. DS, WW, AC = drought stress, well-watered and across all environments respectively.