

**GENETIC ANALYSIS OF EARLINESS AND DROUGHT TOLERANCE IN  
GROUNDNUT (*Arachis hypogaea* L.) IN NIGER**

**By**

**Coulibaly Adama Mamadou  
(10293994)**

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UNIVERSITY OF GHANA  
LEGON**

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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.

.....  
Coulibaly Adama Mamadou  
Student



.....  
Prof. Eric Y. Danquah  
Supervisor

.....  
Prof. Kwadwo Ofori  
Supervisor

.....  
Prof. Vernon Gracen  
Supervisor

A handwritten signature in black ink, which appears to read 'Ntare R. Bonny'.

.....  
Dr. Ntare R. Bonny  
Supervisor

## ABSTRACT

End-of-season drought, characterized by low and erratic rainfall, is the most important factor limiting groundnut (*Arachis hypogaea* L.) production in Niger. Information about farmers' varietal preferences and production constraints are limited. Genotypes have not yet been screened for earliness and tolerance to end-of-season drought. Data on combining ability and heritability estimates are not available. Development of varieties that have better ability to use limited available water or that mature early and avoid drought is needed.

A participatory rural appraisal (PRA) through Focus Group Discussion session was conducted in 2011 to assess farmers' perceptions on groundnut production constraints and to gather information on preferences for elite groundnut varieties.

One hundred and fifty genotypes were screened in 2010 under well watered conditions in an alpha lattice design in an unreplicated trial to select five early maturing parental lines for genetic studies. One hundred intermediate maturing genotypes were selected and, evaluated in 2011 off-season under both well watered and end-of-season drought conditions in an alpha lattice design with two replications to select five drought tolerant parental lines for genetic studies.

The selected parental lines were crossed with the three farmers preferred varieties in a North Carolina II mating design and 7 F<sub>4</sub> populations for earliness and 7 F<sub>4</sub> populations for drought tolerance were developed by selfing. Seven F<sub>3</sub> populations were evaluated for earliness and agronomic traits in RCBD replicated three times under well watered conditions. Seven F<sub>3</sub> and F<sub>4</sub> populations were evaluated for drought related traits in RCBD replicated three times. Data recorded included: % emergence, 50% plants flowering, pod yield, seed weight, seed number, shelling %, pod length, maturity index, and biomass. Among the physiological traits measured

were SPAD chlorophyll meter reading and harvest index. The data were analyzed using appropriate statistical procedures and experimental designs.


The PRA survey revealed that drought was a major production constraint followed by low soil fertility. In the study regions, the varieties 55-437, RRB and JL24, were the most grown.

There was variation among the genotypes screened for the various characteristics. The PCA analysis revealed that 79.62% of the total variation among the genotypes was explained by maturity, pod yield, biomass, harvest index and 50% plants flowering. Out of the 150 genotypes, two extra early maturing genotypes (75 days) Chico and ICIAR19BT, three early maturing genotypes (80 days) ICG3584, 796, and ICGV02022 and five drought tolerant genotypes ICGV-SM99511, Tainan-9, ICG11249, ICG6703 and ICGIS01820 were identified.

In the early maturity experiment, the analysis of variance for the eight traits revealed significant differences ( $P \leq 0.01$  and  $P \leq 0.05$ ) among parents for pod yield, seed weight, pod length and maturity index. Crosses showed highly significant differences for pod yield ( $P \leq 0.001$ ), seed number ( $P \leq 0.001$ ), shelling % ( $P \leq 0.01$ ) and pod length ( $P \leq 0.05$ ). Female and male General combining ability (GCA) mean squares were highly significant ( $P \leq 0.01$ ) only for pod yield. GCA mean squares (119.26) for females were greater than males GCA mean square (32.11) for pod weight indicating that the major contribution to additive variance for this trait was due to the female parents. Specific combining ability (SCA) mean squares differed significantly ( $P \leq 0.01$  and  $P \leq 0.05$ ) for seed number and shelling percentage indicating the importance of both additive and non-additive variance for these characters. Chico, ICIAR19BT, 55-437 and RRB were the best general combiners. The estimates of phenotypic coefficient of variation (PCV) were greater

than genotypic coefficients of variation (GCV) for all the traits studied. None of the traits recorded high PCV and GCV. PCV ranged from 4.36 to 19.34% and GCV from 2.02 to 11.99%. Narrow sense heritability estimates ranged from 35.4 to 95.5%; for days to emergence (95.5%), pod yield (85%), shelling percentage (84.3%), seed number (80%) and 50% plants flowering (72%). Moderate to low heritability estimates were obtained for maturity index (66.1%), pod length (54.4%) and seed weight (35.4%).

Highly significant positive correlations were found between pod yield and seed weight ( $r = 0.97$ ,  $P \leq 0.001$ ) and pod length ( $r = 0.72$ ,  $P \leq 0.01$ ); between pod length and seed yield ( $r = 0.66$ ,  $P \leq 0.01$ ); and between maturity index and days to emergence ( $r = 0.72$ ,  $P \leq 0.001$ ). Correlation between shelling percentage and seed weight was positively significant at  $P \leq 0.05$  ( $r = 0.61$ ).



In the drought tolerant experiment, combined analysis of variance showed large and significant differences ( $P \leq 0.01$ ) between all 14 entries for all traits except for pod yield. Highly significant differences ( $P \leq 0.01$  and  $P \leq 0.05$ ) in chlorophyll content among the crosses at 60 and 80 DAS were found. The overall means of chlorophyll content under end-of-season drought stress conditions were 41.55 and 39.65, at 60 and 80 DAS respectively compared to 35.27 and 38.04 under irrigated conditions. The analysis of variance showed highly significant differences ( $P \leq 0.01$ ) between the crosses in water regimes for pod yield. The drought tolerance index for pod yield ranged from 0.44 to 1.37 for seven crosses.

GCA mean squares for males and females were significant ( $P \leq 0.05$ ) for pod yield and biomass. GCA mean squares for females were greater than males GCA mean square for pod yield and total biomass indicating that the major contribution to additive variance for these traits was due the female parents. SCA mean squares differed significantly ( $P \leq 0.05$ ) for pod yield and harvest

index indicating the importance of both additive and non-additive variance for these traits. Tainan-9, ICGV-SM99511, 55-437 and RRB were the best general combiners.

The estimates of phenotypic coefficient of variation (PCV) were greater than genotypic coefficients of variation (GCV) for all the physiological traits. PCV ranged from 7.27 to 40.20% and GCV from 2.71 to 15.91%.

Narrow sense heritability estimates for physiological traits were higher than for agronomic traits, and varied under both well-watered and end-of-season drought conditions. The heritability estimates for pod yield (0.26) and biomass (0.18) were low, but they were high for harvest index (0.78) and SPAD chlorophyll meter reading (SCMR), estimate of 0.71 and 0.68 respectively, at 60 and 80 days after sowing. Fifty percent (50%) to flowering showed moderate heritability estimate of 0.56. End-of-season drought decreased narrow sense heritability estimates for all the physiological traits. Heritability estimates decreased from 71.6% to 36.8% for SCMR 60 DAS; from 68.2% to 10.6% for SCMR 80 DAS and from 78.9% to 37.8% for harvest index.

Highly significant positive association between pod yield and harvest index was found in both water regimes. The correlation coefficient was higher ( $r = 0.77$ ,  $P \leq 0.001$ ) under end-of-season drought stress conditions than under well watered conditions ( $r = 0.74$ ,  $P \leq 0.01$ ). Strong negative significant ( $P \leq 0.05$ ) correlation was found between biomass and harvest index under well watered and end-of-season drought conditions  $r = -0.66$ ,  $-0.58$ , respectively. Weak positive and non-significant correlation was found between SCMR and pod yield, under well watered conditions ( $r = 0.38$ ).

The results show that development of early maturing and drought tolerant varieties may ensure better yields of groundnut in the Sahel.

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## **DEDICATION**

Dedicated to my Family.

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## **LIST OF ABBREVIATIONS**

**ABA** Abscisic Acid

**AGRA** Alliance for a Green Revolution in Africa

**ANOVA** Analysis of Variance

**ATP** Adenosine triphosphate

**BC** Backcross

**CV** Coefficient of Variation

**DAS** Days after sowing

**DF** Degree of freedom

**DNA** Deoxyribonucleic acid

**DTI** Drought Tolerance Index

**ESTs** Expressed Sequence Tags

**FAO** Food and Agriculture Organization

**FGD** Focus Group Discussion

**GCA** General Combining Ability

**GCV** Genotypic Coefficient of Variance

**$h^2_{ns}$** : heritability narrow sense

**ICRISAT** International Crops Research Institute for Semi-Arid Tropics

**INRAN** Institut National de Recherche Agronomique du Niger

**Kg/ha** Kilogram per hectare

**LSD** Least significant difference

**NGO** Non-Governmental Organization

**PC** Principal Component

**PCV** Phenotypic Coefficient of Variance

**PIC** Polymorphic Information Content

**PN** net photosynthesis

**PRA** Participatory Rural Appraisal

**QTL** Quantitative Trait Loci

**RAPD** Random Amplified Polymorphic DNA

**RFLP** *Restriction Fragment Length Polymorphism*

**SAT** Semi-Arid Tropic

**SCA** Specific Combining Ability

**SCMR** SPAD Chlorophyll Meter Reading

**SLA** Specific Leaf Area

**SPAD** Soil Plant Analytical Development

**SSA** sub-Saharan Africa

**SSR** Simple sequence repeat

**TE** Transpiration Efficiency

**T ha<sup>-1</sup>** Tons per hectare

**USDA** United States Department of Agriculture

**WACCI** West Africa Centre for Crop Improvement

**WS** Water stress

**WUE** Water-use efficiency

**WW** Well water

## CHAPTER ONE

### 1.0 GENERAL INTRODUCTION

Groundnut (*Arachis hypogaea* L., *Fabaceae*), is the 13<sup>th</sup> most important food crop and 4<sup>th</sup> most important oilseed crop of the world (Jharma *et al.*, 2001; Nigam *et al.*, 2005; Mace *et al.*, 2006; Cuc *et al.*, 2008). The crop is grown in all tropical and sub-tropical regions of the world as a result of its adaptability to a wide range of soil and climatic conditions. It is grown from latitude 40°N to 40°S (Frimpong, 2004; Arunyanark *et al.*, 2008, Furlan *et al.*, 2012).

Groundnut is grown in 108 countries on nearly 26.4 million ha worldwide with the total production of 36.45 million tons and an average yield of 1520 kg/ha in 2009 (FAOSTAT, 2011). The global output comes from seasonally rainfed areas of tropical, subtropical and warm regions of the world (Upadhyaya, 2005, Upadhyaya *et al.*, 2011). Developing countries account for 96.9% of the world groundnut area with 93.8% of total production (Nageswara and Nigam, 2003). Asia accounts for two-thirds of the world groundnut production while Africa produces only one-fifth (Mathur *et al.*, 2004). According to USDA (2010), the world average yield of groundnut is about 1.3 t ha<sup>-1</sup>, to 3.36 t ha<sup>-1</sup> in China, 0.98 t ha<sup>-1</sup>, to 3.36 t ha<sup>-1</sup> in USA, to 3.84 t ha<sup>-1</sup> in Nigeria and only 0.42 t ha<sup>-1</sup> in Niger.

Groundnuts are very important legumes and are nutritious and complement the major staples cereal in Africa, where cases of malnutrition are rampant. Groundnut seeds are a rich source of high quality edible oil (45 -56%), easily digestible protein of 12-36% and 10-20 % carbohydrates (Stalker, 1997; Nageswara and Nigam, 2003; Reddy *et al.*, 2003a; Reddy *et al.*, 2003b). Groundnut grains are a nutritional source of vitamin E, niacin, folacin, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium (Nwokolo, 1996). Groundnut haulms

provide excellent fodder for animal feeding and add an extra income to smallholder farmers (Arslan, 2005). Groundnut also provides nutrients to the soil and its cultivation improves soil fertility by nitrogen fixation that makes it an important component for crop rotation. It is grown as a sole crop, intercrop, or mixed crop (Nageswara *et al.*, 1990; Ghosh *et al.*, 2005). These multiple uses of groundnut make it an excellent cash crop for domestic markets as well as for foreign trade in several developing and developed countries.

Over two thirds of the global groundnut production occurs in rainfed regions that experience erratic and insufficient rainfall resulting in unpredictable droughts (Arunyanark *et al.*, 2009; Songsri *et al.*, 2009). Above 80% of the smallholder farmers are located in areas where rainfall is low and erratic, and soils tend to be infertile (Muzari *et al.*, 2012). The natural capacity of groundnut to moderately tolerate drought renders it suitable to be grown largely under rain-dependent conditions, especially by the resource-poor farmers.

Groundnut is the second most widely grown legume in Niger after cowpea. It is cultivated mainly during the rainy season from June to September. In Niger, groundnut farming experienced a remarkable development between 1950 and 1970, with a period of increased production in the 1960s due to a rapid increase in land areas and yield. This was followed in the seventies and eighties by a real slump in production and exports due to drought spells and lack of improved varieties to such a point that groundnut became a crop mostly processed traditionally into vegetable oil and oil-cakes for local consumption (Toukoua, 1986).

Groundnut yields have dropped from 0.894 t ha<sup>-1</sup> in the 1960s to 0.42 t ha<sup>-1</sup> in 2008 (FAOSTAT, 2008). Since the 1970s, Niger has suffered from severe droughts which have triggered important

food crises in particular in 1973, 1984 and 1991, and more recently in 2005, 2009 and 2010 (Leblois *et al.*, 2011). Since groundnut's water requirements are related to the variety, short-cycle varieties (90 days) are cultivated in the north of Niger (<500 mm), medium-cycle varieties (105 days) in the center (rainfall between 500 and 600 mm) and long-cycle varieties (120 days) in the southern part where annual rainfall exceeds 600 mm (Oumarou *et al.*, 1990). The southwards shifting of isohyets according to Ben Mohamed *et al.*, (2002) led to a reduced groundnut farming zone due to the unadaptability of the varieties to water deficits.

Groundnut production in Niger fluctuates greatly. Yields per hectare are typically low, because of a combination of production factors such as mostly: unreliable and/or poorly distributed rainfall, lack of small scale irrigation facilities, traditional farming with little mechanization, and cultivation on marginal land. In addition there was also insufficient selection of suitable crop varieties, outbreaks of pests and diseases, inefficiencies in distribution of seeds and fertilizers coupled with, use of low-yielding seed varieties. Poor research-extension linkages, infertile soils, failure of the smallholder farmer to adapt to changing environments and adopt new technologies and political instability contributed significantly to reduce groundnut production in Niger (Dulvenbooden *et al.*, 2002).

Groundnut production is severely constrained by both biotic and abiotic stress factors. The most important constraint among the abiotic stress is drought. Drought patterns in groundnut have been classified into four groups: early season drought (immediately after germination to flowering), mid-season drought (flowering to pod formation), end-of-season drought (pod filling to pod maturity) and intermittent drought (Rachid *et al.*, 2003; Hamidou *et al.*, 2012).

The most prevalent drought pattern in Niger is the end-of-season. One of the key challenges of the smallholder farmers in Niger is how to harness limited available resources to mitigate harsh environment conditions for the improvement of groundnut production to enhance incomes and reduce malnutrition and poverty.

Consequently varieties that can escape end-of-season drought should be developed. In the context of climatic variation with rainfall reduction in terms of duration and amount, recurrent drought affects groundnut performance in Niger. Therefore, priorities in groundnut improvement in Niger should include tolerance to drought and earliness as drought escape mechanism. There is a lack of information on genetic parameters required for breeding groundnut for earliness and drought tolerance related traits in Niger.

Because of the low groundnut productivity, smallholder farmers have reduced the amount of land allocated to groundnut and resulting in increased poverty. This has led Niger becoming a major importer of vegetable oil (Dulvenbooden *et al.*, 2002). In seeking to solve the problem of drought stress in Niger for groundnut production, there is the need for breeders to involve farmers. One of the crucial aspects to consider in plant breeding is the way that breeders involve farmers in the improvement of existing cultivars and selection of new varieties. When farmers are not involved in breeding activities, breeder's products may not be easily adopted. This is because the varieties developed may not meet farmers' and consumers' preferences.

This research aimed to exploit existing germplasm pool and farmer knowledge and expectations to develop groundnut lines with early maturity and improved drought tolerance.

The specific objectives of the study were to:

- i. Identify the production constraints and farmers preferred varieties of groundnut in Niger;
- ii. Identify and select early maturing and drought tolerant groundnut genotypes;
- iii. Determine the combining ability for earliness and drought tolerance traits for hybrid development; and
- iv. Estimate the heritability of earliness and drought tolerance traits to assess potential for selection of these traits.

## CHAPTER TWO

### 2.0. LITERATURE REVIEW

#### 2.1 Effect of drought on plant performance

Drought is the most damaging of all the abiotic stresses affecting groundnut production in Niger. The composite nature of drought stress limits its management through conventional breeding methods (Gosal *et al.*, 2009). Drought stress is a complex syndrome, involving several climatic, edaphic and agronomic factors that severely limit groundnut productivity depending on: timing of its occurrence, duration and intensity (Nigam *et al.*, 2005). The general complexity of drought is often aggravated under the Semi-Arid Tropic (SAT) conditions, by unpredictable rainfall and by the occurrence of high temperatures, high levels of solar radiation and poor soil characteristics (Nageswara and Nigam, 2003).

Drought can have an effect from seedling establishment to seed filling and thereby severely reduce seed yield and biomass production (Abdalla *et al.*, 2008). Both yield and quality of groundnuts are compromised by drought. Nigam *et al.*, (2003) reported that drought affects yield and groundnut quality under rainfed conditions. Drought, occurring during the late reproductive phases; from pegging to pod filling, can drastically reduce pod yield (Plaut and Ben, 2005; Clavel *et al.*, 2006; Painawadee *et al.*, 2009; Wuma *et al.*, 2009).

Yield reduction is estimated at 56% to 85% (Nageswara *et al.*, 1989). Nageswara and Nigam (2003) reported that annual groundnut production losses due to drought were estimated at over 250 million USD (at the market price of 1994). Global yield losses due to drought have been estimated as 6.7 million tons in groundnut (Subbarao *et al.*, 1995).

A survey of the literature suggests that sustainable strategies that enable farmers to manage drought at the most critical growth stages are required to increase yield of groundnuts and to enhance quality.

Drought stress varies spatially and temporally at several different levels. Drought affects membrane lipids and photosynthetic responses and yield in groundnut (Lauriano *et al.*, 2000). Water deficit affects thylakoid electron transport, phosphorylation, carboxylation and photosynthesis. Changes in the lipid content and composition are common in water-stressed plants and this increases membrane permeability. This causes damage and membrane disruption as well as reduction in photosynthesis (Lauriano *et al.*, 2000).

## **2.2. Effect of drought during flowering and pod formation**

### **2.2.1. Flowering**

The start of flowering is not delayed by drought stress (Boote and Ketring, 1990). The rate of flower production is reduced by drought stress during flowering but the total number of flowers per plant is not affected due to an increase in the duration of flowering (Meisner and Karnok, 1992). A significant burst in flowering on alleviation of stress occurs, particularly when drought is imposed just prior to reproductive development (Janamatti *et al.*, 1986). When stress is imposed during 30-45 days after sowing, the first flush of flowers, produced up to 45 days, do not form pegs during that time. However, flowers produced after re-watering compensate for this loss (Gowda and Hegde, 1986).

### **2.2.2. Pod formation**

Drought stress during pegging and pod development may lead to a drastic yield reduction and the magnitude of reduction would depend on the cultivars (Jogloy *et al.*, 1996). Peg elongation,

which is turgor dependent, is delayed due to drought stress (Boote and Ketring, 1990). Pegs failed to penetrate effectively into air-dry soil, especially in crusted soils. Often, within 4 days of withholding water, the soil surface becomes too dry for peg penetration. Rucker *et al.* (1995) mentioned that the quality of groundnut products decreases under drought stress. Adequate pod zone moisture is critical for development of pegs into pods and adequate soil water in the root zone cannot compensate for lack of pod zone water for the first 30 days of peg development (Gowda and Hegde, 1986). Dry pegging zone soil delays pod and seed development. Soil water deficits in the pegging and root zone decrease pod and seed growth rates by approximately 30% and decrease weight per seed from 563 to 428 mg (Janamatti *et al.*, 1986). Sexton *et al.* (1997) reported that peg initiation and growth during drought stress demonstrated ability to suspend development during the period of soil water deficit and to re-initiate pod development after the drought stress was relieved. Nageswara *et al.* (1989) reported that under water stress, pegging and seed set responses of different groundnut cultivars varied substantially. This leads to a large reduction in pod yield, and the reduction percentage also varies among groundnut cultivars.

## **2.3. Environmental resource utilization**

### **2.3.1. Groundnut water use**

Boote (1982) and Ghosh *et al.* (2005) described and defined the growth stages of groundnut as a series of vegetative and reproductive stages. The total water use by a groundnut crop is controlled by climatic conditions in addition to agronomic and varietal factors that include growth stages. Sivakumar and Sharma (1986) reported that water use of groundnut varies from 250 mm in the rainfed conditions to 830 mm under irrigated conditions (with irrigation at weekly intervals). Thus, groundnut needs water throughout its entire life cycle, but the reproductive stages are the most critical in terms of water use.

### **2.3. 2. Rainfall or soil moisture**

Rainfall is the most significant climatic factor affecting groundnut production, as 70% of the crop area is under Semi-Arid Tropical conditions characterized by low and erratic rainfall (Ong, 1986). Low rainfall and prolonged drought spells during the crop growth period have been reported to be the main reasons for low average yields in most of the regions of Asia and Africa; for example in India (Reddy *et al.*, 2003a), and several parts of Africa, (Camberlin and Diop, 1999). Camberlin and Diop (1999) reported that almost half of the variance in groundnut production is explained by rainfall variability, especially during the early part of the rainy season (July - August). Dulvenbooden *et al.* (2002) reported that groundnut production in Niger is significantly affected by rainfall during July to September. Therefore, to increase groundnut production, water availability must be considered as a critical factor in any production system.

### **2.3.3. Photoperiod or day length**

It is well-known that long days promote vegetative growth at the expense of reproductive growth and increased crop growth rate, decreased partitioning of photosynthesis to pods and decreased duration of effective pod filling phase (Ketring 1979, Nigam *et al.*, 1998). Groundnut cultivars may show differences in response to photoperiod.

Bagnall and King (1991) mentioned that flower, peg and pod numbers were consistently enhanced by short day treatments for a range of groundnut varieties. Flower and peg number at 60-70 days after sowing were almost doubled by 12 hour days exposure compared with plants in 16 hour days. Pod number and therefore yield was more influenced by photoperiod than was flower or peg formation. Bell *et al.* (1991) observed reduction on number of pegs, pods and total

pod weight per plant in long (16 or 17 h) photoperiods, but no effect of photoperiod was evident on time to first flower in a cool subtropical environment.

Nigam *et al.* (1994) studied the effect of temperature and photoperiod and their interaction on plant growth as well as partitioning of dry matter to pods. They observed that photoperiod did not significantly affect partitioning of dry matter to pods under low temperature regime (18/22°C) but at higher temperatures (26/30°C) partitioning to pods was significantly greater under short days (9 h) and this study provided evidence of genotypic variability for photoperiod and temperature interactions.

#### **2.4. Consequences of water stress**

Reddy *et al.* (2003b) reported that canopy photosynthesis is reduced by water stress due to reduced stomatal conductance, and reductions in leaf area that lead to transpiration reduction. Periodic water stress leads to anatomic changes such a decrease in size of cells and intercellular spaces, thicker cell walls and greater development of epidermal tissue (Reddy *et al.*, 2003b). Drought stress has been shown to cause alterations in the chemical composition and physical properties of the cell wall (Ingram and Bartels, 1996). The cellular water deficits results in the concentration of solutes, loss of turgor, change in cell volume, disruption of water potential gradients, change in membrane integrity, denaturation of proteins and several physiological and molecular components (Griffiths and Parry, 2002). The stress effects depend on: the timing, the intensity, the duration, the developmental stage of the plant, the genotype and the environmental interactions (Sharma, 2006). Rates of net photosynthesis (P<sub>n</sub>) decrease when plants are subjected to moisture stress (Nautiyal *et al.*, 2002; Vorasoot *et al.*, 2004). Decreases in net photosynthesis due to moisture stress are accompanied by increased resistance to CO<sub>2</sub> diffusion into the leaf (Bhagsari *et al.*, 1976). Adenosine triphosphate (ATP) synthesis was the most

affected process susceptible to drought stress. Collino *et al.* (2001) observed that the fraction of photosynthetically active radiation intercepted and harvest index were reduced under water stress. Abscisic acid (ABA) concentration increases under water stress as well as under some other abiotic and biotic stresses (Christmann *et al.*, 2005). Lauriano *et al.* (2000) reported that drought affects membrane lipids and photosynthetic responses. Water deficit affects thylakoid electron transport, phosphorylation, carboxylation, and decreases photosynthesis. Clavel *et al.* (2004) reported that water deficit decreased leaf area index, relative water content and transpiration at about 3 weeks after the occurrence of water deficit at the soil level.

Vorasoot *et al.* (2003) observed a drastic reduction in yield, as well as yield components like total dry weight and shelling percentage. Naveen *et al.* (1992) showed that water deficit reduced seed size, and increase the number of shriveled seed, if water stress occurs during the flowering stage. Water stress during reproductive development resulted in embryo abortion, reduced seed development and aggravated aflatoxin contamination, and finally, reduced yield (Stalker, 1997; Holbrook and Stalker, 2003; Vorasoot *et al.*, 2003). In addition, drought conditions influence the growth of weeds, agronomic management, and the nature and intensity of insects, pests and diseases (Reddy *et al.*, 2003b). Nageswara and Nigam (2003) reported that under drought conditions, the beneficial effects of improved crop management practices in terms of increased production are not fully realized. Calcium uptake by pods and nitrogen fixation processes are adversely affected by drought. Consequently water stress has several negative effects on the plant at different levels such as anatomic, physiological, molecular and agronomical.

## **2.5. Mechanisms of drought stress avoidance**

In groundnut, genetic differences in water use efficiency appear to be due to photosynthetic capacity. Nevertheless, variability in water use efficiency can be due to reduced stomatal

diffusion or intrinsic photosynthetic capacity (Wright *et al.*, 1994). A waxy layer on the top of the leaf cuticle is present to protect against water stress and help survival in harsh conditions (Tanka *et al.*, 2004). The cuticle of flowering plants is a complex matrix that consists of lipids, cutins and waxes (Kolattukudy, 1980). Cutins are composed of hydroxy and epoxy fatty acids and serve as the barrier between the aerial parts of higher plants and their environment. Serraj and Sinclair, (2002) proposed osmotic adjustment as a mechanism for drought tolerance. The accumulation of osmolytes in the cells will result in a decrease in osmotic potential and in the maintenance of water absorption and turgor pressure. During water stress, abscisic acid is generated in the root and transported to the shoot to mediate stomatal closure as well as more general adaptive shoot responses (Christmann *et al.*, 2005). Root structure, accumulation of osmolytes, leaf folding, and reduction in leaf area and regulation of transpiration are known mechanisms that increase drought tolerance (Samdur *et al.*, 2003).

## **2.6. Approaches for combating drought stress**

According to Nageswara and Nigam (2003), three genetic enhancement approaches were developed and implemented simultaneously to enhance the adaptation to drought-prone environments. These are: (i) development of short-duration genotypes that can escape the end-season drought; (ii) development of genotypes with superior yield performance in drought prone regions following conventional breeding approaches and (iii) development of drought tolerant genotypes following physiological breeding approaches. In addition to these approaches, Sharma (2006) reported that molecular markers and Marker Assisted Breeding and Transgenic Technology have been used.

### 2.6.1. Physiological breeding approach

There has been significant progress in understanding the physiological basis of genotypic variability of drought response in groundnut, suggesting that selecting genotypes with traits contributing to superior performance under water-limited conditions is possible (Nageswara and Nigam, 2003). Substantial genetic variation has been observed in partitioning of dry matter to pods (Nageswara *et al.*, 1993). Nageswara (1994) reported a significant genotypic variation in root system for the capacity to penetrate deeper soil layers. Significant genotypic variation in total amount of water transpired and transpiration efficiency has been shown under field conditions (Mathews *et al.*, 1998).

Physiological measurements such as water transpired, water-use efficiency (WUE) and harvest index (HI) have been identified and can be highly correlated with pod yield (Basu *et al.*, 2003). Transpiration efficiency (TE) varied significantly among groundnut cultivars irrespective of whether plants were drought-stressed or well-watered (Hubick *et al.*, 1988). Wright *et al.* (1994) confirmed that there are large cultivar differences in transpiration efficiency in groundnut grown in field conditions. Although a large variation has been found for each of these physiological traits in groundnut, there are significant difficulties in accurately measuring them because large number of plants are needed for selection programmes. However, there has been significant progress in understanding the mechanisms involved, and in developing novel and indirect selection tools for the model parameters (Nageswara and Nigam, 2003). For example, transpiration efficiency and carbon isotope discrimination in leaf are well correlated in groundnut (Hubick *et al.*, 1986), suggesting the possibility of using carbon isotope discrimination in leaves as a rapid, nondestructive tool for selection of transpiration efficiency. Carbon isotope discrimination and specific leaf area (SLA) have been shown to be correlated with water-use

efficiency of groundnut. SLA has been proposed as an indirect selection criterion for carbon isotope discrimination and water-use efficiency (Craufurd *et al.*, 1999). Nageswara and Wright (1994) showed that the stability of relationship between carbon isotope discrimination in leaf and SLA over a wide range of cultivars and environments has raised the possibility of using SLA as an even more rapid and inexpensive technique for selection of transpiration efficiency. Madhava *et al.* (2003) suggested that the soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) can be used as a rapid preliminary screening tool to select groundnut genotypes with high transpiration efficiency. Thus, through physiological approaches there are several techniques for combating water stress via indirect selection by targeting specific traits such as SLA, TE, HI, SCMR.

### **2.6.2. DNA marker-assisted selection**

The use of DNA markers for indirect selection offers the greatest potential gain for quantitative traits with low heritability, as these are the most difficult characters to work with in the field through phenotypic selection (Sharma *et al.*, 2002). A large number of genes with a potential role in water stress tolerance have been identified and characterized (Ingram and Bartels, 1996). Genetic improvement for drought tolerance is crucial in environments where agriculture depends on limited water resources. Therefore, finding genes involved in the tolerance to drought and their insertion into the genetic background of agronomically preferred varieties could enhance and/or stabilize yields under drought-prone conditions. Once genomic regions contributing to the trait of interest have been assigned and the alleles at each locus designated, they can be inserted into locally adapted high-yielding cultivars by making requisite crosses (Mathur *et al.*, 2004). The progenies that carry desired combinations of alleles will be selected for further evaluation using marker-assisted selection.

Halward *et al.* (1993) developed the first genetic RFLP linkage map in groundnut from an F<sub>2</sub> population of a cross between A-genome diploids *Arachis stenosperma* and *Arachis cardenasii* for use in genetic studies and breeding programmes to improve the cultivated species (*Arachis hypogaea* L.). A second map based on the previous parents used a BC<sub>1</sub> population and added 167 RAPD markers to a skeleton of 39 RFLP markers from which the first map was constructed (Garcia *et al.*, 2005). A third A-genome map was developed from the cross *A. duranensis* x *A. stenosperma* consisting of 170 SSR markers on 11 linkage groups, with a total map length of 1,231 cM (Gomez *et al.*, 2009). A total of 370 RFLP loci were mapped onto 23 linkage groups, for a map distance of 2210 cM (Burow *et al.*, 2001).

Proite *et al.* (2007) analyzed the transcriptome of wild species, *Arachis stenosperma* accession V10309. Almost nine thousand (8,785) ESTs were generated from four cDNA libraries. ESTs were classified into 23 different categories according to putative protein functions. Numerous sequences related to disease resistance and drought tolerance were identified. Cuc *et al.* (2008) have developed a set of 104 SSR markers for cultivated groundnut. The polymorphic SSR markers detected 2 to 5 alleles with an average of 2.44 per locus. These markers showed a good level of polymorphic information content (PIC) value in cultivated germplasm and, therefore, would be very useful for germplasm analysis, linkage mapping, diversity studies and phylogenetic relationships in cultivated groundnut as well as related *Arachis* species. Recently Varshney *et al.* (2009) constructed the first SSR-based genetic linkage map for cultivated groundnut (*Arachis hypogaea* L.). A total of 1,145 microsatellite (SSR) markers available in the public domain as well as unpublished markers from several sources were screened on two genotypes, TAG 24 and ICGV 86031, that are parents of a recombinant inbred line (RIL) mapping population. As a result, 144 (12.6%) polymorphic markers were identified and these

amplified a total of 150 loci. As the mapping population used for developing the genetic map segregates for drought tolerance traits, phenotyping data obtained for transpiration, transpiration efficiency, specific leaf area and SPAD chlorophyll meter reading (SCMR) for two years were analyzed together with genotyping data. Two to five QTLs for each trait mentioned above were identified. Because of the complexity of drought, some molecular tools such as molecular markers are used to select genotypes with desirable genes playing an important role in water stress tolerance. Molecular tools can be used later on to introgress drought tolerance and earliness genes into farmers' preferred varieties.

## **2.7. Farmer participation in variety development in Niger**

Participatory rural appraisal (PRA) has been defined as a: 'family of participatory approaches and methods which emphasize local knowledge and enable local people to do their own appraisal, analysis and planning (Brown *et al.*, 2002). PRA uses group animation and exercises to facilitate information sharing, analysis and action among stakeholders. There has been lack of information about farmers' groundnut varieties preferences and production constraints in Niger.

In addition, farmers had never involved in participatory groundnut varieties development in Niger. Farmers' perceptions on sorghum production constraints and their traits preferences were identified through PRA in Niger (Aissata, 2013). Ahmadou (2013) used PRA tools such as focus group discussions and questionnaire to determine constraints and opportunities of pearl millet production and to get general information on the production systems from farmers in Niger. Participatory rural appraisal methods were used to establish farmer management strategies and perceptions on major constraints to pigeonpea productivity in Zimbabwe (Mapfumo *et al.*, 2001). Participatory rural appraisals were conducted to identify the major characteristics of sorghum

landraces. This was done in village meetings by Focused Group Discussions (FGDs), matrix ranking, and individual interviews in Malawi. The classical PRA tools (maps, sketches, diagrams, ranking) were used to investigate the indigenous soils and agroecological knowledge and identify determinants of land degradation and to identify specific land management queries in Lebanon (Zurayk *et al.*, 2001).

## **2.8. Estimation of genetic parameters in groundnut**

In Niger, there is a lack of information on genetic parameters required for breeding groundnut for earliness and drought tolerance related traits. Therefore, combining ability and heritability estimates studies are needed.

### **2.8.1. Combining ability estimates**

Earliness is important for groundnut adaptation to a wide range of cropping systems in Semi-Arid Tropics. An early maturing variety may escape damage from drought. In any breeding programme knowledge of the genetic composition of the breeding stocks in hand and the nature of gene action involved in the expression of the trait to be improved is the basic requirement of the breeder. The combining abilities for physiological and earliness traits in groundnut are examined to understand the type of gene action governing these traits, and to identify groundnut genotypes suitable for use as parents in breeding for improvement in physiological and earliness traits. John, (2011) reported that the information on the precise nature of genetic control of physiological traits in groundnut is still lacking.

General combining ability (GCA) of a line is defined as the mean performance in all its crosses, when expressed as deviation from the mean of all crosses. It is the average value of all crosses having this line as one parent, the value being expressed as a deviation from the overall mean of

crosses. Any particular cross, then, has an expected value, which is sum of the general combining abilities of its two parental lines. The cross may deviate from this expected value to a greater or lesser extent. This deviation is called specific combining ability (SCA) of the two lines in combination (Griffing, 1956, Falconer and Mackey, 1996). This information provides guidelines for plant breeders to select parental lines to be used in breeding programmes and to use promising cross combinations for further selection.

Jogloy *et al.* (1987) found that general combining ability was highly significant for pod yield, and shelling percentage and specific combining ability was significant for pod length and seed size. Swe and Branch (1986) found that estimates of general and specific combining abilities were significant for biomass, harvest index, total pod weight. In general, estimates of specific combining ability are more pronounced in the crosses of more diverse cultivars than in the closely related cultivars (Isleib *et al.*, 1980).

Mekonthehou (1987) studied the combining ability of early maturity for a selected group in *Spanish* and *Virginia* type of groundnut and found that GCA was always larger than SCA for most of the maturity parameters in F<sub>1</sub> hybrid of *Virginia* x *Spanish* parents. Rachmeler (1988) suggested that selection for yield and earliness if practiced in later generation would be more effective. Therefore, he found greater and significant GCA than SCA estimated for early maturity in F<sub>2</sub> and F<sub>3</sub> generation. Bansal *et al.* (1991) showed that non additive gene effects were predominant for yield components although the magnitude of additive effects was considerable. They also reported that intra-group crosses were better than inter-group crosses. John *et al.* (2011) indicated that combining ability analysis was primarily non-additive gene action in the inheritance of SPAD (soil plant analytical development). Intermating of the F<sub>2</sub> segregants followed by recurrent selection and pedigree breeding can harness the different kinds of gene -

effects (John *et al.*, 2011). They stated that repeated selection and inter-mating of segregating materials for two or three cycles, makes it possible to achieve simultaneous improvement in physiological attributes. Venkateswarlu *et al.* (2007) mentioned the involvement of both additive and non-additive gene action in the inheritance of physiological and pod yield traits. In general high magnitude of general combining ability variance showed the greater importance than additive gene action in the inheritance of physiological and pod yield traits. Through combining ability study information on the best general combiners' parental lines will be available.

### **2.8.2. Heritability estimate for agronomic and yield traits**

All broad and narrow-sense heritabilities are defined on individual and family basis for prediction of response to selection for a target population of environments in space and time. The heritability of a trait within a population is the proportion of observable differences in a trait between individuals within a population that is due to genetic differences (Nyquist and Baker, 1991; Falconer and Mackay, 1996; Holland *et al.*, 2003). Factors including genetics, environment and random chance can all contribute to the variation between individuals in their observable characteristics. Heritability is measured by estimating the relative contributions of genetic and non-genetic differences to the total phenotypic variation in a population.

A consequence of the definition of heritability is that it depends on the population, because both the variations in additive and non-additive genetic factors, and the environmental variance, are population specific (Visscher *et al.*, 2008). Genetic variance depends on segregation in a population of the alleles that influence the trait, the allele frequencies, and the mode of gene actions. All these variables can differ across populations. Similarly, environmental variance can vary across populations. Consequently, the heritability in one population does not, in theory,

predict the heritability of the same trait in another population (Visscher *et al.*, 2008). For example, heritabilities are higher for morphometric traits than for fitness traits; the former are often higher in more favorable environments.

Heritabilities and the variances that contribute to them are parameters of a population. Heritability can be estimated from empirical data of the observed and expected resemblance between relatives. The expected resemblance between relatives depends on assumptions regarding its underlying environmental and genetic causes. Sometimes these assumptions are straightforward. Traditionally, heritability was estimated from simple and often balanced designs, such as simple functions of the regression of offspring on parental phenotypes, the correlation of full or half sibs, and the difference in the correlation of monozygotic and dizygotic identical pairs.

Selection for drought tolerance using pod yield under drought conditions as the selection criterion has produced only slow progress due to large genotype x environment interactions (Wright *et al.*, 1994; Nageswara and Wright, 1994; Sheshshayee *et al.*, 2006). The integration of physiological traits or their surrogates in the selection scheme would be advantageous in selecting genotypes that are more efficient water utilizers or partitioners of photosynthates into economic yield (Nigam *et al.*, 2005; Pimratch *et al.*, 2009, Upadhyaya and Sharma, 2011). Improving water access and management are practically difficult since water is a rare resource. Therefore, breeding for drought tolerance is an important strategy in alleviating the problem and offers the best long-term solution. Selection of segregating populations under stress conditions has been a standard approach for developing cultivars with improved stress tolerance. More rapid progress may be achieved by using physiological traits (Nigam *et al.*, 2005) such as harvest index or water use efficiency, and SPAD (Songsri *et al.*, 2008). Both specific leaf area and

SPAD have been used as surrogate traits for water use efficiency (Wright *et al.*, 1994; Nigam *et al.*, 2005; Sheshshayee *et al.*, 2006). A strong and positive relationship between SPAD chlorophyll meter reading and WUE was found in groundnut (Sheshshayee *et al.*, 2006). Upadhyaya, (2005) reported genetic variation for SCMR in groundnut. SPAD that is easy to measure and suitable as a selection criterion trait for drought tolerance because of high heritability, simplicity in gathering and positive correlation with pod yield and agronomic traits (Songsri *et al.*, 2008; Girdthai *et al.*, 2010). Upadhyaya and Sharma, (2011) found that additive effects were important for SPAD chlorophyll meter reading (SCMR) at 80 days after sowing (DAS) while predominance of dominance effects with duplicate epistasis was observed for SCMR at 60 DAS and specific leaf area (SLA) in groundnut. So they concluded that predominance of additive effect for SCMR at 80 DAS suggested effective selection could be practiced even in early generations, whereas SCMR at 60 DAS and SLA at both stages, it will be better to start selection in later generations. From these results, recording SCMR and SLA should be done between 60 and 80 DAS for screening germplasm for drought tolerance.

## CHAPTER THREE

### 3.0. IDENTIFICATION OF THE PRODUCTION CONSTRAINTS AND FARMERS' PREFERRED VARIETIES OF GROUNDNUT IN NIGER

#### 3.1. Introduction

One of the crucial aspects to consider in plant breeding is to involve farmers in the improvement of existing cultivars and the selection of new varieties. There is limited information in Niger on groundnut production constraints and farmers' preferred groundnut varieties traits. This makes a study in this area is necessary. When farmers are not involved in breeding activities, breeder's products may not be easily adopted; because they may not meet farmers and consumer expectations. Chambers (1994) described PRA as a growing family of approaches and methods to enable local (rural or urban) people to express, enhance, share and analyze their knowledge of life and conditions, to plan and to act. When PRA is well done, local people, and especially the poorer, enjoy the creative learning that comes from presenting their knowledge and their reality.

Nkongolo *et al.* (2008) conducted a PRA to identify the major characteristics of sorghum landraces in Malawi by using focus group discussion (FGDs), matrix ranking, and individual interviews. Joshi and Witcombe, (1996) used Farmer participatory varietal selection to identify farmer-acceptable cultivars of rice and chickpea in India. Scientists' selection criteria will not always be linked with that of farmers; therefore, integration of farmers' opinion in breeding various crops as a way of enhancing variety adoption is becoming increasingly popular and effective in terms of cost and transferring the right varieties and technology to farmers (Efisue *et al.*, 2008). The objectives of this study were to (i) determine production constraints in two groundnut production regions in Niger; (ii) identify the farmers preferred groundnut varieties.

## **3.2. Methodology**

### **3.2.1. Study area**

The PRA was carried out in two main regions of the Niger “groundnut basin”; Maradi and Zinder. Focus group discussions (FGDs) were conducted in six villages of Madarounfa (Maradi) and Magaria (Zinder) (Figure 3.1). The six villages were Angoual gamji, N’cha Roua, Wadata in Magaria (12°59’N and 8°56’ E); and Angoual Roudji, N’Yelwa and Yardaji in Madarounfa (13°18'27"N and 7°9'21" E). The two districts are located in Sudano-Sahelian agro ecological zone with two main seasons: (i) a short rainy season from June to September, with an average annual rainfall estimated at 500-600 mm, (ii) a dry season spanning from October to May. This includes a cold period (December to March) and a hot period (April-May). The soil type is tropical ferruginous soils of clay loam in Madarounfa and mainly sandy and infertile in Magaria.

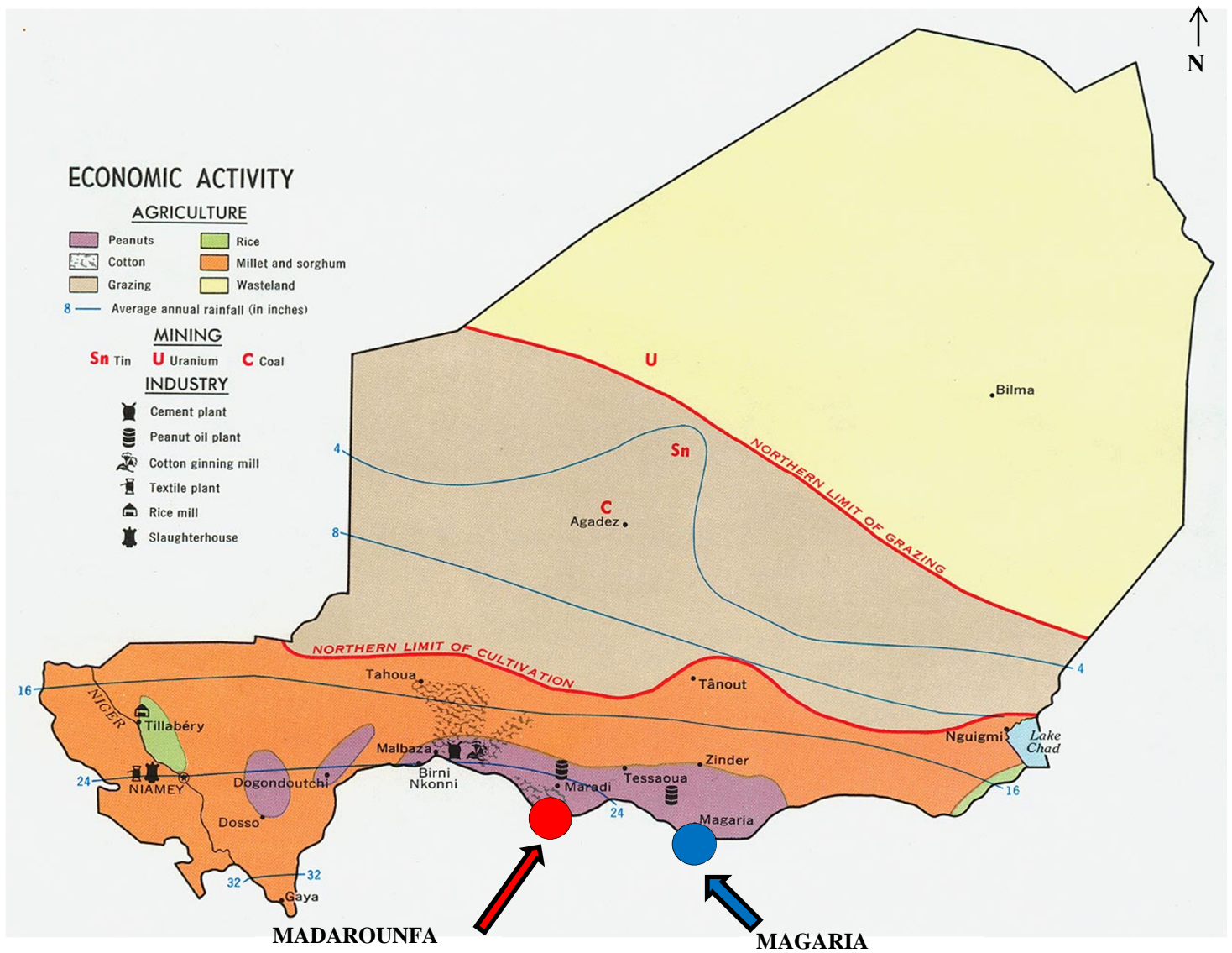


Figure 3.1: Niger map with study areas

### **3.2.2. Study villages**

Selection of sites was done jointly by National Institute of Agricultural Research (INRAN) researcher and the agricultural extension agents. The six villages were selected by using the following criteria:

- Having a Farmer's organizations that would enable the study to build on existing trust of local farmers;
- Groundnut was important in the local farming systems and farm household incomes;
- They were representative of the regions in terms of agro-environmental and socio-economic conditions,
- Closeness to INRAN substations.

Once a village was selected, the investigator and the agricultural extension agent jointly identified one or two villagers (male and female) as potential local representatives for preparing the FGD session.

### **3.2.3. Introduction to villages**

The extension agent introduced the principal investigator to the chief of each village and to the presidents of farmers' organizations. The objectives were clearly explained: (i) identify the production constraints; (ii) determine farmers preferred varieties of groundnuts. Several discussions with farmers were held to explain FGDs procedures. Later an introductory meeting with farmers was scheduled in each village to explain the purpose of the research that pave the way for future contacts with them.

### 3.2.4. Sampling method

This study was conducted in January 2011 in collaboration with the agricultural extension unit, and INRAN. Because of common heterogeneity among agricultural households, stratified sampling was used. In each village, the village chief assisted in selecting the participants from the farmer's organizations. Thirty farmers were selected per village based on their experience in groundnut production. At least 15 men and 15 women participated in FGDs sessions, thus totaling 187 farmers (98 male and 89 female) for the six villages (Table 3.1).

**Table 3.1:** The number of farmers by gender that participated in Focus group discussion sessions

	<b>Department/Villages</b>	<b>Male</b>	<b>Female</b>	<b>Total</b>
	<i>Angoual Gamji</i>	17	14	31
<b>Magaria</b>	<i>N'cha Roua</i>	15	21	36
	<i>Wadata</i>	15	14	29
	<i>Angoual Roundji</i>	12	18	30
<b>Madarounfa</b>	<i>N'Yelwa</i>	19	13	32
	<i>Yardaji</i>	14	15	29
	<b>Total</b>	<b>98</b>	<b>89</b>	<b>187</b>

### 3.2.5. Data collection and analysis

The PRA technique used in this study was focus group discussion. The FGD supervisors included a moderator (the investigator), agronomist (recorder) from INRAN and an agricultural extension agent of the district. Before the focus group discussions sessions, a visit was made to the six villages. The objective was to identify the farmers' organisations and establish selection criteria of the participants to the FGDs sessions. FGDs sessions were set jointly and a reminder was sent one week before the date. Two meetings were held in the village between 8:30 and 10:30 a.m. in the morning and 2:00 to 4:00 p.m. in the afternoon. FGD began with the moderator welcoming participants and briefing them on the process (e.g., that there are no right or wrong answers, that it's important to speak one at a time and that the session will be recorded). Farmers

sat in a semi-circle (Plate 3.1 and 3.2) to facilitate identification of key points raised by each farmer and also ensure full participation by all the participants. Participants were informed about the one to take records of the entire session. The discussions were held in Hausa (local language). Refreshments were served to participants at break in each session.

Following a check list (Appendix1), the moderator moderates the session and ensured that all topics were covered. Participants were encouraged to express their views and even disagree with one another about the topics. The order in which topics were covered was flexible but generally the sessions started with more general issues and slowly moved into more specific ones. Towards the end, a few probing questions were asked to reveal more in-depth information or to clarify earlier responses. The topics discussed included main groundnut production constraints (biotic and abiotic stresses), varietal preferences, and marketing issues. A chart was used to rank the varieties and constraints. Each record was labeled with village name and date of the session.



**Plate 3.1:** Focus group discussion with women at N'cha Roua

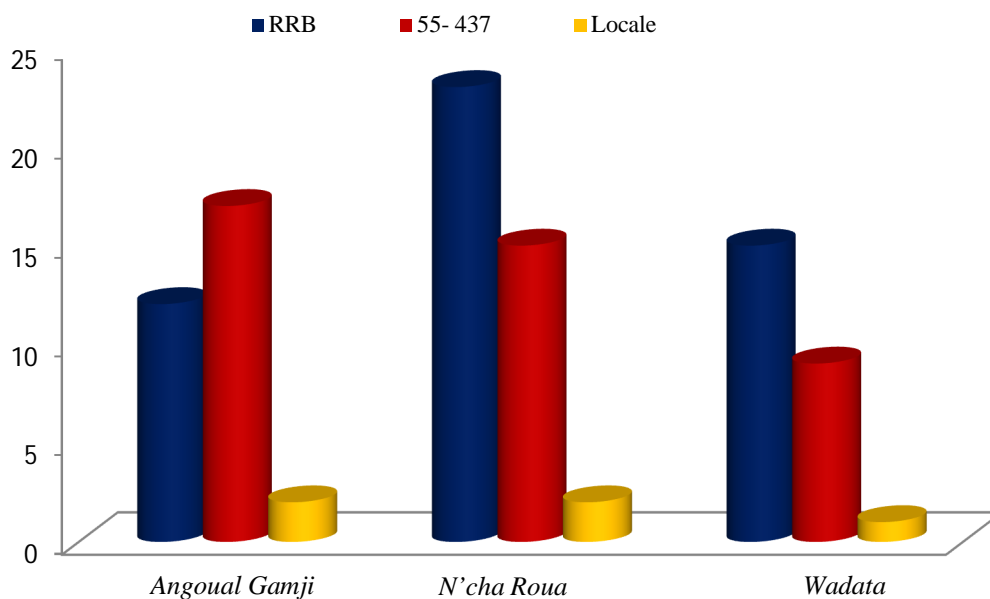


**Plate 3.2:** Focus group discussion with men at Wadata

### 3.3. Results

#### 3.3.1. Farmers preferred varieties in Magaria

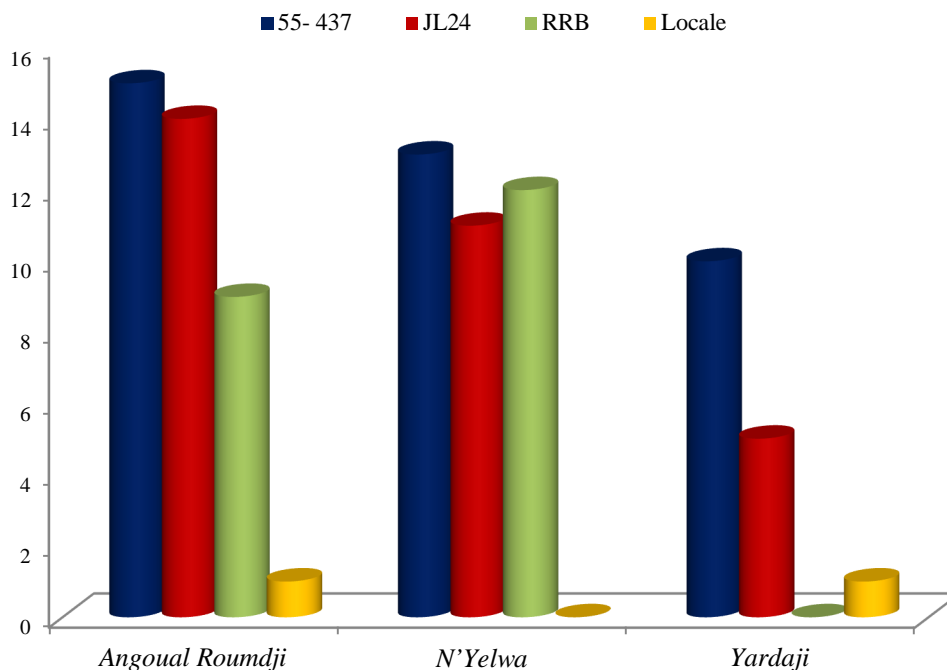
RRB was the most preferred variety in the two villages followed by 55- 437. The varieties RRB and 55-437 were used by the farmers in all the three locations in Magaria. The variety RRB was preferred by 52.08% of the respondents followed by 55-437 which was preferred by 42.70% of the respondents (Figure 3.2). Only 5.22% of the respondents used local varieties. The respondents preferred the variety RRB to the variety 55-437 because of its oil content, tolerance to rosette disease and haulm production. All (100%) of the FGDs respondents required new groundnut varieties that are early maturity, drought tolerant and highly productive in terms of yield, oil content and haulm. Most of the respondents used the variety 55-437 because it was the first improved variety that was introduced since 1974 and well known to be drought tolerant initially.



**Figure 3.2:** Farmers preferred varieties ranked in Magaria

### 3.3.2. Farmers preferred varieties in Madarounfa

The varieties 55-437 and JL24 were the best preferred and most cultivated by farmers, in all the three villages in Madarounfa followed by the variety RRB. These varieties were used by the farmers in all the three locations; RRB was less used in Yardaji. The variety 55-437 was preferred by 41.75% of FGD respondents, followed by the variety JL24, 32.96% and the variety RRB, 23.07% (Figure 3.3). The respondents preferred the variety 55- 437 to the varieties JL24 and RRB because of its yield potential, drought tolerance and earliness (90 days). Only 2.2% of the FGDs respondents in all the three localities used local groundnut varieties. Most of the respondents mentioned the need of new groundnut varieties that are high yielding, early maturing and drought tolerant.



**Figure 3.3:** Farmers preferred varieties ranked at Madarounfa

### 3.3.3. Sources of Seed

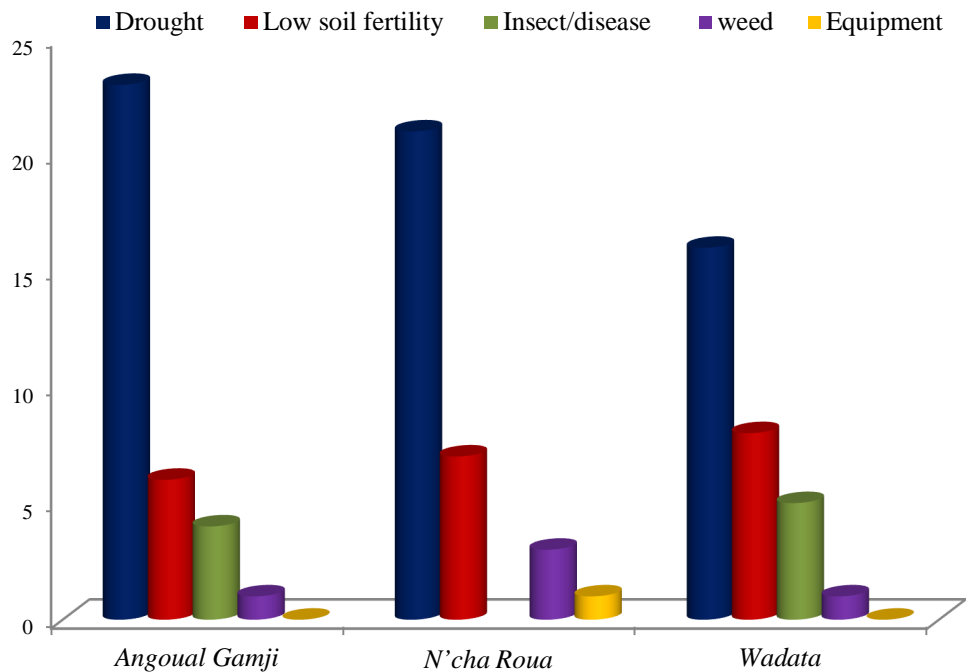
Farmers in all the six villages bought groundnut seeds from different sources (Table 3.2). The majority of the respondents (52.4 %) purchased their groundnut seeds from the village markets, and 25.66% from their neighbors. Only 21.91% of the farmers used improved groundnut seeds from the National Institute for Agricultural Research. Other sources were, NGOs/Projects and seed shops.

**Table 3.2:** Groundnut seeds sources

Seeds sources	% of respondents
Village Market	52.40
Agricultural services	8.05
Farmers	25.66
INRAN	2.67
NGOs/Project	6.95
Seed shops	4.27

### 3.3.4. Production constraints in Magaria

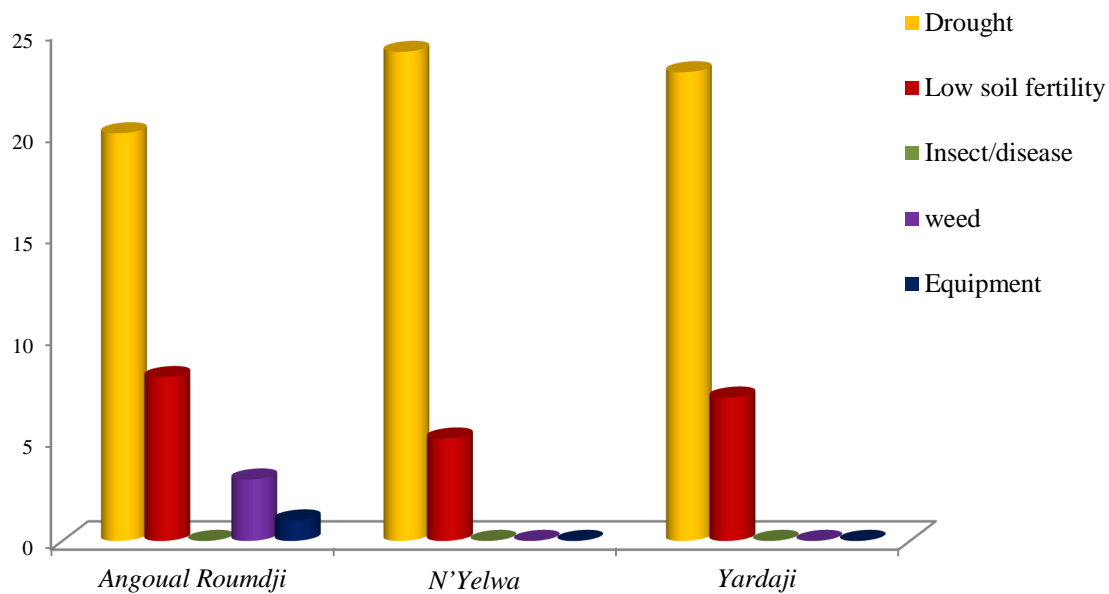
Drought, low soil fertility, insect/disease, weeds and lack of equipments were the most frequently mentioned constraints to groundnut production in Magaria. Drought was the greatest production constraint in all the three villages, followed by low soil fertility. Sixty-two percent (62.70%) of the respondents, mentioned drought, as the greatest production constraint; while 21.80% ranked low soil fertility as the second greatest constraint (Figure 3.4). The year to year variation in rainfall with frequent drought spells was the justification of ranking drought as the main production constraint. Low soil fertility was caused by a lack of manure and mineral fertilizer utilization, because most of the respondents are poor farmers and lack resources to purchase fertilizers. Insect/disease, weeds and lack of equipment were ranked 3, 4 and 5<sup>th</sup> with 9.30%, 5.2 and 1%, respectively.



**Figure 3.4:** Main production constraints ranked by gender in the 3 villages of Magaria

### 3.3.5. Production constraints in Madarounfa

Five production constraints were listed by the farmers in all the three villages. Out of the five production constraints, drought was the major constraint followed by low soil fertility. Drought was ranked first by 73.62% of the respondents as the major production constraint followed by low soil fertility (21.97%) (Figure 3.5). The reasons for ranking these constraints are the same as described in Section 3.4.4. Weeds and lack of equipment were mentioned by 3.29% and 1.09% respectively.



**Figure 3.5:** Main production constraints ranked by gender in the 3 villages of Madarounfa

### 3.4. Discussion

The varieties 55-437 and RRB were preferred in Magaria while in Madarounfa, JL24 and 55-437 were preferred by the farmers. There is a difference in groundnut varietal preferences in the two locations. None of the respondents in the three villages in Magaria mentioned the variety JL24, whereas 32.96% of the respondents in all the villages of Madarounfa mentioned the variety JL24. Among the varieties identified in this study, 55-437 was introduced in 1974 while JL24 and RRB were introduced in the last two decades by the International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) and INRAN. Overall, the three varieties 55-437, RRB and JL24 are the most farmers preferred varieties across the six villages according to FGD respondents. These varieties were preferred to local varieties because of their oil content (around 50%), yield potential and haulm production. Although, these varieties are the farmers' preferred varieties; they are still low yielding and susceptible to drought and rosette disease. The main production constraints are similar in all the six villages. From the ranking, drought is the major challenging

constraint to groundnut production, followed by low soil fertility, insect/disease, then weeds and finally lack of equipment.

The majority of FGD respondents believed that there was a reduction in rainfall during the last 10 years in time and space. They also believed that drought spells are more in recent times than in the past. Chiteka (1985), cited drought as the single most important constraint to groundnut production in Zimbabwe. The most prevalent drought in the study areas is the end-of season drought. Ndunguru *et al.* (1995) found that late-season drought has the largest impact; while Nageswara *et al.* (1985) have found that end-of-season droughts (pod-filling stage) result in poor yields. Unpredictable and unreliable rainfall distributions, and the recent change in weather conditions, have shortened the growing season in western Africa, rendering the existing long-duration cultivars unsuitable (Ntare and Waliyar 1994). To counteract late season drought, short-duration cultivars (80-100 days to maturity) have been introduced and are showing promise in short-season and drought-prone environments.

Most FGD participants mentioned low soil fertility as one of the main obstacles to agriculture development particularly groundnut production. Low soil fertility is due predominantly sandy soils type. The respondents lack resources to purchase fertilizer or manure in order to improve soil fertility, consequently even though improved groundnut seeds will be available, they need also capacity building on how to enhance soil fertility. Soil fertility constraints to crop production are recognized widely as a major obstacle to food security and agro-ecosystem sustainability in sub-Saharan West Africa (Buerkert, 2002). Soil fertility depletion on smallholder farms has been cited as the fundamental biophysical root cause responsible for the declining per capita food production in Africa (Enyong, *et al.*, 1999). Ajayi (2007) reported that

low soil fertility is one of the greatest biophysical constraints to agricultural production in sub-Saharan Africa.

The respondents in this study also mentioned the lack of government support to poor farmers to control pest damage as a major constraint. Most of the respondents cited rosette disease as one of the most damaging diseases. It is transmitted by the vector *Aphis crassivora*. The farmers faced serious yield losses (25-100%) due to this disease during the last seven years. Initially the farmers ignored the vector of the disease, but currently they understand how the disease is spread from farm to farm and best methods to control the disease. ICRISAT estimates that groundnut rosette disease causes greater yield loss than any other virus disease affecting groundnut in the semiarid tropics. Duivenbooden *et al.* (2002) cited rosette as the most destructive disease in Niger in 1975. During the same period, an epidemic in northern Nigeria that destroyed approximately 0.7 million ha of groundnuts, with an estimated loss of \$250 million (Naidu *et al.*, 1999). Similarly, the epidemic that occurred in 1995 in eastern Zambia affected approximately 43,000 ha, causing an estimated loss of \$4.89 million. In the following year, in the central region of neighboring Malawi, groundnut production was reduced 23% by groundnut rosette disease. Yield losses due to groundnut rosette disease depend on the growth stage of the plant when infection occurs. A 100% loss in pod yield may result if infection occurs before flowering. Yield loss is variable if infection occurs between flowering and the pod maturing stage, whereas subsequent infections cause negligible effects.

FGDs respondents in all the villages cited weeds among the main groundnut production constraints. Competition from weeds reduces yield and farmers complained about the lack of government support to control weeds. The large distribution of poor sandy soil in all the villages contributes to quick development of weeds that compete with the crop. The lack of equipment

has been also cited by Angoual Roundji farmers as one of the production constraints that reduces production.

Most of FDG respondents mentioned the following local methods to alleviate drought in the six villagers: prayers, sowing before the onset of the rainy season, utilization of early maturing genotypes, early sowing just after the first rainfall, land ploughing before sowing. Although, utilization of early maturing varieties as an escape mechanism of drought, particularly the end-of-season drought; these early maturing genotypes are not available to the farmers.

### **3.5. Conclusions**

Drought and low soil fertility were the most important constraints contributing to low groundnut production in the study areas.

The most popular farmers preferred varieties were 55-347, RRB, and JL24. These will be used in the crossing programme to develop new early maturing genotypes that are drought tolerant. It was also clear that drought is the major production constraint in both regions.

The information gathered is useful to groundnut breeders to develop good quality groundnut varieties that take into account farmers' preferences.

## CHAPTER FOUR

### 4.0. PHENOTYPING GROUNDNUT GERMPLASM FOR EARLINESS AND DROUGHT TOLERANCE

#### 4.1. Introduction

Groundnut is grown widely under rainfed conditions in the semi-arid tropics, where drought, particularly during the pod and seed forming stages, is a major constraint to productivity that significantly reduces pod yield. The yield of groundnut in Niger is frequently severely limited by drought arising from unpredictable rainfall, high evaporative demands and production on low water holding capacity soils.

The relatively shorter growing seasons in semi-arid regions of West Africa as compared to the southern savannah ecologies prevent groundnut from maturing properly. Therefore, early maturing groundnut cultivars with improved yield are required for several agro-ecologies of the semi-arid regions of West Africa. However, information on the genetic variability for earliness among the early maturing candidate parental lines is lacking.

Breeding early maturing cultivars is an important objective in most groundnut improvement programmes. Bailey and Bear (1973) demonstrated that the early onset of flowering and early accumulation of a given number of flowers (10 to 30) are important components of early maturity in groundnut.

Tolerance to drought in late maturity varieties would also be useful. Drought is known to affect chlorophyll content and inhibit the photosynthetic capacity. The ability to maintain chlorophyll density under water deficit conditions has been suggested as a drought tolerance mechanism in groundnut (Jongrungklang *et al.*, 2008). The SPAD chlorophyll meter readings (SCMR) could be

used for indirect selection of drought tolerance as a rapid and cost effective tool for assessment of relative chlorophyll status in groundnut leaves (Arunyanark *et al.*, 2008; Wunna *et al.*, 2009).

This study was conducted to screen 150 genotypes and identify drought tolerant and early maturity varieties.

#### **4.2. Experimental site**

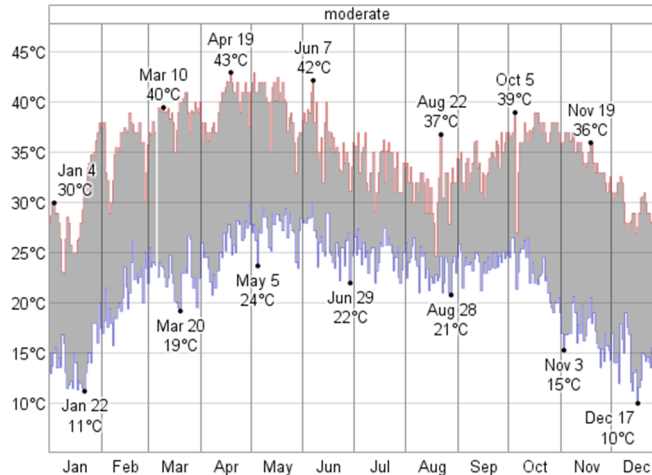
The experiment was conducted at Tarna station in Maradi's region (13° 28'N latitude and 7 ° 10'E longitude) in May 2010. The annual rainfall ranges from 230 to 630 mm, a typical Sahelian climate. The soils at Maradi are sandy soils with low water holding capacity, low inherent soil fertility and organic matter content. The experimental site soil has a pH of 6.5 and contains 90% sand, 8% clay, and 2% organic matter.

#### **4.3. Weather conditions**

The weather was recorded at the Maradi Airport station that is located 4 km from Tarna during 2011.

##### **4.3.1. Temperature**

The hottest day of 2011 was April 19, with a maximum of 43°C (Figure 4.1). The hottest month of 2011 was May with an average daily temperature of 40°C. The bar at the top of the graph is red where both the daily high and low temperatures are above average, blue where they are both below average and white otherwise (Figure 4.1). The coldest day of 2011 was December 17, with a low temperature of 10°C. The coolest month of 2011 was January with an average daily minimum temperature of 14°C.

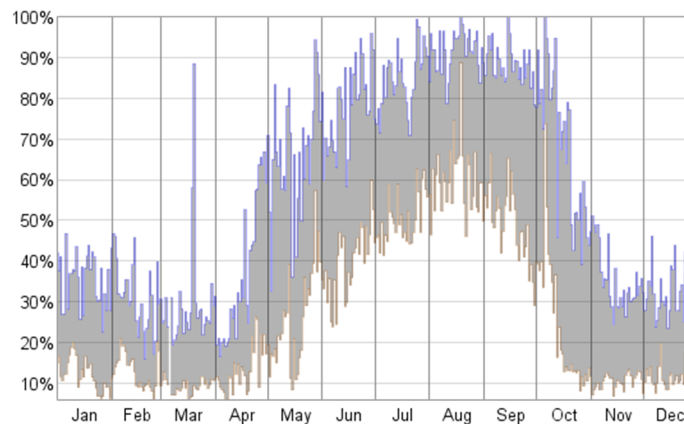


Source: <http://weatherspark.com/history/28574/2011/Maradi-Niger>

**Figure 4.1:** Temperature variation during 2011

#### 4.3.2. Relative Humidity

Hot and humid days feel even hotter than hot and dry days because the high level of water content in humid air discourages the evaporation. The least humid month of 2011 was March with an average daily low humidity of 9%, and the most humid month was August with an average daily low humidity of 60% (Figure 4.2).

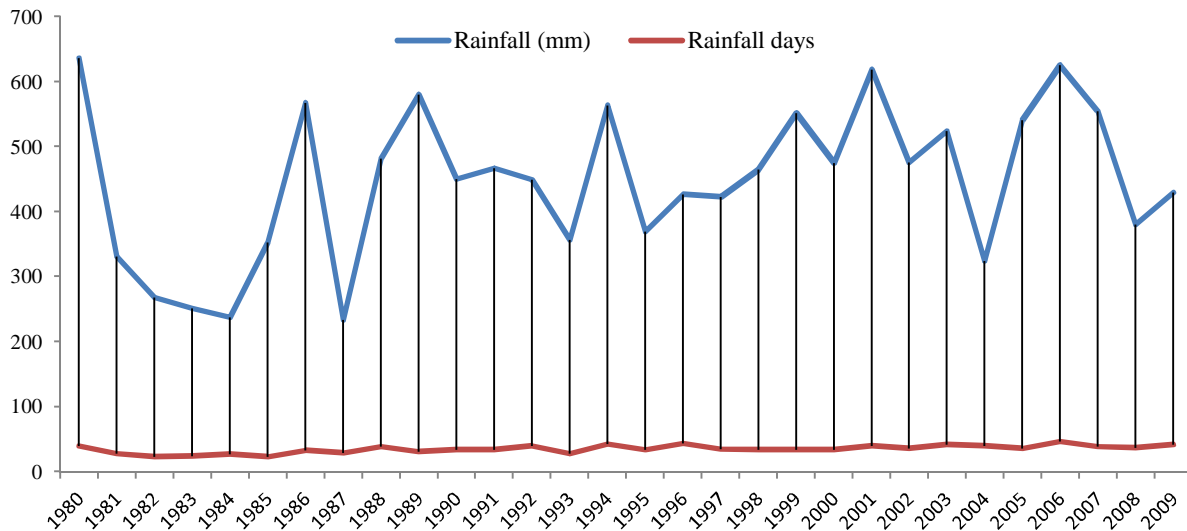


Source: <http://weatherspark.com/history/28574/2011/Maradi-Niger>

**Figure 4.2:** Humidity variation during 2011

### 4.3.3. Precipitation

The average annual precipitation and total rainfall days was collected at Tarna station (Figure 4.3).



**Figure 4.3:** Rainfall pattern from 1980 to 2009 at Tarna INRAN station

## 4.4. Selection of early maturing varieties

### 4.4.1. Genetic material

The plant material in this study included 150 accessions of which 43 were the best performing accessions from a reference set of 300 accessions evaluated under water stress condition during 2008 and 2009 by ICRISAT (Sadore) in Niger, 42 were promising drought tolerant and early maturing accessions from the ICRISAT Niger gene bank, and 65 were genotypes from the National Agricultural Research Institutes in West Africa.

### 4.4.2. Experimental conditions

The fertilizers DAP [Diammonium phosphate  $(\text{NH}_4)_2\text{HPO}_4$ ] 150kg/ha (Jogloy *et al.*, 2011) and farm yard manure 2000 kg/ha (Hamidou *et al.*, 2012) were incorporated; after that, the land was

disk-ploughed two times, leveled and harrowed. The field was irrigated with once before sowing. To prevent seed borne diseases, seeds were treated before planting with a combination of fungicide/insecticide: Thiram 10% ( $C_6H_{12}N_2S_4$ ) and Imidacloprid 25% ( $C_9H_{10}ClN_5O_2$ ) 25g for 10kg of seeds. The sowing depth was 2.5 cm to 3 cm as recommended by Ghosh *et al.*, (2005). Seeds were hand planted in three rows per plot in a ridge-furrow system, 3 m long, with spacing of 0.5 m between rows and of 0.20 m between plants (Arunyanark *et al.*, 2010). The plot size was 1.5 m<sup>2</sup> (0.5 m x 3 m). All the trials were surrounded by two border rows. The design of experiment was an unbalanced  $\alpha$ -lattice design unreplicated (10x15) with 10 blocks and each block contained 15 entries. The trial was irrigated twice a week during the first month, after that, once a week up to the harvesting by surface irrigation. The insecticide dimethoate ( $C_5H_{12}NO_3PS_2$ ) was sprayed at 1l/ha two times to control aphids (*Aphis craccivora*) attack.

#### 4.4.3. Data collection

The following data were recorded:

- % Emergence (% EMERG): The percentage of plants emerged was recorded from 3 to 7 days after sowing.
- 50% Plants flowering (50% PF): Plots were regularly monitored to record the date at which 50% of the plants by plot flowered.
- Plant height (PH): Five plants selected at random were used to record plant height 75 days after sowing.
- Maturity date (MD): Seventy five days after sowing, one plant was harvested from each plot to determine the percentage of developed pods. The plots were harvested when at

least 75% of the developed pods were mature as determined by the blackening of the internal shell wall (Williams and Drexler, 1981).

- Biomass (BIO) weight: Above ground biomass was calculated from 15 plants harvested from each plot after 3 weeks air drying.
- Pod yield (PY): Pod yield was determined from pod harvested from 15 plants in the middle of the plot after air drying to constant weight for two weeks.
- Harvest index (HI): HI was calculated by using the following formula:

$$\text{HI} = \text{Total pod weight (g)} / \text{Total Biomass weight (Girdthai *et al.*, 2010)}$$

#### **4.4.4. Data analysis**

Principal component analysis was used to classify the genotypes with GenStat 12th Edition software. The principal components were computed from the  $n$  eigenvalues and their corresponding eigenvectors are calculated from the correlation matrix. Each eigenvector defines a principal component.

#### **4.4.5. Results for earliness screening**

Principal components measure the importance of each variable in accounting for the total variability. From the principal component analysis, the first three eigenvalues which were greater than 1 (2.63, 1.63 and 1.31), were identified and accounted for 79.62% of the total variation among the genotypes (Table 4.1). The first PC accounted for 37.59 % whereas the second and the third PC axes accounted for 23.30% and 18.73%, respectively. The first PC (Table 4.1) was positively associated with characters such as maturity and pod yield. The second PC was positively associated with days to emergence and negatively associated with harvest index and 50% plant flowering. The third PC correlated positively with pod yield and biomass.

**Table 4.1:** Eigenvectors from the three PC axes used to classified groundnut genotypes

Variable	Component		
	PC1	PC2	PC3
1. % emergence 7 DAS	0.34	0.43	-0.2
2. Harvest index	0.26	-0.63	-0.02
3. Maturity	0.52	0.09	0.17
4. 50% Plant flowering	-0.3	-0.46	0.37
5. Plant height	-0.32	0.27	0.41
6. Pod yield	0.49	-0.14	0.45
7. Biomass	0.3	0.29	0.63
Eigenvalues	<b>2.63</b>	<b>1.63</b>	<b>1.31</b>
Percentage of variance explained	<b>37.59%</b>	<b>23.30%</b>	<b>18.73%</b>

**PC:** Principal Component, **DAS:** Days after sowing

The performance of the 150 genotypes is presented in Appendix 2. The genotypes evaluated were classified into three groups based on the maturity:

- First group: 5 extra early maturing genotypes (75 to 80 days),
- Second group: 29 early maturing genotypes (85 days),
- Third group: 105 intermediate genotypes ( $90 \leq x \leq 110$  days).

Eleven remaining genotypes were not adapted to Tarna conditions due to poor seed quality. Most of these accessions were collected from Mali National Agricultural Institute.

The top five genotypes selected as early maturing varieties based on maturity were Chico, ICGV02022, 796, ICG3585 and ICIAR19BT. The genotype ICIAR19BT had the highest pod yield 1540 g followed by ICGV02022 and ICG 3584 with 700 and 620 g, respectively. Chico had the lowest pod yield (430 g). All the selected genotypes reached 50% flowering in 24 days after sowing. Seven days after sowing, all the selected genotypes had over 70% of emergence.

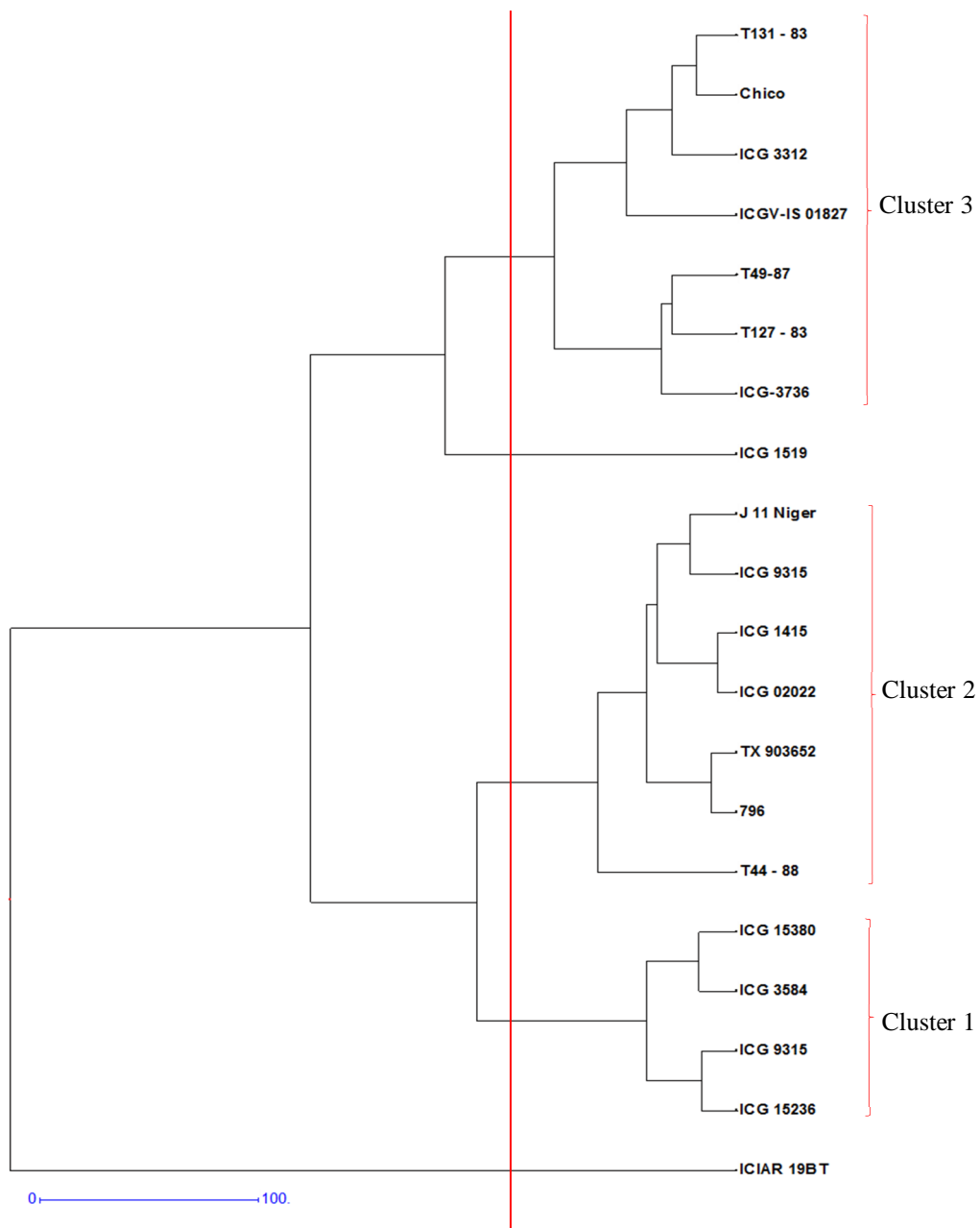
The harvest indices ranged from 0.26 to 0.51. The best 20 genotypes (Table 4.2) based on the maturity were used to draw a dendrogram using DARWIN5 software version 5.0.158 (Figure

4.4). The dendrogram showed three clusters of genotypes depending on the maturity, pod yield, harvest index, biomass weight, percentage of emergence, plant height and 50% plant flowering (Figure 4.4). Out of the best 30%, the top 5 extra early maturing genotypes were selected.

**Table 4. 2:** The top 20 genotypes based on their maturity and their performance for other traits

Ranking	Genotypes	% EMERG 7DAS	ND 50% PF	DM (days)	PY (g)	BIO (g)	HI	PH (cm)
1	Chico	75	24	75	430	900	0.47	39.33
2	ICG 02022	83	24	80	700	1800	0.38	33.33
3	ICG 3584	96	24	80	620	2380	0.26	49.66
4	796	100	24	80	520	1700	0.3	47.33
5	ICIAR 19BT GH	100	24	75	1540	3010	0.51	43.66
6	T127 - 83	58	26	85	480	1340	0.35	51.33
7	ICG-3736	67	26	85	630	1250	0.5	48.66
8	ICG 1415	75	26	85	720	1760	0.4	48.66
9	ICG 15236	67	28	85	540	2570	0.21	50
10	T44 - 88	83	28	85	530	2100	0.34	44.66
11	T49-87	46	28	85	600	1440	0.41	43.33
12	ICG 3312	92	26	85	420	1090	0.38	48.66
13	ICGV-IS 01827	92	26	85	240	830	0.28	47.33
14	T131 - 83	79	26	85	480	985	0.48	49.33
15	ICG 1519	79	24	85	100	520	0.19	47
16	ICG 9315	75	24	85	530	1830	0.28	49.33
17	TX 903652	62.5	26	85	490	1660	0.29	45.33
18	J 11 Niger	100	24	85	580	1930	0.3	45.33
19	ICG 15380	87.5	22	85	550	2320	0.23	42.66
20	ICG 9315	75	24	85	470	2520	0.18	55.33

**% EMERG:** Percentage of emergence, **50% PF:** 50% plant flowering, **DM:** Date to maturity, **PY:** Pod yield, **BIO:** Biomass, **HI:** Harvest index, **PH:** Plant height



**Figure 4.4:** Dendrogram of selected early maturing genotypes

## **4.5. Selection of drought tolerant varieties**

### **4.5.1. Genetic material**

The top 100 intermediate maturing genotypes were selected from the activity, conducted previously in Section 4.4.5., based on their pod yield.

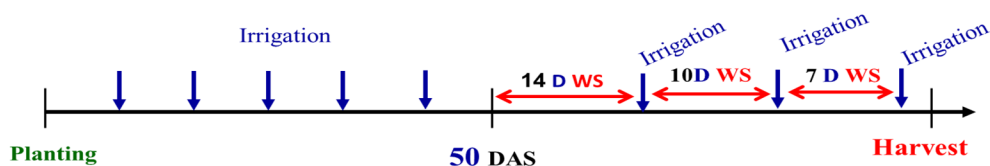
### **4.5.2. Experimental conditions**

Field preparation was done as described in section 4.4.2. The planting day was 21<sup>st</sup> February 2011. The crop was grown in two-row plots on ridges, 2 m long, with spacing of 0.5 m between rows and of 0.20 m between plants (Arunyanark *et al.*, 2010). Seeds were hand planted in two environments (well watered and water stressed conditions) replicated two times in a balanced  $\alpha$ -lattice design (10 x 10). The plot size was 1 m<sup>2</sup> (0.5 m x 2 m), each block contains 10 genotypes. The distance between water regimes (well water and water stress) was 5 m and 5 m between replications. The trial was surrounded by two border rows. Dimethoate (C<sub>5</sub>H<sub>12</sub>NO<sub>3</sub>PS<sub>2</sub>) was applied at 1/ha five times to control aphids and caterpillar attack. Surface irrigation was used to apply water during the experiment.

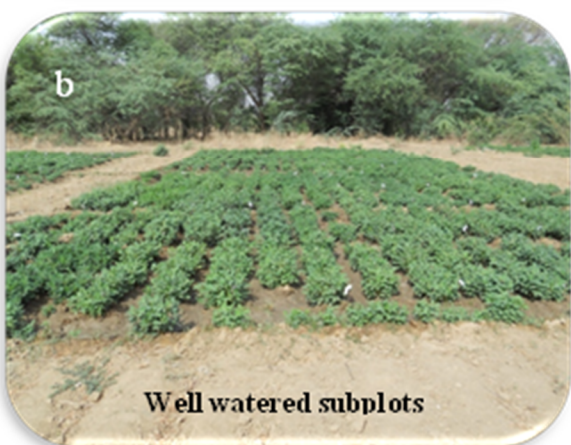
### **4.5.3. Management of irrigation for treatment application**

The experiment was conducted during April, 2011 that is the most critical month with high temperature during the day (average of 40°C) described in Section 4.3.1. After sowing, the crop was irrigated twice a week up to when 50% plants flowed (30 DAS). After that, the plants were maintained fully irrigated until pod filling time by irrigating up to saturation weekly. The plants were exposed gradually to end-of-season drought from the pod filling (50DAS) until maturity. At 50 DAS, which corresponded with peg penetration and pod filling, drought stress was imposed for 14 days and irrigation was resumed at the 15<sup>th</sup> day to bring the soil up to saturation (Plate

4.1a, b, c, d). Then, drought stress was imposed for 10 days, followed by irrigation up to saturation. After that, drought stress was imposed for 7 days followed by irrigation up to harvest (Figure 4.5). The well-watered plots were irrigated fully weekly until harvest stage.



**Figure 4.5:** Drought stress imposition and irrigation frequencies



**Plate 4.1:** Stressed plants versus non stressed plants (a, b); Plants after 2 weeks drought effect and resume irrigation (c, d)

#### 4.5.4. Field day

During harvesting of drought screening experiment, a field day was organized to allow farmers to select drought tolerant genotypes based on their own criteria. A team was composed of six farmers; each was a member of a farmer organization in the 6 villages where the PRA was conducted. The farmers were divided in two groups of three each. Each group selected the best genotypes by using their own criteria in both well watered and water stressed plots (Plate 4.2).



**Plate 4.2:** Farmers selecting genotypes based on their preference criteria

#### 4.5.5. Data collection

The following data were collected:

- The SPAD chlorophyll meter reading [SCMR] Minolta (SPAD-502 meter, Tokyo, Japan) measures the greenness or relative chlorophyll content of leaves. SPAD is defined as soil plant analysis development. However, the leaf transmittance depends not only on the content of

chlorophylls but also on the distribution in leaves. The chlorophyll content was recorded at 45 DAS (before water stress was imposed) and at 60 and 90 DAS to monitor the chlorophyll content. Five plants from each plot were sampled at random, and the second fully expanded leaf from the top of the main stem was used for SCMRs assessment during the morning period (0900±1200h) (Nageswara *et al.*, 2001). The chlorophyll content was recorded on each of the four leaflets of the tetrafoliate leaf. An average SCMR for each plot was derived from 20 single observations (four leaflets x 5 plants per plot) (Arunyanark *et al.*, 2008). While recording the SCMR, care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina in order to avoid interference from veins and midribs (Nageswara *et al.*, 2001).

- Pod Yield (PY): Pod yield was determined from 10 plants selected at random from all the treatments.

- Drought tolerance index (DTI): DTI was calculated for each trait as the ratio of the trait under water stress (WS) treatment to that under well-watered (WW) condition as suggested by Nautiyal *et al.* (2002). DTI for SCMR is as follows:

$$\text{DTI (SCMR)} = \text{SCMR under WS} / \text{SCMR under WW}$$

#### **4.5.6. Statistical Analysis**

Combined analysis of variance was computed for the 100 entries across water regimes (Gomez and Gomez 1984) for pod yield and SCMR (45, 60 and 90 DAS) data using GENSTAT software version 12.0. In the combined analysis, water regimes, replications and blocks were treated as random effects while entries were considered as fixed effects.

#### **4.5.7. Results of drought tolerance screening**

The mean performance of one hundred genotypes for the traits measured under both water regimes is shown in Appendix 3. The best five drought tolerant genotypes were selected based on:

- The highest yielding genotype under water stress condition,
- The highest yielding genotype under well water condition,
- The least yield difference between stressed and non-stressed conditions.

##### **4.5.7.1. Farmers selection of the best genotypes under both water regimes**

The farmers were able to select the best genotypes in terms of haulm production and pod yield. The best genotypes selected were ICG6703 under stressed condition and ICGV-SM99511 under well watered condition. In addition, the genotypes Tainan-9 and ICG11249 were selected based on their good performance under both water regimes. The farmers focused on biomass production as one criterion because this trait adds economic value to the variety.

##### **4.5.7.2. Pod yield and SCMRs of the drought tolerant genotypes**

###### **4.5.7.2.1. ANOVA**

Combined analysis of variance for pod yield and SCMRs are presented in Table 4.3. All the genotypes performed differently in both water regimes due to the significant interaction effect observed between water regimes and genotypes. This implied that the difference between genotypes performances was significantly affected by the water regimes and the water stress effect differed significantly among genotypes. Consequently, the genotypes showed different ranking from one water regime to another for all tested traits.

Nevertheless, highly significant differences were seen among the genotypes for all the traits. The effect of the two water regimes was significant for all traits measured.

**Table 4.3:** Mean square from the combined analysis of variance for pod yield and SCMRs under both water regimes

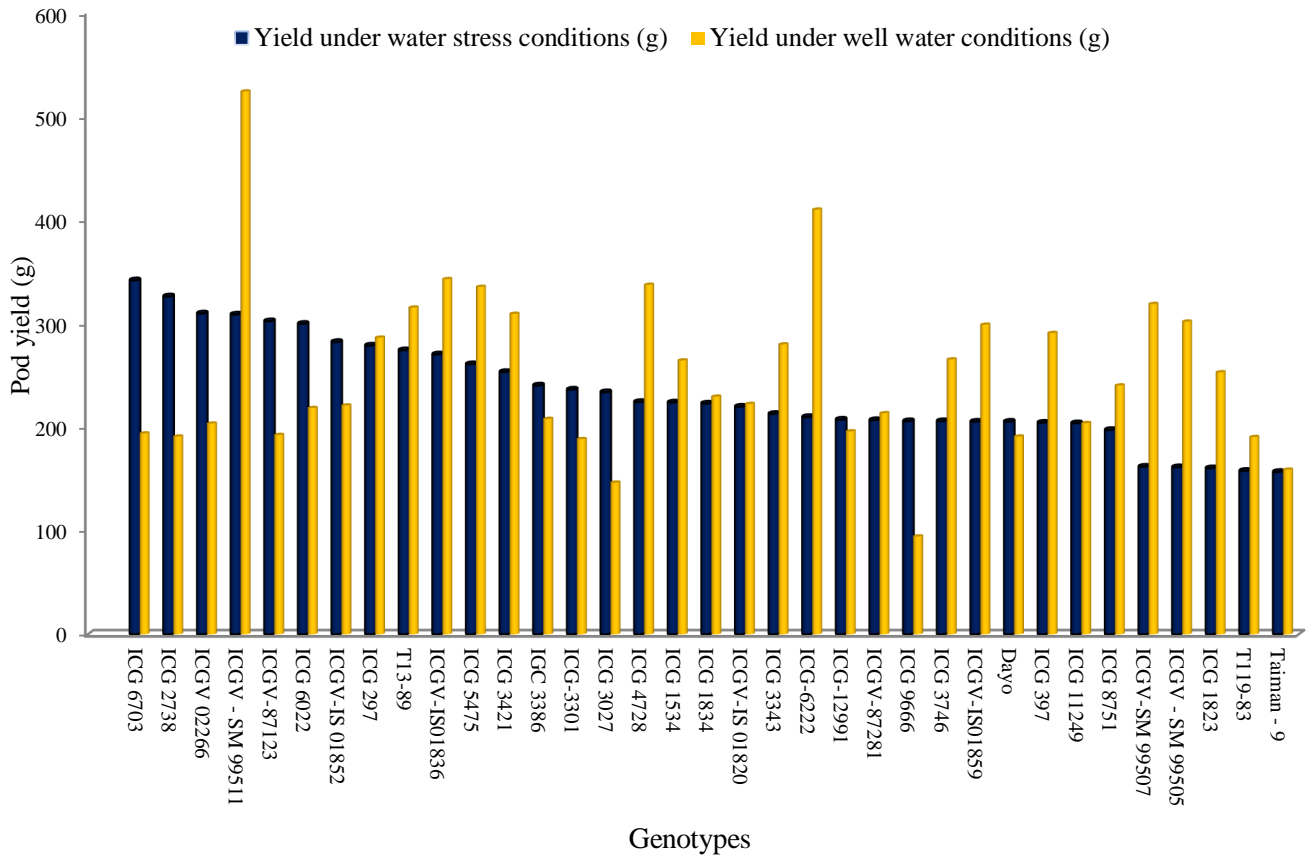
Source of variation	DF	Mean Square			
		PY	SCMR 45DAS	SCMR 60DAS	SCMR 90DAS
Replications	1	129278	188.067	52.95	381.535
Genotypes	98	17134**	17.744**	26.14**	17.669**
Water regimes (Env 1 & 2)	1	328815**	220.207**	892.2**	1760.247**
Genotypes x water regimes	98	7386*	8.77*	12.91*	8.35*
Residual	197	7423	8.071	15.78	7.067
Total	395	10885	11.426	19.7	15.116
<b>Means</b>		<b>165<sup>a</sup>/222.6<sup>b</sup></b>	<b>41.16<sup>a</sup>/39.66<sup>b</sup></b>	<b>47.78<sup>a</sup>/47.77<sup>b</sup></b>	<b>45.97<sup>a</sup>/41.75<sup>b</sup></b>
CV %		<b>46.11</b>	<b>7.03</b>	<b>8.59</b>	<b>6.06</b>
LSD at 5%		<b>169.9</b>	<b>5.603</b>	<b>7.835</b>	<b>5.242</b>

\*\*Significant at  $P \leq 0.01$ , \*Significant at  $P \leq 0.05$ , **a**: under drought stress, **b**: under well water condition, Env: Environment

#### 4.5.7.2.2. Drought effect on pod yield

The genotype ICGV-SM 99511 had the highest yield (524 g) under well watered condition (Table 4.4). However, under end-of-season drought condition, the genotype ICG6307 was the best yielding (342 g) genotype. Interestingly, certain genotypes such as ICGV-IS01836, ICG4728, ICG5475, T13-89, ICGV-SM 99505, and ICGV-SM99511 performed well under both water regimes. Genotypes with least yield difference included Tainan-9, ICGV-IS01820 and ICG11249. Based on the selection criteria defined in section 4.5.7, the five best drought tolerant genotypes were ICG6703, ICGV-SM99551, Tainan-9, ICG11249 and ICGV-IS01820. The drought tolerance index ranged from 0.59 to 1.76 for five selected genotypes. ICG6703 had the highest DTI 1.76 and ICGV-SM 99511 the lowest DTI 0.59. Therefore, ICG6703 was the most

drought tolerant genotype followed by ICG11249, then Tainan-9 and ICGV-IS01820 and finally ICGV-SM 99511. Genotypes pod yield performances are shown in Figure 4.6.



**Figure 4. 6:** Pod yield under well watered (WW) and water stressed (WS) conditions

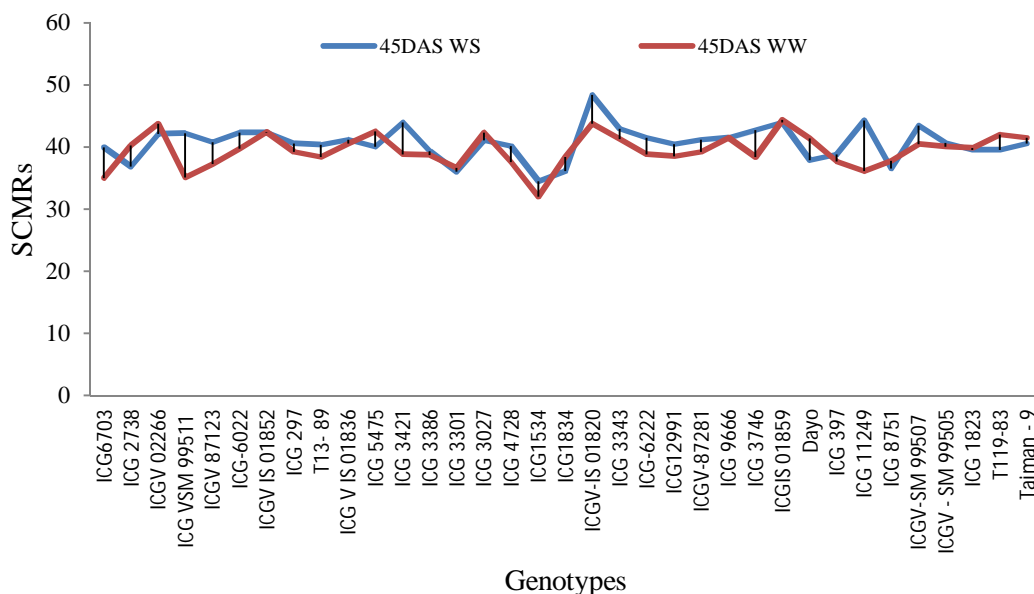
**Table 4.4:** Pod yield of entries under drought stress and their performance under well water conditions and their respective drought tolerance indices

Rank	Entry	Pod yield (g) under WS	Pod yield (g) under WW	Least Pod yield (g) difference	DTI
<b>1</b>	<b>ICG 6703<sup>a</sup></b>	<b>342</b>	194	148	<b>1.76</b>
2	ICG 2738	326.5	191	135.5	1.71
3	ICGV 02266	310	203.5	106.5	1.52
<b>4</b>	<b>ICGV - SM 99511<sup>b</sup></b>	309	<b>524</b>	215	<b>0.59</b>
5	ICGV-87123	302.5	192.5	110	1.57
6	ICG 6022	300	218.5	81.5	1.37
7	ICGV-IS 01852	282.5	221	61.5	1.28
8	ICG 297	279	286.5	7.5	0.97
9	T13-89	274.5	315.5	41	0.87
10	ICGV-IS01836	270.5	343	72.5	0.79
11	ICG 5475	261	335.5	74.5	0.78
12	ICG 3421	253.5	309.5	56	0.82
13	IGC 3386	240.5	208	32.5	1.16
14	ICG-3301	236.5	188.5	48	1.25
15	ICG 3027	234	146.5	87.5	1.6
16	ICG 4728	224.5	337.5	113	0.67
17	ICG 1534	224	264.5	40.5	0.85
18	ICG 1834	223	229.5	6.5	0.97
<b>19</b>	<b>ICGV-IS 01820<sup>c</sup></b>	220	222.5	<b>2.5</b>	<b>0.99</b>
20	ICG 3343	213	280	67	0.76
21	ICG-6222	210	410	200	0.51
22	ICG-12991	207.5	196	11.5	1.06
23	ICGV-87281	207	213.5	6.5	0.97
24	ICG 9666	206	94.5	111.5	2.18
25	ICG 3746	206	265.5	59.5	0.78
26	ICGV-IS01859	205.5	299	93.5	0.69
27	Dayo	205.5	191	14.5	1.08
28	ICG 397	204.5	291	86.5	0.7
<b>29</b>	<b>ICG 11249<sup>c</sup></b>	204	204	<b>0</b>	<b>1</b>
30	ICG 8751	197.5	240.3	42.8	0.82
31	ICGV-SM 99507	162	319	157	0.51
32	ICGV - SM 99505	161.5	302	140.5	0.53
<b>33</b>	<b>Tainan - 9<sup>c</sup></b>	157	159	<b>2</b>	<b>0.99</b>
	<b>LSD 5%</b>	155.17	195.71	-	-
	<b>CV %</b>	47.4	44.3	-	-

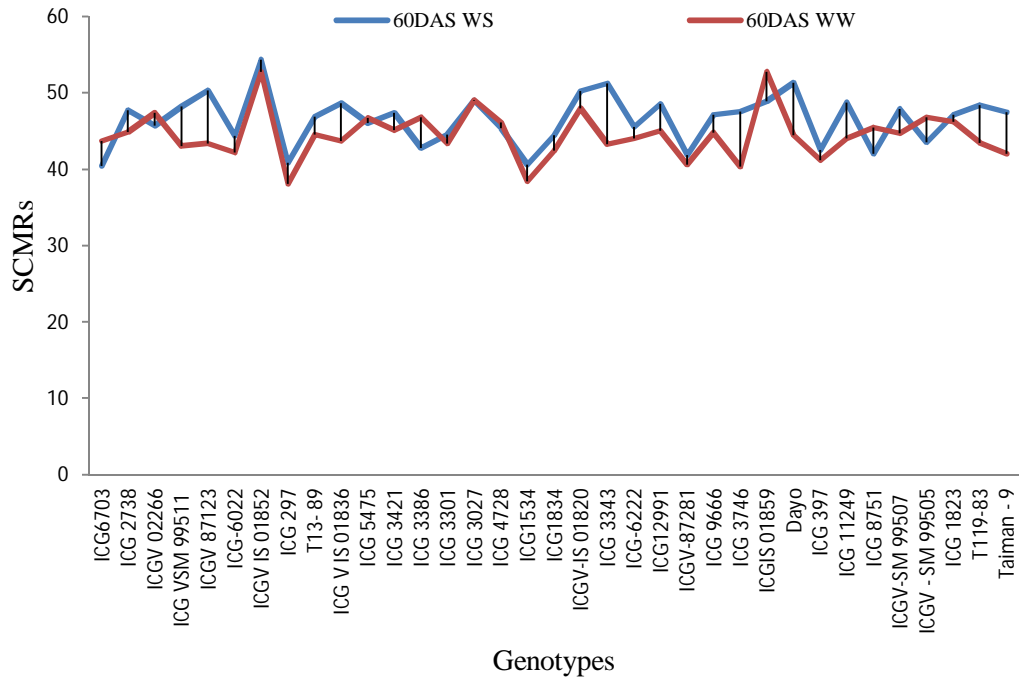
**a:** best high yielding genotype under WS, **b:** best high yielding genotype under WW, **c:** Entries selected based the least yield difference between WW & WS, WW: Well Water, WS: Water stress

#### 4.5.7.2.3. Drought effect on SPAD chlorophyll meter readings

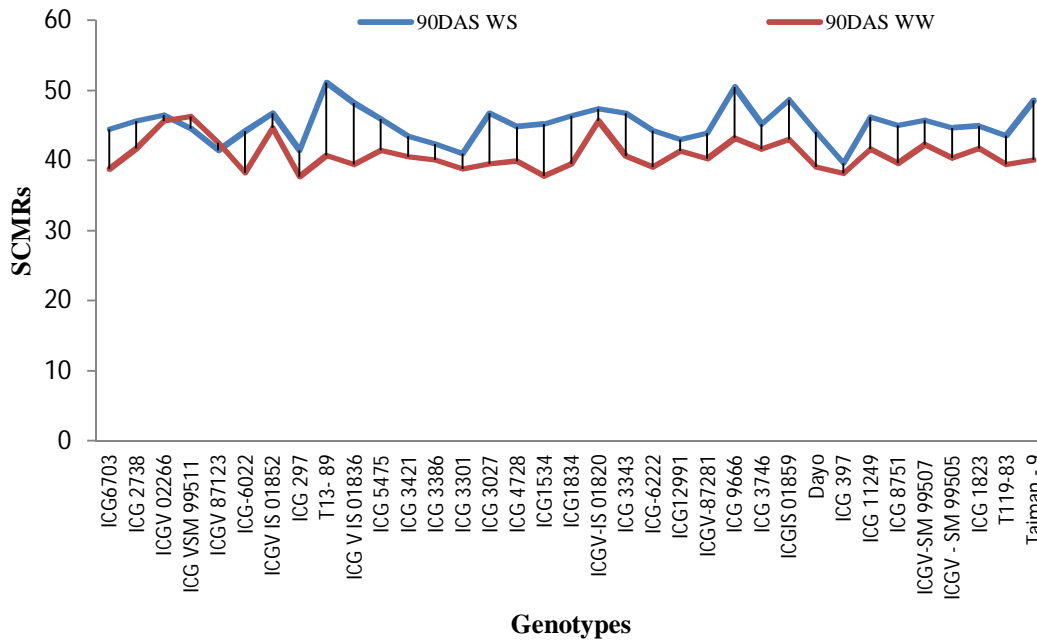
Entries showed significant ( $P < 0.01$ ) differences in chlorophyll content at 45, 60 and 90 DAS, under both water regimes (Table 4.3). The overall means of chlorophyll content under drought stress condition of 41.16, 47.78 and 45.9, respectively, at 45, 60 and 90 DAS were higher than the overall means under irrigated condition, 39.66, 47.77 and 41.75, respectively. There was no genotype by water regimes interaction observed. Under drought condition, ICGV-IS01820 showed the highest SCMR reading (48.4) at 45DAS, followed by ICG11249 (44.3). The genotypes ICGVIS01852 (54.35) and T13- 89 (51.15) showed the highest SCMR reading at 60 and 90 DAS under drought stress condition, respectively. Tainan - 9 had a better SCMR, 48.6, with a rank of 2<sup>nd</sup> at 90D AS. The magnitude of SCMRs was higher at 90 DAS compared to 45 and 60 DAS (Figure 4.7.a, b, c.) Tainan-9 displayed the highest DTI of 1.13, followed by ICGV-SM99511 1.12, and ICG11249 that showed 1.11 at 60 DAS (Table 4.5).



**Figure 4.7a:** Chlorophyll content 45 DAS under WS and WW conditions



**Figure 4.7b:** Chlorophyll content pattern 60 DAS under WS and WW conditions



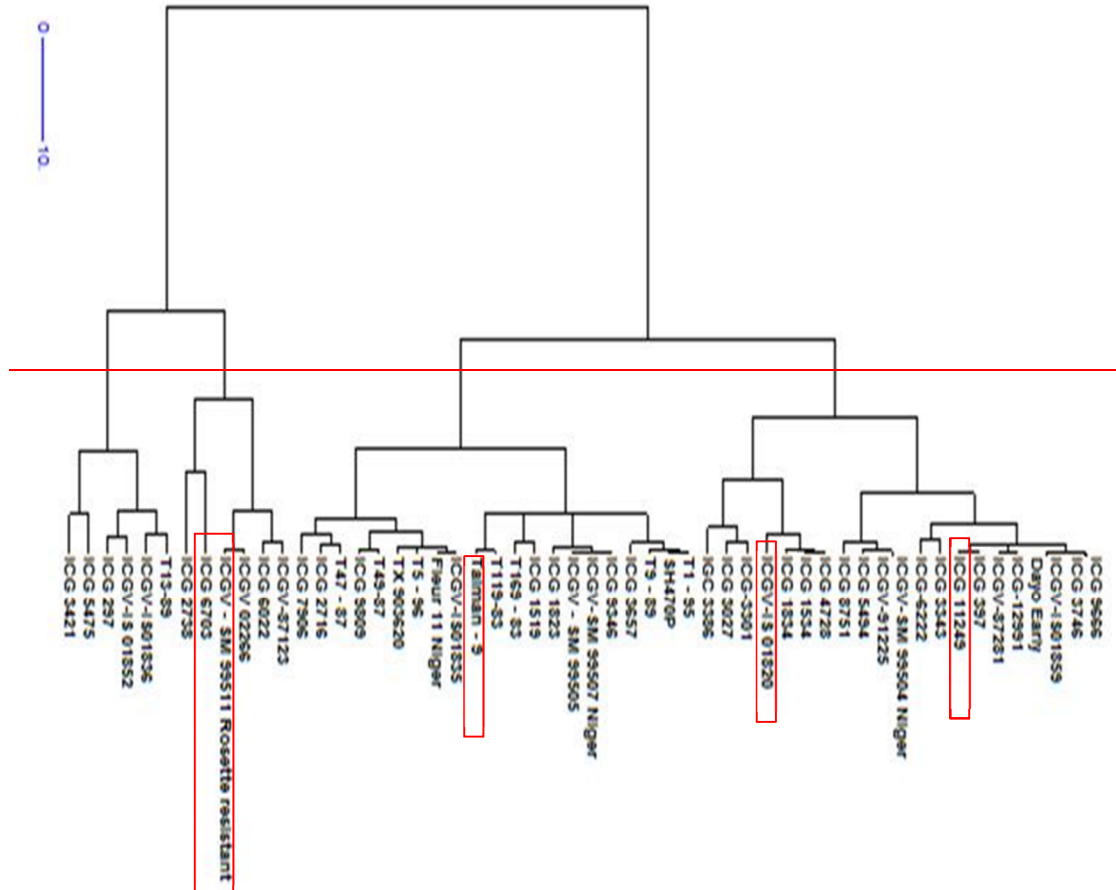
**Figure 4.7c:** Chlorophyll content pattern 90 DAS under WS and WW conditions

The genotypes that had pod yield above 150 g were used to draw a dendrogram using DARWIN5 software version 5.0.158. The five selected drought tolerant genotypes are in three different clusters (Figure 4.8).

**Table 4.5:** Drought tolerance indices of entries at 45, 60 and 90 DAS

<b>Genotypes</b>	<b>DTI SCMR 45DAS</b>	<b>DTI SCMR 60DAS</b>	<b>DTI SCMR 90DAS</b>
<b>ICG6703</b>	<b>1.14</b>	<b>0.93</b>	<b>1.15</b>
ICG 2738	0.91	1.06	1.09
ICGV 02266	0.96	0.96	1.02
<b>ICG VSM 99511</b>	<b>1.2</b>	<b>1.12</b>	<b>0.96</b>
ICGV 87123	1.1	1.06	0.97
ICG-6022	1.07	1.05	1.06
ICGV IS 01852	1	1.03	1.05
ICG 297	1.03	1.07	1.1
T13- 89	1.05	1.05	1.11
ICG V IS 01836	1.02	1.11	1.02
ICG 5475	0.94	0.99	1.11
ICG 3421	1.13	1.05	1.07
ICG 3386	1.02	0.91	1.06
ICG 3301	0.98	1.03	1.06
ICG 3027	0.97	1	1.08
ICG 4728	1.07	0.98	1.12
ICG1534	1.08	1.06	1.02
ICG1834	0.94	1.05	1.17
<b>ICGV-IS 01820</b>	<b>1.1</b>	<b>1.05</b>	<b>1.04</b>
ICG 3343	1.04	1.08	1.05
ICG-6222	1.07	1.03	1.13
ICG12991	1.05	1.08	1.04
ICGV-87281	1.05	1.03	1.09
ICG 9666	1	1.05	1.17
ICG 3746	1.11	1.08	1.08
ICGIS 01859	0.99	0.93	1.13
Dayo	0.92	1.06	1.13
ICG 397	1.03	1.03	1.04
<b>ICG 11249</b>	<b>1.22</b>	<b>1.11</b>	<b>1.11</b>
ICG 8751	0.97	0.92	1.14
ICGV-SM 99507	1.07	1.07	1.08
ICGV - SM 99505	1.01	0.93	1.11
ICG 1823	0.99	1.02	1.08
T119-83	0.94	1.03	1.1
<b>Tainan - 9</b>	<b>0.98</b>	<b>1.13</b>	<b>1.21</b>

**DTI:** Drought tolerance index, **SCMR:** SPAD chlorophyll meter reading



**Figure 4.8:** Dendrogram showing the selected drought tolerant parents based on pod yield

## 4.6. Discussion

### 4.6.1. Early maturity

In this study, two extra early maturing varieties Chico and ICIAR19BT which matured in about 75 days after sowing and three early maturing ICG3584, ICGV02022 and 796 that matured in 80 days after sowing were identified. All selected early maturing varieties reached 50% flowering within 24 days after sowing. Chico is the most widely used source of earliness in several breeding programmes. It was used 1,180 times as a parent in developing early maturity lines at ICRISAT between 1976 to 2002 (Upadhyaya *et al.*, 2006).

Several studies reported Chico as the early maturing variety used to develop new early maturing varieties (N'Doye and Smith, 1993; Ali and Wynne, 1994; Upadhyaya and Nigam, 1994). The variety ICIAR19BT has been released under the name SAMNUT 24 in 2011 as an extra early, high yielding and rosette resistant variety in Nigeria. Most of popular varieties (55-437, RRB and JL24) identified through participatory rural appraisal are intermediate maturing varieties that matured between 90 to 95 days after sowing. Therefore, genes of earliness from the extra early maturing varieties identified in this study can be introgressed into farmers' preferred varieties to improve those varieties for earliness through hybridization.

Days to maturity also determines the differences in pod yield. In general, late maturing genotypes yield better than early maturing genotypes (Culbreath *et al.*, 1999; Padi, 2008). Kotzamanidis *et al.* (2006) found that early maturity in groundnut is associated with narrow pod distance from the main stem, leading to more synchronous maturity of the pods. Jogloy *et al.* (2011) reported that extremely early maturity is not desirable because it is generally associated with yield reduction. However, in this study among the selected early maturing varieties, some varieties exhibited good performance for pod yield. These varieties included ICIAR19BT (1540

g), followed by ICGV02022 (700 g). Chico is the lowest pod yielding variety (430g) which is consistent with all the studies that used Chico as a parental in developing new early maturing varieties. The one hundred and fifty genotypes screened for earliness were classified into three maturity group that are extra early (5), early (29) and intermediate (105) maturing genotypes. The eleven remaining genotypes were not adapted to experimental conditions. The extra early maturing varieties can be used as parental lines to develop new early maturing varieties in a breeding programme by hybridization. Information generated from this screening is useful for creating a mini core collection for further studies.

#### **4.6.2. Drought tolerance**

In this study, some promising groundnut varieties with good performance for pod yield under drought stress (ICG6703) and well watered conditions (ICGV-SM99511) were identified. The varieties Tainan-9, ICG11249 and ICGV-IS 01820 performed well under both conditions. These varieties also showed good performance for SCMRs and showed higher drought tolerance indices for pod yield and chlorophyll content. Farmers' selected three genotypes ICGV-SM99511, ICG6703 and Tainan-9 based on pod yield and biomass production performance under both water regimes. The selected genotypes by the farmers are among the five drought tolerant varieties identified in this study. Therefore, farmers' involvement in this study was very useful because it enabled breeders to take farmers' preferred traits into consideration. Farmers were very happy to be involved in parental lines selection.

Higher DTI values indicate the selected genotypes are drought tolerant (Nautiyal *et al.*, 2002). In this study, the responses to drought among the groundnut genotypes for SCMR at 45, 60 and 90 DAS were rather similar in patterns but somewhat different in extents at 90 DAS. There was no

significant difference among the genotypes for chlorophyll content (Figure 4.7a, b., c). An increase in drought stress period may probably show chlorophyll content difference among the genotypes.

However, an increase in chlorophyll content under drought stress condition based on the increase of SCMR values was observed. Genotypes that showed high values of SCMRs and maintain high biomass production under drought stress may be considered as drought tolerant.

Drought is known to affect chlorophyll content in many crops including wheat (Sarker *et al.*, 1999), and cattail (*Thypha latifolia*) where it inhibits photosynthetic capacity (Epron and Dreyer, 1993). The ability to maintain chlorophyll density under drought stress has been suggested as a drought tolerance mechanism in groundnut (Arunyanark *et al.*, 2008; Sheshshayee *et al.*, 2006). The results are in agreement with Moreshat *et al.* (1996) who found increased the chlorophyll content under mild drought stress. Jongrunklang *et al.* (2008) also found the increase of SCMR of groundnut under water limiting conditions and as this trait is related to photosynthetic capacity, they concluded that the increase of SCMR could be attributed to drought tolerance. However Reddy and Rao (1968) reported that severe drought stress decreased the levels of chlorophyll a, b and total chlorophyll. It could be hypothesized that groundnut genotypes with high SCMR have more photosynthetic machinery per unit leaf area and hence potential for greater assimilation under drought stress (Songsri *et al.*, 2009).

Boontang *et al.*, (2010) found that groundnut genotypes with high SCMR under drought stress could maintain higher biomass production.

Groundnut genotypes showing consistently high SCMRs values across water regimes and sampling dates were ICG-VSM 99511, ICGV87123, ICG6703, ICG 11249, ICGV-IS01820,

Tainan-9, ICGV-IS01852, ICG12991, ICG3386, ICGV-IS01859, ICG9666, T13- 89, ICG3746 and ICG297 (Appendix 3).

In this study, end-of-season drought caused pod yield reduction that varies from genotype to genotype. However, certain genotypes showed least pod yield difference in both water regimes. The varieties Tainan-9, ICG11249 and ICGV-IS01820 that showed least pod yield difference can be used by farmers in the short time as drought tolerant varieties prior to improvement of their popular varieties identified through the PRA study. In a participatory varietal selection conducted by INRAN in three locations in Niger in 2012, farmers in all the locations selected the variety Tainan-9 as the best drought tolerant variety and also high yielding with good biomass production among the varieties evaluated.

#### 4.7. Conclusions

- Two extra early maturing varieties (75DAS) Chico and ICIAR19BT were identified.
  
- Three early maturing varieties (80DAS) ICG3584, ICGV02022 and 796 were selected. These materials can be used as parental lines in a breeding programme to develop early maturing varieties.
  
- ICG6703, ICGV-SM 99511, Tainan-9, ICG11249 and ICGV-IS01820 were selected as drought tolerant material based on their performance for yield and chlorophyll content under well water and end-of-season drought stress conditions. Therefore, these materials can be used as parental lines to develop drought tolerant groundnut varieties.
  
- ICG6703, ICGV-SM 99551, Tainan-9 are the varieties selected by the farmers during the field day.
  
- The varieties ICIAR19BT and ICGV-SM 99511 were the best high yielding among the parental lines.

## CHAPTER FIVE

### 5.0. GENETIC ANALYSIS OF EARLINESS AND DROUGHT TOLERANCE

#### 5.1. Introduction

Early maturing and high yielding cultivars are needed in most all groundnut growing areas to fit into a cropping system involving two crops a year, and to escape natural hazards such as drought and diseases. Improvement of drought tolerance in groundnut would be beneficial in rainfed regions where drought is a major constraint limiting productivity and quality. End-of- season drought is the most prevalent type in the major groundnut growing agroclimatic semi-arid environments. It occurs during the pod filling phase of groundnut (Nageswara *et al.*, 1985; Wright *et al.*, 1994; Ndunguru *et al.*, 1995). Therefore, breeding for end-of-season drought tolerance can increase productivity in drought-prone environments and reduce aflatoxin contamination.

With new knowledge of easily measurable surrogates of transpiration efficiency (TE), a trait associated with drought tolerance, specific leaf area (SLA) and soil plant analytical development (SPAD) chlorophyll meter readings (SCMR), it is now possible to integrate TE through the surrogates in breeding and selection schemes in groundnut (Nigam and Aruna, 2008). SCMR is an indication of the light-transmittance characteristics of the leaf which is dependent on the leaf chlorophyll content (Richardson *et al.* 2002). As a noninvasive surrogate of TE, SCMR is easy to operate, reliable, fairly stable and low cost (Sheshshayee *et al.*, 2006). Recent studies indicated that specific leaf area (SLA) and soil plant analytical development (SPAD) chlorophyll meter reading (SCMR), that are easy to measure, are highly correlated with TE (Sheshshayee *et al.*, 2006). Both traits (SLA, SCMR) have considerable genetic variation in groundnut (Upadhyaya 2005; Lal *et al.*, 2006; Sheshshayee *et al.*, 2006). Positive relationship between TE and SCMR

has been reported (Bindu Madhava *et al.*, 2003; Sheshshayee *et al.*, 2006). Nageswara *et al.* (2001) and Upadyaya (2005) found a significant negative correlation between SCMR and SLA and suggested that this chlorophyll meter could be used as a rapid and reliable measure to identify genotypes with high water use efficiency in groundnut. SCMR is reported to be more stable than SLA (Upadhyaya, 2005). It is also correlated with pod yield in groundnut (Reddy *et al.*, 2004; Upadhyaya 2005). Harvest index, has also been found to be correlated with SLA and SCMR under both well-watered and long-term drought conditions (Songsri *et al.*, 2008).

The concept of combining ability is important in designing plant breeding programmes. It is especially useful in testing procedures used to study and compare the performance of lines in hybrid combinations. Combining ability in crosses is defined as the ability of parents or cultivars to combine amongst each other during the process of hybridization so that favorable genes/characters are transmitted to their progenies (Panhwar *et al.*, 2008). Specific combining ability is defined as the deviation in the performance of hybrids from the expected productivity based upon the average performance of lines involved in the hybrid combinations, whereas general combining ability is defined as average performance of a line in a series of crosses (Griffing, 1956; Falconer and Mackey, 1996). According to Sprague and Tatum (1942), general combining ability is due to genes which are largely additive in their effects and specific combining ability is due to the genes with dominance or epistatic effects. Rawlings and Thompson (1962) used line x tester analysis to estimate GCA and SCA of inbred parents.

Since the development of new cultivars through hybridization is a continuous process, information on combining ability of new cultivars remains important.

Estimates of heritability from segregating populations are useful in understanding the genetics of hybridization and inbreeding (Ali and Wynne, 1994). They can help breeders in selecting and utilizing superior individuals from a population. Heritability in the narrow sense is important, because the effectiveness of selection depends on the additive portion of genetic variance in relation to total variance (Fernandez and Miller, 1985). The parent-offspring regression method is commonly used to compute heritability estimates of quantitative characters in both self- and cross-fertilizing crops (Fernandez and Miller, 1985). Some of the routinely used parent-offspring combinations in self-fertilizing crops are:  $F_1/F_2$ ,  $F_2/F_3$ , and  $F_3/F_4$ , (Smith and Kinman 1965). To develop the desired population for earliness and drought tolerance, knowledge of the combining abilities of lines is very important in selecting parents. Efficient utilization of the physiological traits for improving drought tolerance requires an understanding of the inheritance of the target traits. The present studies were carried out to estimate the combining ability and heritability of selected parents for earliness and drought tolerance traits for effective selection and use in a groundnut breeding programme.

## **5.2. Material and methods**

### **5.2.1 Experimental site**

The experimental site was INRAN Maradi that is located in the south-central part of the country (Chapter IV: Section 4.2). Soil has a pH of 6.5 and contains 12% clay, 5% loam, 4% coarse silt, 77% sand and 2% organic matter (Raynaut *et al.*, 1984).

### 5.2.2. Genetic material and hybridization techniques

The genetic material included three farmers' preferred varieties 55-437, RRB and JL24 from the PRA and five early maturing (Chico, ICIAR19BT, 796, ICG3584, ICGV02022) and five drought tolerant (ICG6307, ICGV-SM99511, Tainan-9, ICGV-IS01820, ICG11249) varieties selected from germplasm screening in Chapter IV (Table 5.1). The three farmers preferred varieties were crossed with each set of material (earliness and drought tolerance) in a 3 x 5 North Carolina II mating design to generate 15F1s in the case of earliness and 15F1s of drought tolerance combination given a total of 30F1s. Ten lines of groundnut *viz.*, ICGV02022, ICG3584, Chico, ICIAR19BT, 796, ICGV-SM99511, Tainan-9, ICG11249, ICGV-IS01820 and ICG6703 (female parents) and three testers 55-437, JL24 and RRB (male parents) were crossed in July, 2010 at Tarna INRAN station. Before planting, the field was prepared as described previously in Chapter IV (section 4.4.2). Three rows 5 m long with 1 m between rows and 1 m spacing between hills were hand planted with female parents from the earliness and drought tolerant groups. One seed was planted per hill; each plot contained 15 plants. Each male parent was planted in one row of 25 plants along each two of the female parent. Seven days after planting, missing stands were replanted. Standard cultural practices were applied to keep the field free of weeds and pests. The crossing blocks were replicated two times to increase the F1 seeds. Necessary precautions were taken to avoid the contamination of genetic material at the time of crossing. Hand emasculation of the flower buds and pollination were made by skilled workers under the supervision of researcher. Pollination commenced on July 27, 2010 and lasted for about one month. Five to seven crosses were made on each individual female to increase hybrids seeds. The crosses were harvested during the first week of October 2010. F1Seed set ranged from 3 to 40 for the different combinations of parents.

Ten F<sub>1</sub> seeds of each cross combination along with their parents were hand planted in an unreplicated trial during 2011 off-season. Inter-plant and inter-row spacing were maintained at 0.25 and 0.75 m, respectively. One seed per hole were sown. The experimental population was kept under normal agronomic care from sowing to maturity. At harvest, All F<sub>1</sub> plants were carefully examined for several morphological traits such as number of stem, plant height, leaf color, pod and seed characters and compared with both parents to confirm their hybridity. Out of the 30 F<sub>1</sub>s generated, based on the results of the hybridity test, seven F<sub>1</sub> hybrids of early maturing combinations and seven F<sub>1</sub> hybrids of drought tolerance were selected. The names of the crosses are indicated below:

- |  |   |
|--|---|
| - <b>Early maturity F<sub>1</sub>s</b> | - <b>Drought tolerance F<sub>1</sub>s</b> |
| - ICG 3584 x 55 - 437                  | - ICGV-SM 99511 x 55- 437                 |
| - ICG 3584 x JL24                      | - Tainan-9 x 55- 437                      |
| - ICIAR 19BT x 55 - 437                | - Tainan-9 x JL24                         |
| - ICIAR19BT x RRB                      | - Tainan-9 x RRB                          |
| - 796 x JL24                           | - ICG 11249 x 55- 437                     |
| - 796 x RBB                            | - ICG 11249 x JL 24                       |
| - Chico x RRB                          | - ICG 11249 x RBB                         |

Individual plants were selected from the segregating F<sub>2</sub> populations. Seeds of selected F<sub>2</sub> were planted as bulks to produce F<sub>3</sub> seeds in an unreplicated trial. Similar procedure was followed to produce F<sub>4</sub> seeds following bulk method of selection.

**Table 5.1:** Early maturity and drought tolerant parental lines

Parental lines	Days to maturity	Growth habit	Botanical variety	Origin
<b>Male</b>				
JL 24 (ICG 7827)	90-95	Erect	<i>Vulgaris</i>	India
RRB	90-95	Erect	<i>Spanish</i>	Nigeria
55-437	90	Erect	<i>Spanish</i>	Hungary
<b>Female</b>				
<b>Early maturity</b>				
Chico (ICG 476)	75	Erect	<i>Vulgaris</i>	USSR
ICIAR19BT	75	Erect	<i>Spanish</i>	Nigeria
ICG 3584	80	Erect	<i>vulgaris</i>	India
ICGV 02022	80	Erect	<i>fastigiata</i>	ICRISAT
796	80	Erect	-	Russia
<b>Drought tolerant</b>				
Tainan-9	110	Erect	<i>Spanish</i>	Thailand
ICGV-SM99511	95	Erect	-	ICRISAT
ICG11249	90	Erect	<i>Spanish</i>	Tanzania
ICG6703	95	Erect	<i>hypogaea</i>	Paraguay
ICGV-IS01820	110	Erect	-	ICRISAT

### 5.2.3. Evaluation of populations for earliness and drought tolerance

#### 5.2.3.1. Field experiments

Field experiment was fully described in Chapter IV, Section 4.4.2. The seven crosses in the F<sub>3</sub> populations and their parents were evaluated at Tarna INRAN station. The treatments of 27 entries (Table 5.2) were arranged in a randomized complete block design (RCBD) in three replications.

**Table 5. 2:** Early maturity and drought tolerant parental lines and F<sub>3</sub> populations

Entry	Early maturity	Entry	Drought tolerant
	<b>F<sub>3</sub> populations</b>		<b>F<sub>3</sub> populations</b>
1	ICG3584 x 55 - 437	15	ICGV -SM 99511 x 55 - 437
2	ICG3584 x JL24	16	ICG11249 x 55 - 437
3	ICIAR19BT x 55 - 437	17	ICG11249 x JL24
4	ICIAR19BT x RRB	18	ICG11249 x RRB
5	796 x JL24	19	TAINAN -9 x 55 - 437
6	796 x RRB	20	TAINAN -9 x JL24
7	Chico x RRB	21	TAINAN -9 x RRB
	<b>Parents</b>		<b>Parents</b>
8	ICG3584	22	55 - 437
9	ICIAR19BT	23	JL24
10	796	24	RRB
11	Chico	25	ICGV -SM 99511
12	55 - 437	26	ICG11249
13	JL24	27	TAINAN -9
14	RRB		

F<sub>3</sub> and F<sub>4</sub> populations were also evaluated at Tarna INRAN station. The treatments of 14 entries (Table 5.3) were arranged in a randomized complete block design in three replications. Drought tolerant entries (14) were planted in in  $\alpha$  lattice design replicated three times in two environments (well watered and water stressed conditions). Water regimes treatments were described in Chapter IV, Section 4.5.3. Plant and rows spacing were 25 and 100cm respectively. Two row plots of 10 seeds each were hand planted. The plot size was 2.5m<sup>2</sup> (2.5m x 1m). All recommended cultural practices were done during the experiment. The experiment was harvested 90 days after sowing.

**Table 5.3:** Entries used to estimate Narrow sense heritability

Entry	Early maturity	Entry	Drought tolerant
	<b>F<sub>3</sub> populations</b>		<b>F<sub>3</sub> populations</b>
1	ICG3584 x 55 - 437	15	ICGV -SM 99511 x 55 - 437
2	ICG3584 x JL24	16	ICG11249 x 55 - 437
3	ICIAR19BT x 55 - 437	17	ICG11249 x JL24
4	ICIAR19BT x RRB	18	ICG11249 x RRB
5	796 x JL24	19	TAINAN -9 x 55 - 437
6	796 x RBB	20	TAINAN -9 x JL24
7	Chico x RRB	21	TAINAN -9 x RRB
	<b>F<sub>4</sub> populations</b>		<b>F<sub>4</sub> populations</b>
8	ICG3584 x 55 - 437	22	ICGV -SM 99511 x 55 - 437
9	ICG3584 x JL24	23	ICG11249 x 55 - 437
10	ICIAR19BT x 55 - 437	24	ICG11249 x JL24
11	ICIAR19BT x RRB	25	ICG11249 x RRB
12	796 x JL24	26	TAINAN -9 x 55 - 437
13	796 x RBB	27	TAINAN -9 x JL24
14	Chico x RRB	28	TAINAN -9 x RRB

### 5.2.3.2. Data collection

#### 5.2.3.2.1. Early maturity

A sample of 50 pods was collected from each plot in each replication. In order to reduce sampling error, two to three pods were taken at random from each plant rather than taking pods from the bulk plot. Data for the eight traits recorded were:

- Emergence % (7DAS),
- 50% plants flowering,
- Length of 20 pods (cm),
- Weight of 50 pods (g),
- Number of seeds in 50 pods,
- Weight of seeds in 50 pods (g),

- Number of pods in each of 5 maturity classes (MC) based upon inner hull color ranging from white to black (white = MC1, Yellow = MC2, light brown = MC3, dark brown = MC4 and black = MC5). 1, 2, 3, 4 and 5 are Maturity classes.

A sample of 50 pods were shelled and rated for maturity. From the recorded data, the following variables were computed:

$$\text{Shelling \%} = \frac{\text{Weight of seeds in 50 pods}}{\text{Weight 50 pods}} \times 100$$

$$\text{Maturity index} = (\text{MC1} \times 1) + (\text{MC2} \times 2) + (\text{MC3} \times 3) + (\text{MC4} \times 4) + (\text{MC5} \times 5)$$

For the maturity index, pods in each class were multiplied by its class number and summed.

Higher values of maturity index reflect earlier maturity (Ali *et al.*, 1995).

#### **5.2.3.2.2. Drought tolerance**

Observations were recorded on fifteen plants selected at random among parents and F<sub>3</sub> population. Recommended agronomic and plant protection measures were adopted during the experiment.

Data measured were:

- Days to 50% plants flowering,
- SPAD chlorophyll meter reading at 60 and 80DAS (SCMR),
- Pod yield,
- Biomass,
- Harvest index (HI),
- Drought tolerance index defined as the ratio of trait value measured under water stressed conditions over value recorded under well watered conditions was computed for HI, biomass, pod yield and SCMR. High DTI values indicate drought tolerance and vice versa.

### 5.2.3.3. Data analysis

Analysis of variance (ANOVA) was computed for the entries according to randomized complete block design using PROC GLM in SAS (version 9.2) considering entries as fixed effects, and replications and blocks within replications as random effects. Analysis of variance for traits measured was done separately (Gomez and Gomez, 1984). Combined analysis of variance of two water regimes data was done. Least square difference (LSD) at  $P = 0.05$  was used to compare means. Mean squares caused by difference among crosses were partitioned into difference due to male parents and female parents, which was attributed to general combining ability (GCA), and difference due to male x female interaction, which was attributed to specific combining ability (SCA). In case of the presence of significant GCA and SCA mean squares, GCA and SCA effects were calculated using the method described by Simmonds (1979). Crosses evaluation data were analyzed by regression analysis to estimate the narrow sense heritability by using GenStat 12th Edition software.

The genetic model is as follows:

$$X = \mu + GCA_P + GCA_Q + SCAPQ$$

- Where; X is the true mean of a cross between lines P and Q;
- $\mu$  is the mean of all crosses and GCA and SCA are general and specific combining abilities, respectively.
- The error term was assumed to be zero. If it is present, it should be associated with GCA and SCA effects.

The mathematical model for NCDII is as follows:

$$Y_{ijkl} = \mu + m_i + f_j + (mf)_{ij} + e_{ijkl}$$

- $Y_{ijk}$  is the observed value of the progeny of the  $i^{\text{th}}$  male crossed with  $j^{\text{th}}$  female in the  $k^{\text{th}}$  replication;

- $\mu$  is the overall population mean;
- $m_i$  is the effect of the  $i^{\text{th}}$  mother (effect of the general combining ability of the  $i^{\text{th}}$  mother);
- $f_j$  is the effect of the  $j^{\text{th}}$  father mated to the  $i^{\text{th}}$  mother (effect of the general combining ability of the  $j^{\text{th}}$  father);
- $(mf)_{ij}$  is the interaction effect between the  $i^{\text{th}}$  mother and the  $j^{\text{th}}$  father (effect of the specific combining ability of the  $i^{\text{th}}$  mother and the  $j^{\text{th}}$  father);
- $e_{ijk}$  is the experimental error.

**Table 5. 4:** ANOVA in NC Design II

Source of variation	Degree of freedom	Mean square	Expected MS
Replication	r-1		
GCA <sub>Male</sub>	m-1	MSm	$\sigma_e^2 + r\sigma_{fm}^2 + rf\sigma_m^2$
GCA <sub>Female</sub>	f-1	MSf	$\sigma_e^2 + r\sigma_{fm}^2 + rm\sigma_f^2$
SCA = Male x Female	(m-1)(f-1)	MSmf	$\sigma_e^2 + r\sigma_{fm}^2$
Error	mf(r-1)	MSe	$\sigma_e^2$

**Source:** (Kearsey and Pooni, 1996)

### Estimating variance components in NCDII

- $\sigma_e^2$  = variation within full sibs = environmental variance
- $\sigma_f^2$  = variation between females = GCAf variance
- $\sigma_m^2$  = variation between males = GCAm variance
- $\sigma_{fm}^2$  = variation due to interaction between females and males = SCA variance

From ANOVA table:

- $\sigma_m^2 = (MSm - MSmf)/fr = \text{covHS} = 1/4 \sigma_A^2$
- $\sigma_f^2 = (MSf - MSmf)/mr = \text{covHS} = 1/4 \sigma_A^2$

From the foregoing genetic variances can be estimated as follows:

- $4\sigma_m^2 = 4\text{covHS} = \sigma_A^2$
- $4\sigma_f^2 = 4\text{covHS} = \sigma_A^2$
- $4\sigma_{mf}^2 = 4(\text{covFS} - 2\text{covHS}) = \sigma_D^2$

- where  $\sigma_A^2$  and  $\sigma_D^2 = VA$  and  $VD =$  additive and dominance variances, respectively

### Estimating narrow sense heritability

Using variance ratios as follows:

- Based on female additive variance
- $h_f^2 = 4\sigma_f^2 / (\sigma_e^2 + 4\sigma_{mf}^2 + 4\sigma_f^2) = V_{Af} / V_P$

### Estimate of GCV and PCV

$$GCV = \frac{\sqrt{\sigma_G^2}}{\bar{X}} \times 100, \quad PCV = \frac{\sqrt{\sigma_P^2}}{\bar{X}} \times 100$$

Correlations among traits were determined by Pearson correlations by using GenStat version 12.0.

## 5.3. Results

### 5.3.1. Earliness

#### 5.3.1.1. ANOVA

Results showed that the parental lines and  $F_3$  populations differed significantly for all the traits except for percentage of emergence and number of days 50% plants flowering (Table 5.5).

**Table 5. 5:** Mean squares from ANOVA for parental lines and  $F_3$  populations

Source of variation	DF	EMERSD	NDFTPF	WFTP	WSFTP	NSFTP	SH	PL	MI
Replication	2	100.59	0.74	25.5	27.46	27.59	18.73	0.009	3633.16
Entry	13	164.33	2.33	90.50**	44.24**	32.44*	27.90*	0.09**	1527.25*
Error	26	187.13	1.27	23.46	15.23	14.67	11.62	0.005	631.16

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , %EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

Mean squares from the ANOVA for F<sub>3</sub> and F<sub>4</sub> populations are shown in Table 5.6. The crosses responded similarly for days to emerge, 50% plants flowering, seed number and maturity index. Whereas the two populations differed significantly for pod yield, shelling percentage, seed weight and pod length.

**Table 5.6:** Mean squares from ANOVA for F<sub>3</sub> and F<sub>4</sub> populations for eight traits

Source of variation	DF	EMERSD	NDFTPF	WFTP	WSFTP	NSFTP	SH	PL	MI
Replication	2	100.59	0.74	25.5	27.46	27.59	18.73	0.009	3633.16
Entry	13	46.4	4.33	57.18***	36.28***	5.6	12.31**	0.029*	430.6
Residual	28	103.6	3.92	10.97	7.36	10.64	4.194	0.012	421.8

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , \*\*\*significant at  $P \leq 0.001$ , %EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

### 5.3.1.2. Mean performance

The crosses Chico x RRB, ICIAR19BT x RRB and ICIAR19BT x 55-437 showed the highest values of maturity indices of 223.33, 218 and 214.67, respectively indicating early maturity (Table 5.7). The cross ICG3584 x JL24 showed the lowest maturity index value (178.33). Fifty percent plants flowering was reached in 28 DAS for the cross 796 x RRB, followed by the crosses ICIAR19BT x RRB and ICIAR19BT x 55-437 in 28.33 DAS. The cross ICG3584 reached 50% plants flowering in 30DAS. In terms of pod weight, the cross ICIAR19BT x 55-437 showed the highest value 45.03g while Chico x RRB showed the lowest value 30.6g. The highest value of shelling percentage was obtained with the cross ICG3584 x JL24 (74.82%) followed by ICIAR19BT x 55-437 (70.82). The hybrid ICIAR19BT x 55-437 showed good performance for both agronomic and earliness traits.

**Table 5.7:** Mean performance of parental lines and F<sub>3</sub> populations

Entries	%EMERSD	NDFTPF	WFTP	WSFTP	NSFTP	SH	PL	MI
<b>JL24</b>	83.33	29.33	47.8	31.63	101.33	66.14	2.85	177
<b>RRB</b>	71.67	30.67	44.07	27.53	99.67	62.13	2.45	189.67
<b>55-437</b>	58.33	30.67	32.27	21.07	100.33	65.24	2.15	146
<b>796</b>	81.67	29.67	37.17	25.17	94.67	67.87	2.19	177.33
<b>Chico</b>	70	29.67	31.33	20.13	99.67	64.16	2.28	218
<b>ICG3584</b>	68.33	30	37.07	24.93	100	66.75	2.2	175.67
<b>ICIAR 19BT</b>	78.33	28.33	43.8	30.47	100	69.49	2.41	213.33
<b>F3: 796 X JL24</b>	61.67	29.67	38.9	26.67	107.67	68.37	2.33	210.33
<b>F3: 796 X RRB</b>	70	28	42.83	29.2	99.33	68.2	2.34	193.67
<b>F3: Chico X RRB</b>	70	28.67	30.6	21.17	100.67	69.16	2.23	223.33
<b>F3: ICG 3584 X JL24</b>	76.67	29	36.07	26.93	93	74.82	2.21	178.33
<b>F3: ICG 3584 X 55-437</b>	61.67	30	41.13	28.1	99.67	67.98	2.26	204.33
<b>F3: ICIAR19BT X RRB</b>	75	28.33	43.73	29.2	100	66.55	2.48	218
<b>F3: ICIAR19BT X 55-437</b>	71.67	28.33	45.03	31.9	101.33	70.82	2.4	214.67
<b>Mean</b>	71.31	29.31	39.41	26.72	99.81	67.69	2.34	195.69
<b>Range</b>	58.33 - 83.33	28.00 - 30.67	30.60 - 47.80	20.13 - 31.90	93.00 - 107.67	62.13 - 74.82	2.15 - 2.85	146.00 - 223.33
<b>LSD</b>	22.96	1.9	8.13	6.55	6.43	5.72	0.12	42.17
<b>CV (%)</b>	19.18	3.85	12.28	14.6	3.83	5.03	3.16	12.83

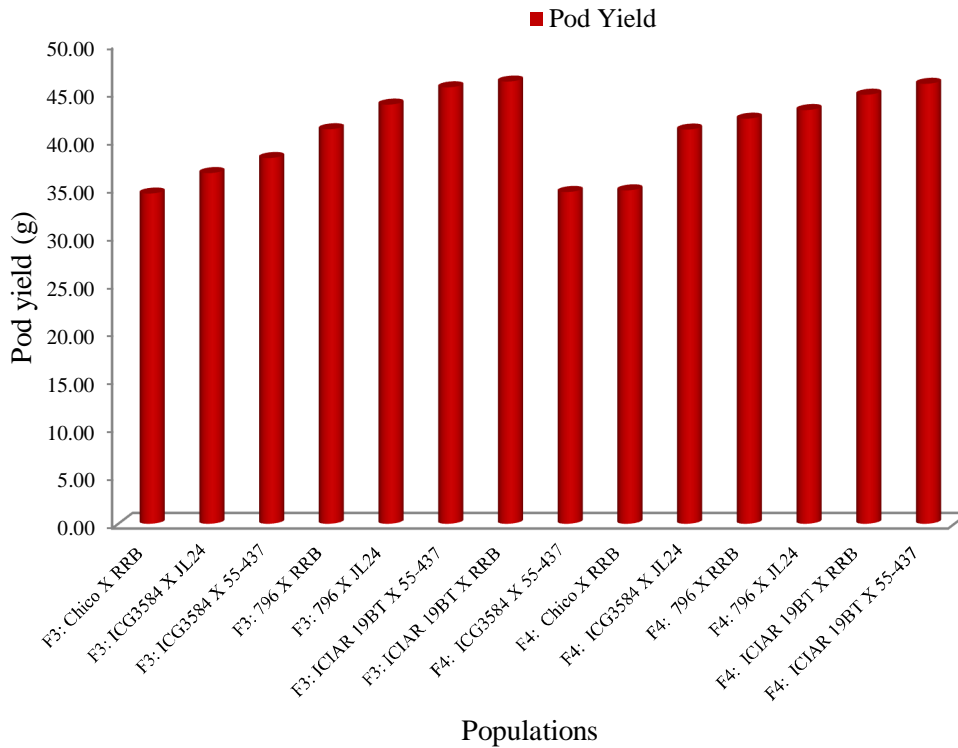
%EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

Results of F<sub>3</sub> and F<sub>4</sub> populations' performance for eight traits are presented in Table 5.8. The crosses F<sub>3</sub>: ICIAR19BT X RRB, F<sub>3</sub>: ICIAR19BT X 55-437, F<sub>3</sub>: 796 X RRB, F<sub>3</sub>: 796 X JL24 and their corresponding F<sub>4</sub> populations exhibited the highest means of pod weight and maturity index. The responses of F<sub>3</sub> and F<sub>4</sub> populations for pod yield (Figure 5.1) and maturity index (Figure 5.2) were rather similar in patterns but somewhat different in extents. However, the crosses F<sub>3</sub>: ICIAR19BT X RRB, F<sub>3</sub>: ICIAR19BT X 55-437, F<sub>3</sub>: 796 X RRB, F<sub>3</sub>: 796 X JL24, and their corresponding F<sub>4</sub> generation displayed similarity in patterns and extents for pod weight and maturity index. The cross Chico X RRB showed good mean performance for maturity index in both populations.

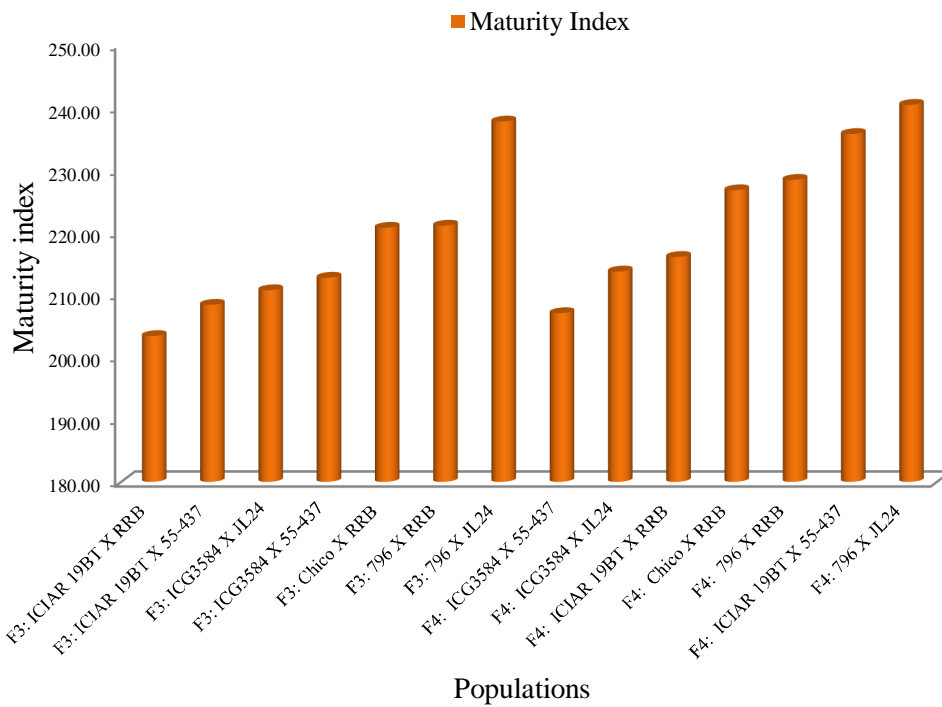
**Table 5.8:** Range and mean of F<sub>3</sub> and F<sub>4</sub> groundnut populations for eight traits

Populations	%EMER7DAS	NUDFTPF	WFTP	NSFTP	WSFTP	SH	PL	MI
<b>F3: 796 X JL24</b>	80	32	43.67	98	31.97	73.21	2.35	237.67
<b>F3: 796 X RRB</b>	76.67	33	41.1	100	27.93	68.03	2.41	221
<b>F3: Chico X RRB</b>	78.33	32.67	34.4	99	24.07	69.83	2.34	220.67
<b>F3: ICG3584 X 55-437</b>	76.67	33	38.1	98.33	25.97	68.12	2.26	212.67
<b>F3: ICG3584 X JL24</b>	78.33	33.33	36.53	95.67	25.6	69.99	2.23	210.67
<b>F3: ICIAR19BT X 55-437</b>	76.67	31.67	45.47	100	33.07	72.69	2.4	208.33
<b>F3: ICIAR 19BT X RRB</b>	70	32	46.07	99	32.47	70.48	2.49	203.33
<b>F4: 796 X JL24</b>	85	34	43.1	101.33	30.37	70.52	2.41	240.33
<b>F4: 796 X RRB</b>	80	30.33	42.2	99	28.27	66.96	2.47	228.33
<b>F4: Chico X RRB</b>	83.33	32	34.73	99	24.7	71.01	2.34	226.67
<b>F4: ICG3584 X 55-437</b>	76.67	34.67	34.57	100	23.3	67.05	2.19	207
<b>F4: ICG3584 X JL24</b>	81.67	34	41.07	99.67	29	70.59	2.5	213.67
<b>F4: ICIAR19BT X 55-437</b>	83.33	31	45.83	98.67	33.33	72.72	2.41	235.67
<b>F4: ICIAR19BT X RRB</b>	75	32.33	44.7	97.33	30.83	68.91	2.49	216
<b>Mean</b>	78.7	32.57	40.82	98.93	28.63	70.01	2.379	220.1
<b>Range</b>	70-85	30.33-34.67	34.40-46.07	95.67-101.33	23.30-33.33	66.96-73.21	2.19-2.50	203.33-240.33
<b>LSD 5%</b>	17.02	3.315	5.539	5.456	4.538	3.425	0.1825	34.35
<b>CV %</b>	12.9	6.1	8.1	3.3	9.5	2.9	4.6	9.3

%EMERSD: % of Emergence 7DAS, **NUDFTPF**: Number of days 50% plant flowering, **WFTP**: Pod weight, **WSFTP**: Seed Weight, **NSFTP**: Number of seed, **SH**: shelling %, **PL**: pod length, **MI**: Maturity index



**Figure 5.1:** Pod yield of F<sub>3</sub> populations and their corresponding performance in F<sub>4</sub>



**Figure 5.2:** Maturity index of F<sub>3</sub> populations and their corresponding values in F<sub>4</sub>

### 5.3.1.3. Phenotypic and genotypic coefficient of variation estimates

The estimates of phenotypic coefficient of variation (PCV) were greater than genotypic coefficients of variation (GCV) for all the characters studied (Table 5.9). None of the traits recorded high PCV and GCV. PCV ranged from 4.36 to 19.34% and GCV from 2.02 to 11.99%. The traits pod and seed weight showed moderate GCV and PCV values. Low PCV and GCV were observed for days to 50% plants flowering, shelling percentage and pod length.

**Table 5. 9:** Components of variation for different groundnut traits

Traits	Mean	Range	$\sigma^2_G$	$\sigma^2_{Ph}$	PCV (%)	GCV (%)
%Emergence 7DAS	71.31	58.33-83.33	-7.6	179.53	18.79	-
50% plant flowering	29.31	28.00 - 30.67	0.35	1.63	4.36	2.02
Pod weight	39.41	30.60 - 47.80	22.35	45.81	17.17	11.99
Seed weight	26.72	20.13 - 31.90	9.67	24.9	18.67	11.64
Number of seed	99.81	93.00 - 107.67	-7.54	47.53	6.91	-
Shelling %	67.69	62.13 - 74.82	5.43	17.05	6.1	3.44
Pod length	2.34	2.15 - 2.85	0.03	0.04	8.54	7.4
Maturity index	195.69	146.0 - 223.33	298.7	929.86	15.58	8.83

$\sigma^2_G$ : Genotypic variance,  $\sigma^2_{Ph}$ : Phenotypic variance, PCV: Phenotypic coefficient of variation, GCV: Genotypic coefficient of variation

### 5.3.1.4. General and specific combining ability estimates

Analysis of variance of combining ability for the eight traits revealed significant differences ( $P \leq 0.01$  and  $P \leq 0.05$ ) among parents for pod weight, seed weight, pod length and maturity index (Table 5.10). The crosses showed highly significant differences ( $P \leq 0.01$ ) for pod weight, number of seed and pod length. GCA mean squares for males were highly significant ( $P \leq 0.01$ ) for only pod weight. Female GCA mean squares were highly significant ( $P \leq 0.01$ ) for pod weight. GCA for the maturity index was significant at 5% level (Table 5.10).

Estimates of general combining ability effect for traits are presented in Table 5.11. Among the males, the variety RRB showed highest GCA effect (5.57) for maturity index followed by the

variety 55-437 (3.4). The male 55-437 exhibited the highest GCA effect for pod and seed weight 3.33 and 2.4 respectively. Chico and ICIAR19BT showed the highest GCA effect for maturity index 17.24 and 10.24 respectively. The female parent ICIAR19BT showed the highest GCA effect for pod and seed weight 4.63 and 2.95 respectively.

**Table 5.10:** Mean square of combining ability analysis for eight traits

Source of variation	DF	%EMERSD	NDFTPF	WFTP	WSFTP	NSFTP	SH	PL	MI
Replications	2	100.59	0.73	25.5	27.46	27.59	18.73	0.009	3633.16
Entries	13	164.33	2.33	90.50**	44.24**	32.44*	27.90*	0.0972**	1527.25*
Parents	6	228.96	1.96	118.66**	57.23**	13.93	17.62	0.180**	1821.93*
Crosses	6	104.96	1.65	76.60**	33.28	14.67**	22.04	0.02**	729.3
Males	2	129.16	1.055	32.11**	7.16	40.05	18.84	0.003	194.66
Females	3	112.5	0.64	119.26**	47.52	78.7	8.36	0.04	712.94
Males x Females	6	200	3.55	0.01	8.26	93.38**	59.86*	0.008	1058
Error	26	187.13	1.27	23.46	15.23	55.07	11.62	0.005	631.16

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , %EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

**Table 5.11:** General combining effect of parental lines for eight traits

Genotypes	MI	%EMERSD	NDFTPF	WFTP	WSFTP	NSFTP	SH	PL
<b>Male</b>								
JL24	-11.76	-0.36	0.48	-2.27	-0.8	0.1	2.18	-0.05
RRB	5.57	2.14	-0.52	-0.7	-1.07	-0.24	-1.44	0.03
55-437	3.4	-2.86	0.31	3.33	2.4	0.26	-0.01	0.01
<b>Female</b>								
796	-4.1	-3.69	-0.02	1.11	0.34	3.26	-1.13	0.01
Chico	17.24	0.48	-0.19	-9.16	-6.43	0.43	-0.26	-0.09
ICIAR19BT	10.24	3.81	-0.52	4.63	2.95	0.43	-0.73	0.12
ICG3584	-14.76	-0.36	0.64	-1.16	-0.08	-3.9	1.99	-0.08

%EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

Estimates of SCA effects of the seven crosses for eight traits measured are shown in Table 5.12.

SCA ranged from -13.9 to 20.09 for maturity index; - 4.64 to 7.85 for percentage of emergence; - 0.97 to 0.52 for 50% plants flowering; -0.79 to 2.66 for pod weight; - 1.82 to 2.33 for seed weight; -3.92 to 4.07 for number of seed; -3.4 to 2.14 for shelling percentage and -0.05 to 0.04 for pod length. The best specific crosses for maturity index were 796 x JL24 and ICG3584 x 55-437. Chico x RRB and ICIAR19BT x RRB were the specific crosses for 50% plant flowering, while 796 x RRB is the specific cross for pod and seed weight. 796 x JL24 and ICG3584 x 55-437 were the best specific combinations for seed number. ICIAR19BT x 55-437 was the best specific cross for shelling percentage.

**Table 5.12:** Specific combining ability effects of the crosses for eight traits

CROSSES	MI	NDFTPF	%EMERSD	WFTP	WSFTP	NSFTP	SH	PL
796 x JL24	20.09	0.35	-3.8	0.3	-0.47	4.07	-2.09	0.04
ICG3584 x JL24	-1.23	-0.97	7.85	-0.25	0.21	-3.42	1.24	0.02
796 x RRB	-13.9	-0.3	2.02	2.66	2.33	-3.92	1.36	-0.02
Chico x RRB	-5.57	0.52	-2.14	0.7	1.07	0.23	1.44,	-0.03
ICIAR19BT x RRB	-3.9	0.52	-0.47	0.05	-0.27	-0.42	-0.68	0.01
ICIAR19BT x 55-437	-5.07	-0.3	1.19	-2.67	-1.05	0.4	2.14	-0.05
ICG3584 x 55-437	9.59	0.19	-4.64	-0.79	-1.82	3.07	-3.4	0.02

MI: Maturity index, %EMERSD: % of emergence 7DAS, NDFTPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length.

### 5.3.1.5. Narrow sense heritability estimates

#### Estimates from variance components

Narrow sense estimates from variance components for different traits under study are presented in Table 5.13. Heritability ranged from 13.72% to 79.14%. The highest heritability estimates were obtained for 50% plant flowering (79.14%); shelling percentage (75.54); pod weight (72.04%); seed weight (70.04) and moderate estimates were found for maturity index and pod

length respectively 42.57% and 40%. Seeds number and maturity index exhibited the lowest heritability estimate 13.72%.

**Table 5.13:** Narrow sense heritability estimate from genetic component of traits

Traits	$\sigma^2_M$	$\sigma^2_F$	$\sigma^2_{MxF}$	$\sigma^2_{Ph}$	$\sigma^2_{A(F)}$	$\sigma^2_{A(M)}$	$\sigma^2_D$	$h^2_{ns}(\%)$
%Emergence 7DAS	-23.61	-29.17	4.29	179.53	-38.88	-23.61	-38.44	-
50% plant flowering	-0.83	-0.97	0.76	1.63	1.29	-0.83	1.12	79.14
Pod weight	10.7	39.75	-7.82	45.81	33	10.68	5.12	72.04
Seed weight	-0.37	13.09	-2.32	24.9	17.44	-0.36	0.85	70.04
Number of seed	-17.78	-4.89	12.77	47.53	6.52	-17.76	80	13.72
Shelling %	-13.67	-17.17	16.08	17.05	12.88	-13.67	7.96	75.54
Pod length	0	0.01	0	0.04	0.016	-0.0016	0.0035	40.00
Maturity index	-287.78	-115.02	142.28	829.86	353.32	-287.76	133.12	42.57

$\sigma^2_M$ : Male genotypic variance,  $\sigma^2_F$ : Female genotypic variance,  $\sigma^2_{MxF}$ : Male x female genotypic variance,  $\sigma^2_{Ph}$ : Phenotypic variance,  $\sigma^2_{A(F)}$ : Additive variance of Female,  $\sigma^2_{A(M)}$ : Additive variance of Male,  $\sigma^2_D$ : Dominance variance,  $h^2_{ns}$ : Narrow sense heritability

### Estimates by parent-offspring regression (F<sub>3</sub>:F<sub>4</sub>)

The estimates of narrow sense heritability by parent-offspring regression are presented in Table 5.14. Heritability estimates of the eight traits studied ranged from 35.4 to 95.5%. The highest estimates were found for days to emergence (95.5%), pod yield (85%), shelling percentage (84.3%), number of seed (80%) and 50% plant flowering respectively (72%). Moderate to low heritability estimates were obtained for Maturity index (66.1%), pod length (54.4%) and seed weight (35.4%).

**Table 5.14:** Narrow sense heritability by parent-offspring regression and standard errors

Traits	$h^2_{ns}$ (%)	SE
% Emergence 7DAS	95.5	0.29
50% Plants flowering	72	1.12
Pod weight	85	0.23
Seed weight	35.4	0.33
Seed number	80	0.22
Shelling %	84.3	0.29
Pod length	54.1	0.48
Maturity index	66.1	0.38

$h^2_{ns}$ : Narrow sense heritability, SE: Standard error

### 5.3.1.6. Correlations

Highly significant positive correlations were found between pod weight and seed weight ( $r = 0.97$ ,  $P \leq 0.001$ ) and pod length ( $r = 0.72$ ,  $P \leq 0.01$ ); between pod length and seed weight ( $r = 0.66$ ,  $P \leq 0.01$ ); between maturity index and days to emergence ( $r = 0.72$ ,  $P \leq 0.001$ ) (Table 5.15). Correlation between shelling percentage and seed weight was positively significant at  $P \leq 0.05$  ( $r = 0.61$ ). However, seed number was found not to be correlated with all the other traits. But, 50% plants flowering showed non-significant and weak negative correlations with seed weight and pod length.

**Table 5.15:** Correlation between earliness and agronomic traits

	%EMER7DAS	NSFTP	WSFTP	SH	PL	50%PF	WFTP
NSFTP	0.237						
WSFTP	-0.060	0.098					
SH	0.297	-0.045	<b>0.612*</b>				
PL	-0.037	0.242	<b>0.664**</b>	0.184			
50%PF	0.017	0.215	-0.466	-0.271	-0.426		
WFTP	-0.145	0.120	<b>0.975***</b>	0.423	<b>0.722**</b>	-0.464	
MI	<b>0.772***</b>	0.185	0.231	0.325	0.164	-0.284	0.183

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , \*\*\*significant at  $<0.001$ , %EMERSD: % of emergence 7DAS, 50% TPF: Number of days 50% plant flowering, WFTP: Pod weight, WSFTP: Seed Weight, NSFTP: Number of seed, SH: shelling %, PL: pod length, MI: Maturity index

### 5.3.2. Drought tolerance

#### 5.3.2.1. ANOVA

Mean squares from the ANOVA for physiological traits and pod yield and biomass are presented in Table 5.16. Results showed that the parents and F<sub>3</sub> populations differed significantly ( $P \leq 0.01$ ) for all the physiological traits except for SPAD chlorophyll meter reading at 60DAS and 50% plants flowering.

**Table 5.16:** Mean squares from ANOVA for parents and F<sub>3</sub> populations for physiological traits

Source of variation	Mean square						
	DF	50%PF	SMCRSD	SMCRED	PY	BIO	HI
Replication	2	0.02	16.67	5.84	144.36	793.19	0.004
Entry	12	1.26	7.3	8.07**	353.05*	1115.78**	0.026**
Error	24	1.6	4.92	4.45	268.67	521.57	0.016

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , **50% PF**: 50% Plant Flowering, **SMCRSD**: SPAD chlorophyll meter reading at 60DAS, **SMCRED**: SPAD chlorophyll meter reading at 80DAS, **PY**: Pod Yield, **BIO**: Biomass, **HI**: Harvest index

Combined analysis of variance showed large and significant differences ( $P \leq 0.01$ ) between all 14 genotypes for all traits (Table 5.17) except for pod yield. The progenies showed high variation. Significant difference in water regimes for pod yield, total biomass and SCMR were also found ( $P \leq 0.05$  to  $P \leq 0.001$ ), but no significant differences for 50% plant flowering and harvest index (Table 5.17). The hybrids responded differently to both moisture regimes. This was shown by the significant interaction effect obtained between water regimes and crosses for chlorophyll content, pod yield, biomass and harvest index. Consequently the crosses exhibited different ranking from one water regime to another, for chlorophyll content, pod yield, biomass and harvest index.

**Table 5.17:** Mean squares from the combined analysis of variance for the traits under well watered and end-of-season drought conditions

Source of variation	Mean Square						
	DF	50%PF	SMCR 60DAS	SMCR 80DAS	PY	BIO	HI
Replication	2	33.03	14	4.18	22825	231878	0.06
Crosses	13	7.58*	23.77**	9.74*	5615	50235***	0.05***
Water regime	1	2.68	828.17***	54.53**	37855**	60380*	0.04
Crosses x water regime	13	2.22	11.91*	7.33*	4997*	18103*	0.03*
Residual	54	3.4	9.77	4.99	4003	14855	0.01
Total	83	4.58	22.08	6.51	5270	26668	0.02

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , \*\*\*significant at  $<0.001$ , **50% PF**: 50% Plant Flowering, **SMCRSD**: SPAD chlorophyll meter reading at 60DAS, **SMCRED**: SPAD chlorophyll meter reading at 80DAS, **PY**: Pod Yield, **BIO**: Biomass, **HI**: Harvest index

### 5.3.2.2. Mean performance

The mean performance of parental lines and F<sub>3</sub> populations for physiological traits is presented in Table 5.18. Among the males, 55-437 showed the highest values for pod yield (178.23g) and total biomass (554.53); whereas the genotype ICGV-SM 99511 exhibited the highest values for the same traits among the females 180.43g and 637.6 respectively. The cross ICG11249 x RRB showed the highest values for pod yield (238.97g) and biomass (574.2g) among the crosses. SPAD chlorophyll meter reading at 80DAS values ranged from 34.49 - 39.71 and the highest valued was recorded with the cross ICGV-SM 99511 x 55-437 (39.71). SPAD chlorophyll meter reading at 80DAS values were greater than SPAD chlorophyll meter reading at 60DAS for all the entries. The highest harvest index was shown by the cross ICGV-SM 99511 x 55-437 (0.54).

**Table 5.18:** Mean performance of parental lines and F<sub>3</sub> populations for physiological traits

Mean performance						
ENTRIES	NDFPF	SMCRSD	SMCRED	PY	BIO	HI
JL24	30.33	30.95	37.83	167.13	356.73	0.47
RRB	31	33.73	39	127.73	380.98	0.31
55- 437	30	33.01	37.12	178.23	554.53	0.33
ICG11249	30.33	30.64	34.57	133.83	443.07	0.31
ICGVSM 99511	32	33.62	38.52	180.43	637.6	0.3
TAIMAN-9	31.33	34.43	37.91	136.72	507.03	0.27
ICG11249 X JL24	31	31.39	36.02	113.73	504.13	0.21
ICG11249 X RRB	31.33	32.87	34.49	238.97	574.2	0.42
ICG11249 X 55- 437	31.33	34.04	37.24	148.2	404.47	0.4
ICGVSM 99511 X 55- 437	30	34.95	39.71	193.83	362.8	0.54
TAINAN-9 x JL24	30.33	30.24	35.39	192.77	442.97	0.44
TAINAN-9 x RRB	30.33	34.25	37.99	104.47	366.07	0.29
TAINAN-9 x 55- 437	30	33.12	37.95	171.8	590.7	0.3
Mean	30.72	32.87	37.21	160.6	471.18	0.35
Range	30.00 - 32.00	30.24 - 34.95	34.49 - 39.71	104.47 - 238.97	356.73 - 637.60	0.21 - 0.54
LSD	2.13	3.74	3.55	102.67	171.47	0.217
CV %	4.12	6.75	5.66	37.93	21.59	36.76

**50% PF:** 50% Plant Flowering, **SMCRSD:** SPAD chlorophyll meter reading at 60DAS, **SMCRED:** SPAD chlorophyll meter reading at 80DAS, **PY:** Pod Yield, **BIO:** Biomass, **HI:** Harvest index

Results of F<sub>3</sub> and F<sub>4</sub> populations mean performance for six traits under both water regimes are shown in Table 5.19. At 60 DAS, the crosses F<sub>3</sub>: Tainan-9 X 55-437, F<sub>3</sub>: ICG11249 X JL24, F<sub>4</sub>: Tainan-9 X JL24 exhibited the highest values of drought tolerance indices for SAPD SCMR respectively 1.35, 130 and 1.27. The lowest value of DTI was obtained with the hybrid Tainan-9 X RRB. The crosses ICG11249 X JL24 and Tainan-9 X 55-437 showed the highest values of DTI for SPAD SCMR at 80 DAS. High values of DTI for total biomass were recorded for the crosses ICGVSM 99511 X 55-437, ICG11249 X 55-437 and Tainan-9 X JL24. The lowest value of DTI for total biomass was found for the hybrid ICG11249 X JL24. Drought tolerance indices values ranged from 1.72 to 0.6 for harvest index. The crosses ICG11249 X RRB and ICGVSM99511 X 55-437 showed the highest values of DTI for harvest index 1.72 and 1.41,

respectively. The lowest value of DTI for harvest index was shown by the hybrid Tainan-9 X RRB.

**Table 5.19:** Range, mean and drought tolerance indices of F<sub>3</sub> and F<sub>4</sub> populations under well-watered and end-of-season drought conditions for the six traits

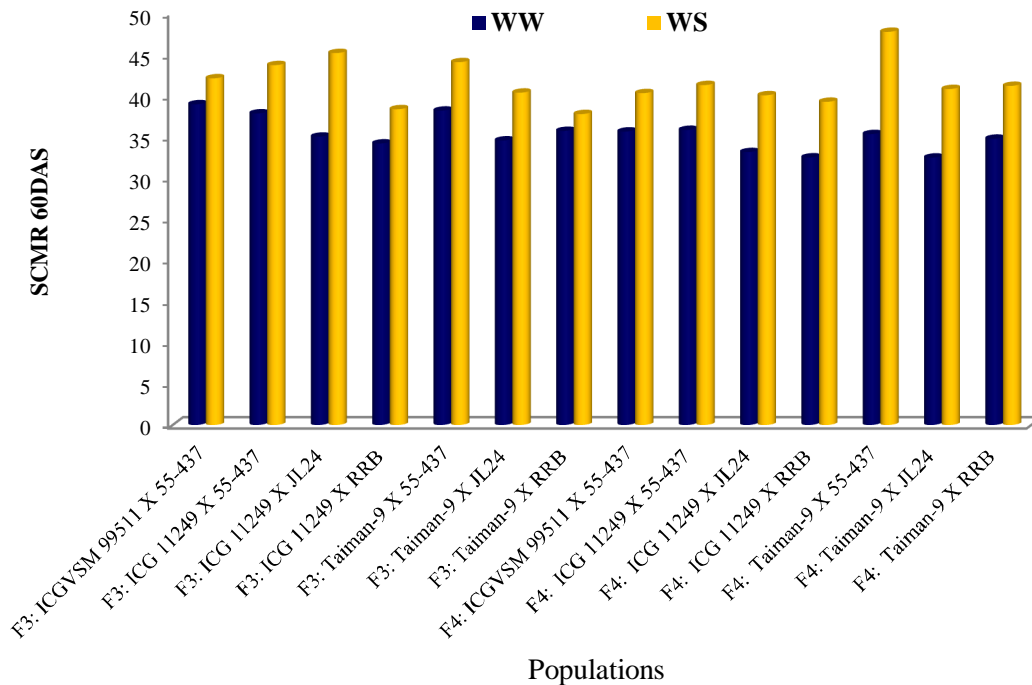
Groundnut crosses	SCMR 60DAS		DTI	SCMR 80DAS		DTI	Biomass		DTI	Harvest index		DTI
	WW	WS		WW	WS		WW	WS		WW	WS	
<b>F3: ICGVSM 99511 X 55-437</b>	38.92	42.07	1.08	40.25	40.93	1.02	739.03	516.03	0.84	0.41	0.45	1.41
<b>F3: ICG 11249 X 55-437</b>	37.81	43.67	1.17	38.65	39.77	1.03	779.93	760.07	0.97	0.29	0.22	0.98
<b>F3: ICG 11249 X JL24</b>	34.99	45.14	1.3	36.57	37.32	1.02	582.7	487.7	0.86	0.47	0.28	0.76
<b>F3: ICG 11249 X RRB</b>	34.16	38.32	1.12	36.6	37.22	1.02	667.03	681.97	1.03	0.18	0.24	1.72
<b>F3: Tainan-9 X 55-437</b>	38.15	44.03	1.18	38.97	41.92	1.08	688.03	510.87	0.79	0.38	0.21	0.83
<b>F3: Tainan-9 X JL24</b>	34.53	40.33	1.17	37.5	37.55	1	547.27	561.37	1.05	0.36	0.38	0.74
<b>F3: Tainan-9 X RRB</b>	35.69	37.73	1.06	40.44	40.98	1.01	604.77	556.03	0.93	0.31	0.24	0.6
<b>F4: ICGVSM 99511 X 55-437</b>	35.61	40.27	1.14	40.41	39.17	0.97	492.77	623.8	1.24	0.34	0.29	0.89
<b>F4: ICG 11249 X 55-437</b>	35.81	41.25	1.15	36.19	38.72	1.07	488.9	572.1	1.17	0.41	0.26	0.67
<b>F4: ICG 11249 X JL24</b>	33.12	40.01	1.21	34.99	41.26	1.18	519.13	379.37	0.73	0.51	0.46	0.81
<b>F4: ICG 11249 X RRB</b>	32.47	39.22	1.22	38.26	39.35	1.03	771.83	588	0.76	0.21	0.24	1.55
<b>F4: Tainan-9 X 55-437</b>	35.3	47.71	1.35	38.27	40.96	1.07	571.13	416.97	0.75	0.33	0.31	0.93
<b>F4: Tainan-9 X JL24</b>	32.45	40.77	1.27	38.86	39.11	1.01	415.4	456.9	1.14	0.54	0.52	0.81
<b>F4: Tainan-9 X RRB</b>	34.74	41.15	1.18	39	40.9	1.05	547.2	553.27	0.99	0.34	0.36	0.83
<b>Mean</b>	<b>35.27</b>	<b>41.55</b>	<b>1.2</b>	<b>38.04</b>	<b>39.65</b>	<b>1.04</b>	<b>601</b>	<b>547</b>	<b>0.95</b>	<b>0.36</b>	<b>0.32</b>	<b>0.97</b>
<b>Maximum</b>	<b>38.92</b>	<b>47.71</b>	<b>1.35</b>	<b>40.44</b>	<b>41.92</b>	<b>1.18</b>	<b>779.93</b>	<b>760.07</b>	<b>1.24</b>	<b>0.54</b>	<b>0.52</b>	<b>1.72</b>
<b>Minimum</b>	<b>32.45</b>	<b>37.73</b>	<b>1.06</b>	<b>34.99</b>	<b>37.22</b>	<b>0.97</b>	<b>415.4</b>	<b>379.37</b>	<b>0.73</b>	<b>0.18</b>	<b>0.21</b>	<b>0.6</b>
<b>LSD 5%</b>	<b>4.68</b>	<b>5.79</b>	<b>0.27</b>	<b>3.22</b>	<b>4.16</b>	<b>0.14</b>	<b>250.4</b>	<b>252.5</b>	<b>0.51</b>	<b>0.188</b>	<b>0.212</b>	<b>0.99</b>
<b>CV %</b>	<b>7.9</b>	<b>8.3</b>	<b>11.9</b>	<b>5.1</b>	<b>6.3</b>	<b>7.4</b>	<b>24.9</b>	<b>27.6</b>	<b>28.6</b>	<b>30.9</b>	<b>39.6</b>	<b>53.9</b>

**DTI:** Drought tolerance index, **50% PF:** 50% Plant Flowering, **SMCRSD:** SPAD chlorophyll meter reading at 60DAS, **SMCRED:** SPAD chlorophyll meter reading at 80DAS, **PY:** Pod Yield, **BIO:** Biomass, **HI:** Harvest index

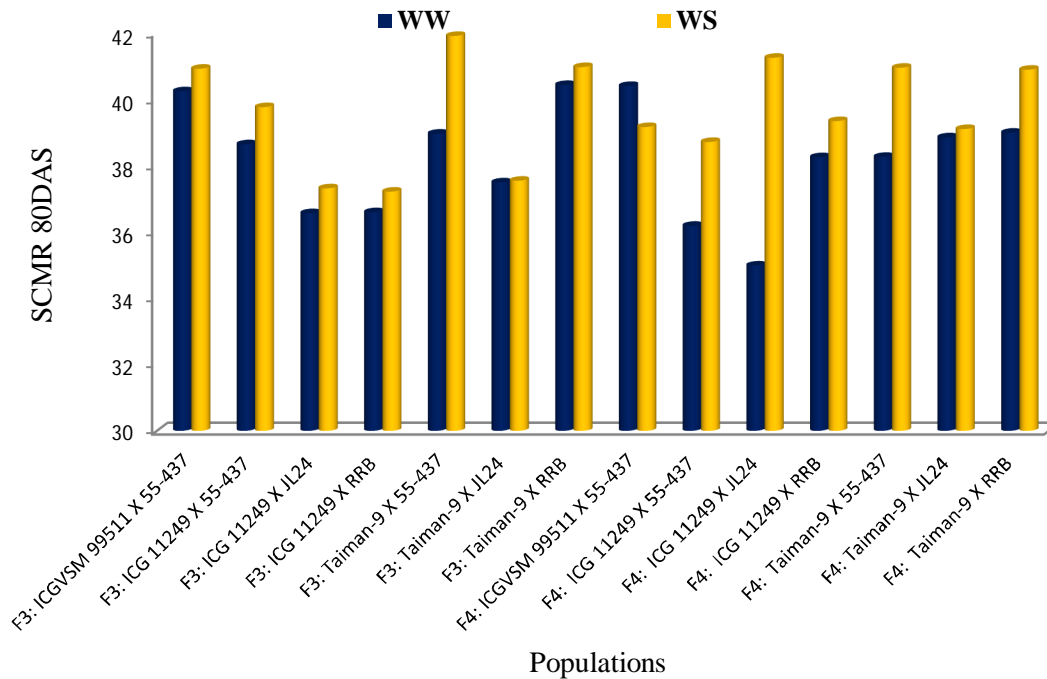
### 5.3.2.3. Effect drought on SPAD Chlorophyll meter reading

Highly significant differences in chlorophyll content among the crosses at 60 and 80 DAS was found ( $P \leq 0.05$  to  $P \leq 0.01$ ) (Table 5.17). The overall means of chlorophyll content under end-of-season drought stress condition, 41.55 and 39.65 respectively, at 60 and 80DAS were higher than the overall means under irrigated conditions, 35.27 and 38.04 respectively. The hybrids

Tainan-9 X 55-437, ICG 11249 X JL24 and ICG 11249 X 55-437 exhibited the highest values of SPAD chlorophyll meter reading at 60 and 80 days after sowing under end-of-season drought stress conditions (Table 5.19). The hybrid Tainan-9 X 55-437 ranked first in terms of chlorophyll content at 60 and 80 DAS with 47.71 and 41.92, respectively under end-of-season drought stress conditions. While, under the same conditions, the cross ICG11249 X JL24 ranked second followed by the hybrid Tainan-9 X RRB. The magnitude of SPAD chlorophyll meter reading was higher at 60 and 80 DAS compared between both water regimes (Figure 5.3 and 5.4).



**Figure 5.3:** Chlorophyll content at 60 DAS under well watered (WW) and water stressed (WS) conditions



**Figure 5.4:** Chlorophyll content at 80 DAS under well watered (WW) and water stressed (WS) conditions

#### 5.3.2.4. Effect of drought on Pod yield

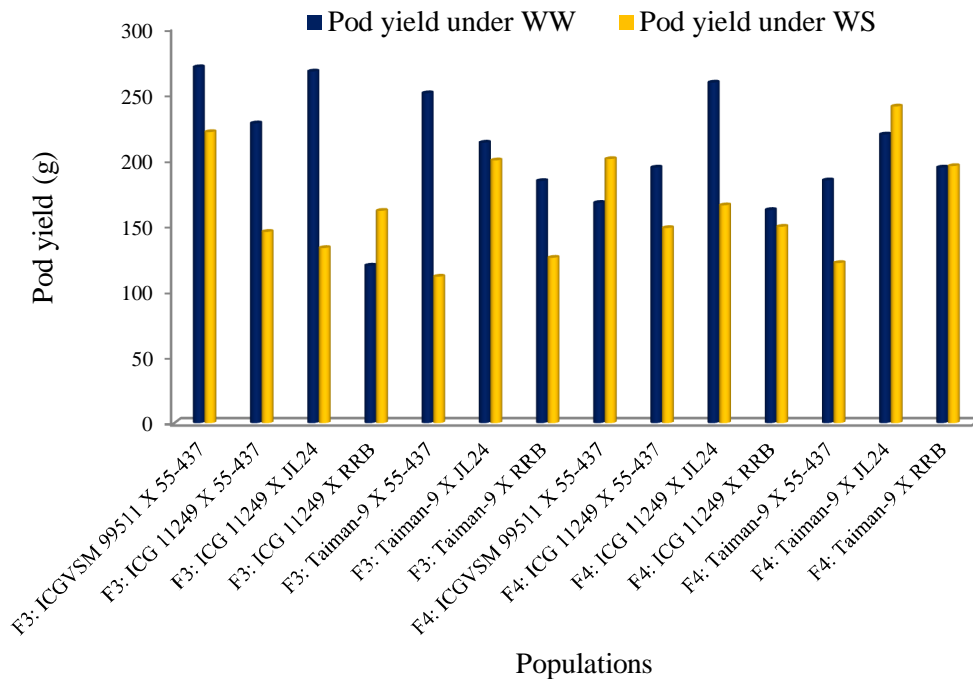
Analysis of variance revealed highly significant differences in water regime among the crosses for pod yield (Table 5.17). The F<sub>3</sub> cross ICGV-SM99511 X 55-437 was the highest yielding (270.37 g) under well water conditions (Table 5.20). However, once end-of-season drought stress was imposed, the F<sub>4</sub> cross Tainan-9 X JL24 was the highest yielding cross at 240.53 g. The crosses ICG11249 X RRB and Tainan-9 X 55-437 showed the lowest pod yield 119.63 g and 111.23 g, respectively, under well watered and end-of-season drought stress conditions. Certain hybrids such as ICGV-SM99511 X 55-437, Tainan-9 X JL24, ICG11249 X RRB and Tainan-9 X RRB performed well for pod yield under both water regimes. The cross Taiman-9 X RRB showed the least pod yield difference among all the crosses. All crosses pod yield performances are shown in Figure 5.5.

The drought tolerance index for pod yield ranged from 0.44 to 1.37 for seven crosses. The crosses ICG11249 X RRB and Tainan-9 X JL24 displayed the highest value of DTI for pod yield 1.37 and 1.27, respectively. While the hybrids Tainan-9 X 55-437 and ICG11249 X JL24 exhibited the lowest values of pod yield DTI 0.44 and 0.5, respectively.

**Table 5.20:** Pod yield (g) of F<sub>3</sub> and F<sub>4</sub> populations under well watered and their corresponding performance under end-of-season drought stress and DTI

Groundnut crosses	Pod yield WW	Pod yield WS	Yield difference	DTI
<b>F3: ICGVSM 99511 X 55-437</b>	270.37	221.07	49.3	0.85
<b>F3: ICG 11249 X 55-437</b>	227.7	145.3	82.4	0.63
<b>F3: ICG 11249 X JL24</b>	267.1	133.03	134.07	0.5
<b>F3: ICG 11249 X RRB</b>	119.63	161.27	41.64	1.37
<b>F3: Tainan-9 X 55-437</b>	250.6	111.23	139.37	0.44
<b>F3: Tainan-9 X JL24</b>	213.07	199.57	13.5	1.27
<b>F3: Tainan-9 X RRB</b>	183.93	125.6	58.33	0.73
<b>F4: ICGVSM 99511 X 55-437</b>	167.3	200.6	33.33	1.11
<b>F4: ICG 11249 X 55-437</b>	194.13	148.2	45.93	0.79
<b>F4: ICG 11249 X JL24</b>	258.7	165.43	93.27	0.66
<b>F4: ICG 11249 X RRB</b>	161.9	149.17	12.73	1
<b>F4: Tainan-9 X 55-437</b>	184.43	121.63	62.8	0.65
<b>F4: Tainan-9 X JL24</b>	219.27	240.53	21.6	1.12
<b>F4: Tainan-9 X RRB</b>	194.17	195.27	1.1	1.11
<b>Mean</b>	<b>208</b>	<b>166</b>		<b>0.87</b>
<b>Maximum</b>	<b>270.37</b>	<b>240.53</b>		<b>1.37</b>
<b>Minimum</b>	<b>119.63</b>	<b>111.23</b>		<b>0.44</b>
<b>LSD 5%</b>	<b>110.9</b>	<b>117.8</b>		<b>0.88</b>
<b>CV %</b>	<b>31.9</b>	<b>42.5</b>		<b>52.9</b>

WW: well watered conditions, WS: water stressed conditions, DTI: Drought tolerance index



**Figure 5.5:** Mean performance of crosses for pod yield under well watered (WW) and water stressed (WS) conditions

### 5.3.2.5. Phenotypic and genotypic coefficient of variation estimates

The estimate of phenotypic coefficient of variation (PCV) was greater than genotypic coefficient of variation (GCV) for all the physiological traits studied (Table 5.21). The traits harvest index, pod yield and biomass showed high PCV estimates of 40.20, 35.81 and 26.91% respectively. Moderate GCV estimates were obtained for the same traits 15.9, 11.02 and 14.12 respectively. The trait SPAD chlorophyll meter reading at both dates (60 or 80 DAS) were low for GCV and PCV estimates.

**Table 5.21:** Components of variation for physiological traits

Characters	Mean	Range	$\sigma^2_G$	$\sigma^2_{Ph}$	PCV (%)	GCV (%)
50% plant flowering	30.72	30.00 - 32.00	-0.113	1.5	3.98	-
SPAD SCMR 60DAS	32.87	30.24 - 34.95	0.79	5.71	7.27	2.71
SPAD SCMR 80DAS	37.21	34.49 - 39.71	1.2	5.66	6.39	2.95
Pod yield	160.6	104.47 - 238.97	28.12	296.8	35.81	11.02
Biomass	471.18	356.73 - 637.60	198.06	719.65	26.91	14.12
Harvest index	0.35	0.21 - 0.54	0.003	0.02	40.2	15.91

$\sigma^2_G$ : Genotypic variance,  $\sigma^2_{Ph}$ : Phenotypic variance, **PCV**: Phenotypic coefficient of variation, **GCV**: Genotypic coefficient of variation

### 5.3.2.6. General and specific combining ability estimates

Analysis of variance of combining ability for the six traits revealed significant differences among parents for SPAD chlorophyll meter reading, pod yield, total biomass and harvest index (Table 5.22). All the crosses were highly significantly different for all the physiological traits, except for 50% plants flowering and chlorophyll content at 60DAS. GCA mean squares for males and females were highly significant for pod yield and biomass. GCA mean squares for females were greater than males GCA mean square for pod yield and total biomass indicating that the major contribution to additive variance for these traits was due the female parents. SCA mean squares differed significantly for pod yield and harvest index indicating the importance of both additive and non-additive variance for these traits.

**Table 5. 22:** Mean square of Combining Ability analysis for six the physiological traits for WW

Source of variation	Mean Square						
	DF	50%PF	SCMRSD	SCMRED	PY	BIO	HI
Replications	2	0.025	4.92	5.84	144.36	793.19	0.0043
Entries	12	1.26	7.3	8.07**	353.05*	1115.78**	0.026**
Parents	5	1.7	7.38	7.36*	271.29**	1601*	0.0152*
Crosses	6	1.04	8.34	9.57**	453.76*	820.76*	0.0367**
Males (GCAm)	2	0.06	15.16	5.7	45.93*	675.96*	0.0012
Females (GCAf)	2	2.69	2.04	7.69	236.49*	1151.83*	0.0351
Males x Females (SCA)	2	0.17	2.96	6.64	1122.51*	1047.6	0.0603*
Error	24	1.69	4.92	4.45	268.67	521.57	0.0167

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , **50% PF**: 50% Plant Flowering, **SCMRSD**: SPAD chlorophyll meter reading at 60DAS, **SCMRED**: SPAD chlorophyll meter reading at 80DAS, **PY**: Pod Yield, **BIO**: Biomass, **HI**: Harvest index

Estimates of combining ability effects of parents for traits measured are presented in Table 5.23. Among the males, RRB showed highest GCA effect for 50% plant flowering. The males RRB and 55-437 exhibited positive GCA effect for pod yield and total biomass respectively. The female ICGV-SM99511 displayed the highest positive GCA effect for SPAD chlorophyll meter reading and pod yield. While Tainan-9 showed the highest GCA effect for biomass and harvest index.

**Table 5.23:** General combining ability effect of parental lines for six traits for WW

General Combining Ability						
Parents	50%PF	SCMRSD	SCMRED	PY	BIO	HI
<b>Male</b>						
JL24	0.047	-2.16	-1.27	-0.67	-7.9	-0.04
RRB	0.21	0.58	-0.74	0.54	3.3	-0.01
55-437	-0.17	1.06	1.33	0.084	3.07	0.04
<b>Female</b>						
ICG11249	0.6	-0.21	-1.05	-3.36	-1.91	-0.04
ICGV-SM 99511	-0.62	1.97	2.74	9.73	-17.41	-0.02
TAINAN-9	-0.39	-0.44	0.14	0.12	7.72	0.042

**50% PF**: 50% Plant Flowering, **SCMRSD**: SPAD chlorophyll meter reading at 60DAS, **SCMRED**: SPAD chlorophyll meter reading at 80DAS, **PY**: Pod Yield, **BIO**: Total Biomass, **HI**: Harvest index

Estimates of SCA effects of the seven crosses for six traits are shown in Table 5.24. SCA ranged from -0.27 to 0.28 for 50% plant flowering; from -0.47 to 1.13; -0.49 to 1.61 for SPAD chlorophyll meter readings at 60 and 80 DAS respectively; from -9.04 to 17.04 for pod yield; from -13.39 to 22.17 for total biomass and from -0.08 to 0.14 for harvest index. ICG11249 x 55-437 was the best specific cross for 50% plant flowering; while Tainan-9 x RRB was the best specific combination for SPAD chlorophyll meter reading. Tainan-9 x JL24 and ICG11249 x RRB were the best specific crosses for pod yield, while the cross Tainan-9 x 55-437 was the best specific combination for biomass.

**Table 5.24:** Specific combining ability effects of the seven crosses for six traits for WW

Crosses	Specific Combining Ability					
	50%PF	SCMRSD	SCMRED	PY	BIO	HI
ICG 11249 x JL24	-0.27	0.79	1.36	-9.04	1.44	-0.08
Tainan-9 x JL24	0.06	-0.13	-0.45	12.28	-7.24	0.14
ICG 11249 x RRB	-0.1	-0.47	-0.69	17.04	7.59	0.09
Tainan-9 x RRB	-0.1	1.13	1.61	-13.8	-13.39	-0.03
ICG 11249 x 55-437	0.28	0.21	-0.007	-7.96	-7.5	0.01
ICGV-SM99511 x 55-437	0.17	-1.05	-1.33	-0.08	-3.06	-0.04
Tainan-9 x 55-437	-0.04	-0.47	-0.48	1.56	22.17	-0.08

**50% PF:** 50% Plant Flowering, **SCMRSD:** SPAD chlorophyll meter reading at 60DAS, **SCMRED:** SPAD chlorophyll meter reading at 80DAS, **PY:** Pod Yield, **BIO:** Biomass, **HI:** Harvest index

### 5.3.2.7. Narrow sense heritability estimates

#### Estimates from variance components

Narrow sense estimate from variance components for physiological traits and pod yield and biomass ranged from 20.33 to 74.44% (Table 5.25). The highest value was obtained for 50% plant flowering (74.44%); while moderate heritability values were found for pod yield (65.28%), harvest index (50%) and SPAD chlorophyll meter reading (43.46%). Biomass exhibited the lowest heritability value (20.33%).

**Table 5.25:** Narrow sense heritability estimate from genetic component of physiological traits for WW

Characters	$\sigma^2_M$	$\sigma^2_F$	$\sigma^2_{MxF}$	$\sigma^2_{Ph}$	$\sigma^2_{A(F)}$	$\sigma^2_{A(M)}$	$\sigma^2_D$	$h^2_{ns}(\%)$
<b>50% plant flowering</b>	-0.04	0.84	-0.48	1.5	1.12	-0.049	-0.087	74.44
<b>SPAD SCMR 60DAS</b>	4.07	-0.32	-0.65	5.71	-0.42	5.42	0.28	-
<b>SPAD SCMR 80DAS</b>	-0.32	0.35	0.73	5.66	2.46	-0.42	0.74	43.46
<b>Pod yield</b>	-358.86	-295.34	284.61	296.8	193.76	-478.48	12.04	65.28
<b>Biomass</b>	-123.88	34.74	175.34	719.65	146.32	-165.16	138.2	20.33
<b>Harvest index</b>	-0.02	-0.01	0.01	0.02	0.01	-0.02	0.0076	50

$\sigma^2_M$ : Male genotypic variance,  $\sigma^2_F$ : Female genotypic variance,  $\sigma^2_{MxF}$ : Male x female genotypic variance,  $\sigma^2_{Ph}$ : Phenotypic variance,  $\sigma^2_{A(F)}$ : Additive variance of Female,  $\sigma^2_{A(M)}$ : Additive variance of Male,  $\sigma^2_D$ : Dominance variance,  $h^2_{ns}$ : Narrow sense heritability

### Estimates by parent-offspring regression

In this study, heritability estimates for physiological traits were higher than for agronomic traits, and varied under both well-watered and end-of-season conditions (Table 5.26). The heritability estimates for pod yield (0.26) and biomass (0.18) were low, but they were high for harvest index (0.78) and SPAD chlorophyll meter reading 0.71 and 0.68 respectively at 60 and 80 days after sowing. Fifty percent (50%) Plants flowering showed moderate heritability estimate of 0.56. End-of-season drought stress effect on heritability estimates decreased narrow sense heritability values for all the physiological traits. Interestingly increased heritability estimates for agronomic traits, pod yield and biomass, under end-of-season drought stress conditions. As a result of drought effect, the heritability estimates varied from low 0.26 to moderate heritability 0.68 for pod yield and 0.18 to 0.49 for biomass.

**Table 5.26:** Narrow sense heritability by parent-offspring regression and standard errors of the seven groundnut crosses for physiological traits

Traits	Well water condition		Drought stress condition	
	$h^2_{ns}$ (%)	SE	$h^2_{ns}$ (%)	SE
<b>50% Pant flowering</b>	56.3	0.2	28.2	0.32
<b>SCMR 60 DAS</b>	71.6	0.12	36.8	0.4
<b>SCMR 80 DAS</b>	68.2	0.41	10.6	0.234
<b>Pod Yield</b>	26.1	0.25	68.6	0.32
<b>Biomass</b>	18.4	0.58	49.5	0.35
<b>Harvest index</b>	78.9	0.4	37.8	0.48

$h^2_{ns}$ : Narrow sense heritability, SE: Standard error

### 5.3.2.8. Correlations

Pod yield displayed highly significant positive association with harvest index in both water regimes; the correlation coefficient was higher ( $r = 0.77$ ,  $P \leq 0.001$ ) under end-of-season drought stress conditions than under well watered conditions ( $r = 0.74$ ,  $P \leq 0.01$ ). Strong negative significant ( $P \leq 0.05$ ) correlation was found between biomass and harvest index under well watered and end-of-season drought conditions  $r = -0.66$ ,  $-0.58$ , respectively (Table 5.27). Weak positive and non-significant correlation was found between SCMR and pod yield under well watered conditions ( $r = 0.38$ ).

**Table 5.27:** Correlations between physiological and agronomic traits under both water regimes

<b>Under well water conditions</b>				
	<b>SCMR60DAS</b>	<b>SCMR 80DAS</b>	<b>Biomass</b>	<b>Harvest Index</b>
<b>SCMR 80DAS</b>	0.434			
<b>Biomass</b>	0.459	0.202		
<b>Harvest Index</b>	-0.064	-0.204	<b>-0.606*</b>	
<b>Pod Yield</b>	0.387	-0.079	0.029	<b>0.745**</b>
<b>Under end of-season drought conditions</b>				
	<b>SCMR60DAS</b>	<b>SCMR80DAS</b>	<b>Biomass</b>	<b>Harvest Index</b>
<b>SCMR 80DAS</b>	0.190			
<b>Biomass</b>	-0.287	-0.373		
<b>Harvest Index</b>	-0.077	0.103	<b>-0.589*</b>	
<b>Pod Yield</b>	-0.340	-0.186	-0.036	<b>0.777***</b>

\*Significant at  $P \leq 0.05$ , \*\*Significant at  $P \leq 0.01$ , \*\*\*significant at  $<0.001$ , **SCMR**: SPAD chlorophyll meter reading, **PY**: Pod Yield, **BIO**: Biomass, **HI**: Harvest index

## 5.4. Discussion

### 5.4.1. Maturity

Four hybrids, out of the seven, 796 x RRB, Chico x RRB, ICIAR19BT x RRB and ICIAR19BT x 55-437, showed good performance for both earliness and agronomic traits. The hybrids ICIAR19BT x RRB, ICIAR 19BT x 55-437, 796 x RRB, 796 x JL24, Chico x RRB exhibited the highest means for pod yield, seed weight and maturity index in both populations. High values of maturity index indicated early maturity. Therefore these hybrids were promising early maturing materials.

The estimates of phenotypic coefficient of variation were higher than genotypic coefficient of variation indicating the influence of environmental factors. None of the traits recorded high PCV and GCV. Pod yield, seed weight and maturity index exhibited moderate PCV estimates and low GCV estimates. 50% plants flowering, shelling percentage and pod length, low magnitude of difference observed indicated that these characters were less influenced by the environments (Narasimhulu *et al.*, 2012). Similar results were reported for low PCV and GCV for 50% flowering by Vetriventhan and Nirmalakumari (2007) and Sumathi *et al.*, (2010). Genotypic coefficient of variation measures the amount of variation present in a particular character (Narasimhulu *et al.*, 2012) while PCV measures total relative variation (Roychowdhury and Tah, 2011). Several authors reported comparable results where PCV values were higher than GCV values for all the traits which reflect the influence of environment on the expression of traits (Yousaf *et al.* 2008; Sumathi *et al.* 2010; Roychowdhury *et al.* 2011 and Narasimhulu *et al.* 2012).

Analysis of variance of combining ability for the eight traits revealed significant differences ( $P \leq 0.05$  to  $P \leq 0.01$ ) among parents for all the traits except for percentage of emergence and 50%

plants flowering. This indicated the presence of genotypic variability among cultivars used as parents. The significance of GCA mean squares indicated the importance of additive gene effect governing the inheritance of pod yield, seed yield, pod length, and maturity index. Selection of superior genotypes in segregating generations should be possible for these traits. These results are in agreement with those of Jogloy *et al.* (2005) who found significant GCA mean squares which indicated the importance of additive gene effects governing the inheritance of pod yield, seed yield and 100-seed weight. Jogloy *et al.* (1999) found that GCA mean squares were important for pod length and seed size. Green *et al.* (1983) and Swe and Branch (1986) found that GCA and SCA mean squares were significant for yield and yield component traits. Similar results were also reported. Holbrook (1990) found that GCA and SCA were also significant for yield and yield components.

The analysis revealed differences among the crosses for almost all the traits. This indicated the presence of genotypic variability among  $F_3$  populations.  $F_3$  and  $F_4$  populations differed significantly for pod yield, shelling percentage, seed weight and pod length. GCA mean squares for females were greater than for the males for pod weight indicating that the major contribution to additive effect for this trait was due the female parent. SCA mean squares were significant for number of seed and shelling percentage at  $P \leq 0.01$  and  $P \leq 0.05$ , respectively, indicating the importance of both additive and non-additive effects for these traits. These results support the findings of Mekonthehou, (1987) who studied the combining ability of early maturity for a selected group of groundnut and found that GCA was always larger than SCA for most of the maturity parameters. Jogloy *et al.* (1987) found that general combining ability was highly significant for pod yield, and shelling percentage and specific combining ability was significant for pod length and seed size. Rachmeler, (1988) found greater and significant GCA than SCA

estimated for early maturity in  $F_2$  and  $F_3$  generations. Bansal *et al.*, (1991) showed that non-additive gene effects were predominant for yield components although the magnitude of additive effects was considerable.

GCA effects clearly identified the variety 55-437 as the best male parent with good combining ability for most traits under study. RRB was the best combiner for maturity index and days to emerge. While the variety JL24 was the best general combiner for shelling percentage. GCA effects revealed that the variety ICIAR19BT as the best female parent with general good combining ability for most traits under study. Chico was the best general combiner for maturity index with the highest positive GCA effect. Ali *et al.* (2001) reported Chico to be the best combiner for maturity index. Several authors reported the use of Chico as parental line in breeding programme for developing early maturing varieties such as N'Doye and Smith (1993), Ali and Wynne (1994); Upadhyaya and Nigam (1994) and Upadhyaya *et al.* (2006).

SCA effects for individual hybrids identified at least one specific hybrid for each trait. The hybrids 796 x JL24 and ICG 3584 x 55-437 were the good specific combiners for maturity index. The hybrid 796 x RRB was the good for pod and seed weight. ICIAR19BT x 55-437 was the best specific combination for shelling percentage. Hybrids 796 x JL24 and ICG 3584 x 55-437 were the good specific combinations for number of seeds. Specific combinations are expected to give transgressive segregation in later generations. Estimates of SCA effects were larger in magnitude than GCA effects for 50% plant flowering, number of seed and shelling percentage indicating that non-additive genetic variance was more important than additive genetic variance for these traits. Redona and Lantican, (1985) reported that the non-additive genetic variation due to dominance interactions should reduce in comparison with the additive genetic variation as inbreeding progresses.

High to moderate heritability was obtained for days to emergence, pod yield, shelling %, number of seed, 50% plants flowering and maturity index from the estimates from variance components and by parent-offspring regression. The lowest heritability value was obtained with the traits seed weight and seed number. Because of higher heritabilities, selection for yield and maturity should be possible among the populations. The results agree with the findings of Coffelt and Hammons (1974), Wynne *et al.*, (1975), Kale and Dhoble (1988), Tsaur *et al.* (1989) who reported high heritability for pod yield, pod length and 100 seed weight. Results also agree with the studies of Rachmeler, (1988) and Mohammed *et al.*, (1978) who found relatively high narrow sense heritability for early maturity in groundnut. Holbrook *et al.*, (1989) reported also high heritabilities for maturity while studying F<sub>1</sub> and F<sub>2</sub> plants of reciprocal crosses involving Chico (extra early maturing) and PI383421(late maturing) groundnut lines. Ali and Wynne, (1994) similarly found high narrow sense heritability estimates for the cross NC7/Chico for 100 seed weight (71%) and pod length (52%), intermediate for maturity index (44%). John *et al.*, (2011), in F<sub>6</sub> generation found moderate broad sense heritability estimates for pod yield high heritability for pod yield (76%) and 100 seed weight (71%) and intermediate estimates for maturity index (44%) and seed number (31%) depending on the crosses. This study results are in agreement with the findings of Khan *et al.*, (2000) and Jogloy *et al.*, (2011). Burton (1951) suggested that the genetic coefficient of variation together with heritability estimates gave the better picture of the extent of heritable variation.

Positive associations between pod yield with seed weight and pod length; between maturity index and days to emergence; and between pod length with seed weight and shelling percentage indicated the possibility for simultaneous improvement of these traits. Waranyuwat and Tongstri (1990) reported highly significant associations between pod and seed yield, pod yield and

number of mature seeds per plant, and seed yield and number of mature seeds per plant, but shelling percentage had variable correlation with pod and seed traits in different generations. They also suggested selection based on high number of pods per plant for high yield. These results are in good agreement with those found by Khan *et al.*, (2000) and Saleh and Masiron (1994) on groundnut lines evaluations in Malaysia.

#### **5.4.2. Drought Tolerance**

The hybrid ICG 11249 x RRB showed the highest values for pod yield and total biomass under drought followed by ICGV-SM 99511 x 55-437. SPAD chlorophyll meter readings values at 80DAS were greater than SPAD chlorophyll meter reading values at 60DAS for all crosses. The highest harvest index was found with the hybrid ICGV-SM 99511 x 55-437 (0.54), while the highest value of leaf chlorophyll content was recorded with ICGV-SM 99511 x 55-437 (39.71). Combined analysis of variance under well water and end of-season drought conditions showed large and significant differences between all 14 genotypes for all the physiological traits except for pod yield. Therefore, the tested progenies displayed high variation. Hybrids ICG11249 x JL24, ICG11249 x RRB, Tainan-9 X 55-437 and ICGVSM 99511 x 55-437 showed the highest values of drought tolerance index for SCMR, biomass and harvest index. Therefore, these hybrids are promising drought tolerant progenies. Nageswara *et al.* (1994) reported that the productivity of drought resistant groundnut lines under drought-stress conditions, as measured by total biomass, were higher than those of drought-sensitive genotypes. Thus, with differential responses to drought stress, high biomass production under drought stress of a tolerant genotype could be due to its ability to produce high biomass under well-watered conditions.

In the present study, pod yield, biomass, and harvest index decreased under end-of-season drought stress, whereas SCMR increased as reported in previous studies under various environments (Nageswara and Wright 1994; Craufurd *et al.*, 1999; Nigam *et al.*, 2008; Songsri *et al.*, 2009; Girdthai *et al.*, 2010;). However, DTI is useful in explaining how some genotypes had higher pod yield under drought. Previous reports on inheritance of drought resistance traits suggested a predominant role of additive gene effects in SLA and HI inheritance (Nigam *et al.*, 2001; Surihan *et al.*, 2005). In early generations (F<sub>3</sub> and F<sub>4</sub>), Cruickshank *et al.* (2004) reported that broad sense heritability of transpiration efficiency (TE) and harvest index (HI) were varied among groundnut crosses and traits depending on levels of genetic variation in parents. The results are also in agreement with Moreshat *et al.* (1996) who found increasing chlorophyll content under mild drought stress. Jongrunklang *et al.* (2008) also found that the more severe the drought stresses the more was the increase in SCMR. The same authors, reported relatedness between increase of SCMR and photosynthetic capacity. They concluded that the increase of SCMR could be attributed to drought tolerance. Painawadee *et al.* (2009) reported that the water loss from cells might affect the concentration of chlorophyll content. Duy Nang, (2004) also found SCMR increased in rice during stress periods but declined rapidly within three days after re-irrigation. It could be hypothesized that groundnut genotypes with high SCMR have more photosynthetic machinery per unit leaf area and hence potential for greater assimilation under drought stress (Songsri *et al.*, 2009). Boontang *et al.* (2010) reported that groundnut genotypes with high SCMR under drought stress could maintain higher biomass production.

The estimates of phenotypic coefficient of variation were higher than genotypic coefficient of variation indicating the influence of environmental factors. Pod yield, biomass and harvest index showed highest PCV estimates respectively 35.81, 26.91 and 40.20 and moderate GCV values

for the same characters. The low magnitude of difference between PCV and GCV observed with SCMR indicated that this character was less influenced by the environment (Narasimhulu *et al.*, 2012). High values of GCV suggest better improvement scope for these traits by selection. A number of authors reported comparable results where PCV values were higher than GCV values for all the traits which reflect the influence of environment on the expression of characters Roychowdhury and Tah (2011); Thirumala *et al.* (2012); Azharudheen *et al.* (2013) and Reddy *et al.* (2013).

Analysis of variance of combining ability for the physiological characters revealed significant differences ( $P \leq 0.05$  to  $P \leq 0.01$ ) among parents for all the traits except for percentage of emergence and 50% plant flowering. This indicated the presence of genotypic variability among cultivars used as parents. The significance of GCA mean squares indicated the importance of additive gene effect governing the inheritance of pod yield, biomass, harvest index and SCMR. The analysis also revealed differences among the crosses for almost all the characters. This indicated the presence of genotypic variability among  $F_3$ . GCA mean squares for males and females were highly significant for pod yield and biomass. GCA mean squares for females were greater than males GCA mean square for pod yield and biomass indicating that the major contribution to additive variance for these traits was due to the female parents. SCA mean squares differed significantly for pod yield and harvest index indicating the importance of both additive and non-additive variance for these characters. The findings are comparable to Swe and Branch (1986) who reported estimates of general and specific combining abilities to be significant for biomass, harvest index, total pod weight. John *et al.*, (2011) indicated primarily non-additive gene action was important in the inheritance SCMR. Venkateswarlu *et al.* (2007)

reported that high magnitude of general combining ability variance showed greater importance than additive gene action in the inheritance of physiological and pod yield traits.

GCA effects identified the variety 55-437 as the best male parent with good combining ability for all physiological characters under study. The variety RRB was the best combiner for biomass and pod yield. The female ICGV-SM 99511 was the best general combiner for SPAD chlorophyll meter reading and pod yield, while Tainan-9 was the best combiner for biomass and harvest index. The hybrid Tainan-9 x JL24 was the best specific combination for pod yield and harvest index. The hybrid Tainan-9 x RRB was the best specific combination for SCMR. ICG 11249 x RRB and Tainan-9 x 55-437 were the best specific combination for total biomass production. GCA Mean squares for females were greater than males for pod yield and biomass indicating the major contribution to additive variance for this trait was by the female parents. Similar results were found by Ali *et al.* (1995) and Ali *et al.* (2001).

The study showed that estimates of SCA effects were larger in magnitude than GCA effects for pod yield and biomass indicating that non-additive genetic variance was more important than additive genetic variance. These results are in agreement with John *et al.*, 2011 who found that the variance due to specific combining ability was greater than the variance due to general combining ability for all the physiological traits and concluded the predominance of non-additive gene action for these traits.

Mechanisms of drought resistance are diverse under different timing and periods of drought conditions (Clavel *et al.*, 2004; Subbarao *et al.*, 1995). Therefore, the inheritance of end-of-season drought tolerance traits might be different from other types of drought; high and moderate narrow sense heritability estimates were found for the physiological traits under study through

both methods of estimation. Nonetheless, parent-offspring regression gave better estimates of heritability compare to variance components estimates. Heritability estimates were higher by parent-offspring regression for physiological traits (SCMR, HI) than for agronomic traits (pod yield, Biomass) under well watered conditions. However, heritability estimates decreased for all physiological traits when compared between different water levels; and increased for agronomic traits. Therefore, selection for higher yield or higher biomass production under drought stress conditions should be possible. More rapid breeding progress may be achieved by using physiological or surrogate traits, such as HI, SLA, and SCMR, which may be used to select for drought tolerance (Wright *et al.*, 1994; Sheshshayee *et al.*, 2006; Arunyanark *et al.*, 2009). The results agree with Songsri *et al.*, (2008) who found high heritability estimates for physiological traits. End-of-season drought stress decreased heritability estimates for all the physiological traits except for pod yield and biomass. These findings are similar with Girdthai *et al.* (2012) who reported increase of broad sense heritability for pod yield and biomass under drought stress conditions. Boontang *et al.* (2010) also reported the maintenance of high chlorophyll under drought stress would benefit groundnuts.

Significant and positive correlation between pod yield and harvest index under both water regimes indicated it will be possible to identify relative performance of groundnut lines for drought tolerance. Harvest index had highly positive direct effects on pod yield. Hence, improvement of this character would also improve pod yield and direct selection of pod yield using this trait will be effective. Negative significant association was also found between biomass and harvest index. Wunna *et al.* (2009) reported moderate association between HI and biomass under early drought and irrigated conditions. These results support the findings of Ravi

Kumar *et al.* (2012) for SCMR, harvest index. Ahamed (1995), Abdalla *et al.* (2008) and Jayalakshmi *et al.* (2000) have reported similar results for harvest index.

## 5.5. Conclusions

Additive gene effects were found to govern the inheritance of pod yield, seed weight, pod length, maturity index. Moderate narrow sense heritability of seed weight and pod length coupled with their positive association with pod yield, indicated that these traits would be good criteria for selection programmes to improve yield of groundnut. Even though maturity index, giving a high heritability, it was not associated with the yield traits. However maturity index could be a good criterion for earliness selection because it showed a strong positive correlation with days to emergence.

The variety 55-437 was identified as the best male parent for pod yield, seed weight, and number of seed. RRB was the best male parent for maturity index and days to emergence. ICIAR19BT was the best female parent for days to emergence, pod yield, seed weight, pod length and Chico was the best female parent for maturity index.

Most physiological traits measured in these seven groundnut crosses had high heritability, indicating that breeding progress should be possible. The results of the present study indicated that harvest index, and SPAD chlorophyll meter reading observations can be recorded at both stressed and nonstressed conditions. This gives groundnut breeders flexibility to record these observations in a large number of segregating populations and breeding lines, thus making it easy to incorporate these physiological traits associated with drought tolerance in breeding and

selection schemes in groundnut. SPAD chlorophyll meter reading should be particularly useful as a selection criterion for drought tolerance in groundnut because of high heritability and the simplicity in gathering data. Groundnut lines with the ability to maintain high chlorophyll content and high biomass under drought conditions may also show better tolerance to drought. High heritability estimate for harvest index coupled with strong positive association with pod yield under both water regimes indicated the harvest index should also be considered as a selection criterion to ensure progress for pod yield.

The variety 55-437 was identified as the best male parent with good general combining ability for all physiological characters under study. The female ICGV-SM 99511 was the best female parent with good general combining ability for SPAD chlorophyll meter reading and pod yield, while Tainan-9 was the best combiner for biomass and harvest index.

## CHAPTER SIX

### 6.0. GENERAL DISCUSSION

#### 6.1. Identification of the production constraints and farmers' preferred varieties of groundnut in Niger

Farmers in Niger recognized the importance of drought as an important constraint to groundnut productivity and yields. Farmers were growing three varieties, namely 55-437, RRB and JL24, because of their adaptation to production systems. Some of the farmers were aware that they could get other types of groundnut varieties from research institutions. The farms were all family owned and the fields were small ( $\leq 2$ ha), resulting in low production levels. Groundnut is allocated a very small portion of the farm or generally intercropped with other crops, which is the most common cropping system in the Sahel. The farmers felt that producing groundnut on a larger scale would be “risky” due the frequent drought spells and rosette disease infestation. The study revealed that the farmers were ready to accept new technologies of groundnut that can mitigate the changing environment.

PRA results showed that drought and lack of improved groundnut varieties caused many farmers to abandon groundnut production and shift to other crops such cowpea and sesame. The low productivity affected women farmers more than men, because they are highly engaged in groundnut production and are not able to contribute consistently to the welfare of the household without groundnut income. In the groundnut "basin" that includes Dosso, Maradi and Zinder regions, groundnut was the major source of income. Recurrent drought has instigated a significant decrease in farmers' incomes. Groundnut production decline affected farmers' livelihood and reduced social celebrations.

Involving farmers in the developing breeding programme objectives is very important because it will (i) improve relationships between breeders and farmers, (ii) guide breeders to focus on priority constraints of farmers, and (iii) allow breeders to identify farmers' criteria for adopting new varieties. Farmers' participation in the selection process can change the classical breeder's approach.

## **6.2. Phenotyping groundnut germplasm for earliness and drought tolerance**

**Early maturity:** PCA analysis revealed that 79.62% of the total variation among the genotypes was explained by pod yield, biomass, harvest index and 50% plants flowering. The genotypes evaluated under well water condition were classified into three groups based on their maturity: (i) extra early maturing genotypes (75 to 80 days), (ii) early maturing genotypes (85 days) and (iii) intermediate genotypes ( $90 \leq x \leq 110$  days). Out of the 150 genotypes, 2 extra early (75 days) and 3 early (80 days) genotypes were identified. ICIAR19BT had the highest pod yield 1540g/15plants. ICIAR19BT was released in Nigeria in 2011 as an extra early and rosette resistant variety under the name SAMNUT 24. Chico had the lowest pod yield 430 g/15plants. It is the most widely used source of earliness in several breeding programmes. It was used 1180 times as a parent in developing early maturity lines at ICRISAT (Upadhyaya *et al.*, 2006). The selected early and extra early lines were crossed onto three farmers preferred varieties (55-437, JL24, RRB) to generate 7 F<sub>3</sub> and 7 F<sub>4</sub> populations for genetic studies.

**Drought tolerance:** Genotypes were evaluated under both water regimes to select the best drought tolerant lines. Farmers were involved in selecting these drought tolerant lines. Highly significant differences were found between the genotypes for all the traits and water regimes.

ICGV-SM99511 was the highest yielding (524 g/10plants) under well water conditions. ICG6307 was the best yielding (342 g) under end-of-season drought stress. Tainan-9, ICG11249 and ICGV-IS 01820 performed well under both well watered and end-of-season drought conditions. The five best drought tolerant genotypes were ICG6703, ICGV-SM99551, Tainan-9, ICG11249 and ICGV-IS01820. Their drought tolerance indices ranged from 0.59 to 1.76. ICG6703 had the highest DTI (1.76) and ICGV- SM 99511 the lowest DTI (0.59). Higher DTI values indicate drought tolerance (Nautiyal *et al.*, 2002). In this study, the responses to drought among the groundnut genotypes for SCMR at 45, 60 and 90 DAS were rather similar in patterns but somewhat different in extents at 90DAS. Increase of chlorophyll contents under drought stress condition was observed. Genotypes that showed high values of SCMRs under drought stress may be considered as drought tolerant. The findings are in agreement with Jongrunklang *et al.*(2008) who found an increase of SCMR of groundnut under water limiting conditions and as this trait is related to photosynthetic capacity, they concluded that the increase of SCMR could be attributed to drought tolerance. It could be hypothesized that groundnut genotypes with high SCMR have more photosynthetic machinery per unit leaf area and hence more potential for greater assimilation under drought stress (Songsri *et al.*, 2009). Boontang *et al.*, (2010) found that groundnut genotypes with high SCMR under drought stress could maintain higher biomass production. The selected drought tolerant lines were crossed onto farmers preferred varieties to develop 7 F<sub>3</sub> and 7 F<sub>4</sub> populations for genetic studies.

Some varieties have been developed at Tarna INRAN station. They are early maturing and performed well under end-of-season drought stress. Unfortunately they have not reached the farmers and seed companies yet. Six varieties out of the 10 lines selected in this study, were used in a farmer's participatory varietal selection in three locations: Angoual Doua, Dan Saga and

Elguéza. Farmers were impressed by the performance of ICIAR19BT, Tainan-9 and ICGV-SM99511 based on their earliness, drought tolerance and high yielding potential.

Selection of a preferred variety is only part of the story. For these varieties to reach a large number of farmers, seed must be available to those who want to grow them. This must involve various actors to ensure that breeder seed is available to seed companies to produce subsequent classes of seed.

### **6.3. Genetic analysis of earliness and drought tolerance**

**Early maturity:** Four hybrids, out of the seven, showed good performance for both earliness and agronomic traits. Pod yield ranged from 34.40 to 46.07g/50pods and maturity indices ranged from 203.33 to 240.33 for the hybrids ICIAR19BT x RRB, ICIAR 19BT x 55-437, 796 x RRB, 796 x JL24, and Chico x RRB in both F<sub>3</sub> and F<sub>4</sub> populations.

Significant GCA mean squares indicated the importance of additive gene effect governing the inheritance pod yield, seed yield, pod length and maturity index. Selection of superior genotypes in segregating generations should be possible for these traits. These results are in agreement with those of Jogloy *et al.*, (2005) who found significant GCA mean squares for the inheritance of pod yield, seed yield and 100-seed weight. Jogloy *et al.* (1999) found that GCA mean squares were important for pod length and seed size. Green *et al.* (1983) and Swe and Branch (1986) found that GCA and SCA mean squares were significant for yield and yield component traits.

Specific combining ability (SCA) mean squares differed significantly (at  $P \leq 0.01$  and  $P \leq 0.05$ ) for number of seed and shelling percentage indicating the importance of both additive and non-additive variance for these traits. These results support the findings of Jogloy *et al.* (1987) who

found that general combining ability was highly significant for pod yield, and shelling percentage and specific combining ability was significant for pod length and seed size. Rachmeler, (1988) found greater GCA than SCA estimates for early maturity in  $F_2$  and  $F_3$  generations. Bansal *et al.*, (1991) showed that non additive gene effects were predominant for yield components although the magnitude of additive effects was considerable.

The variety 55-437 had the best general combining ability for most traits under study. RRB was the best general combiner for maturity index and days to emergence. JL24 was the best general combiner for shelling percentage. ICIAR19BT was the best general combiner for days to emergence, pod yield, seed weight, pod length. Chico was the best general combiner for maturity index corroborating the findings of Ali *et al.* (2001). Several authors reported the use of Chico as parental line in breeding programmes for developing early maturing varieties such as N'Doye and Smith (1993), Upadhyaya and Nigam (1994) and Upadhyaya *et al.* (2006).

Estimates of SCA were larger in magnitude than GCA for 50% plant flowering, number of seed and shelling percentage indicating that non-additive genetic variance was more important than additive genetic variance for these traits.

The estimates of phenotypic coefficient of variation (PCV) were greater than genotypic coefficient of variation (GCV) for all the traits. PCV ranged from 4.36 to 19.34% and GCV from 2.02 to 11.99%. Several authors reported comparable results which reflect the influence of environment on the expression of characters (Yousaf *et al.* 2008; Sumathi *et al.* 2010; Roychowdhury *et al.* 2011 and Narasimhulu *et al.* 2012).

Narrow sense heritability estimates ranged from 35.4 to 95.5% with days to emergence being 95.5%, pod yield (85%), shelling percentage (84.3%), number of seed in 50 pods (80%) and 50% plants flowering (72%). Moderate to low heritability estimates were obtained for maturity index (66.1%), pods length (54.4%) and seed weight (35.4%). Because of higher heritabilities, selection for higher yield and maturity should be possible among the populations. The results agree with the findings of Tsaur *et al.* (1989) who reported high heritability for pod yield, pod length and 100 seed weight. Results also support the findings of Holbrook *et al.* (1989) who reported high heritability for maturity while studying F<sub>1</sub> and F<sub>2</sub> plants of reciprocal crosses involving Chico and PI383421(late maturing) groundnut lines. Ali and Wynne, (1994) similarly found high narrow sense heritability estimates for the cross NC7/Chico for 100 seed weight (71%) and pod length (52%), intermediate for maturity index (44%).

Highly significant positive correlations were found between pod yield and seed weight ( $r = 0.97$ ,  $P \leq 0.001$ ) and pod length ( $r = 0.72$ ,  $P \leq 0.01$ ); between pod length and seed weight ( $r = 0.66$ ,  $P \leq 0.01$ ); and between maturity index and days to emergence ( $r = 0.72$ ,  $P \leq 0.001$ ). Correlation between shelling percentage and seed weight was positively significant at  $P \leq 0.05$  ( $r = 0.61$ ). Simultaneous improvement of these traits should be possible. Waranyuwat and Tongsri (1990) reported highly significant associations between pod and seed yield, pod yield and number of mature seeds per plant, and seed yield and number of mature seeds per plant, but shelling percentage had variable correlation with pod and seed traits in different generations.

### **Drought tolerance:**

Pod yield, biomass, and Harvest index decreased under end of-season drought stress, whereas SCMR increased as reported in previous studies under various environments (Nigam *et al.*, 2008;

Songsri *et al.*, 2009; Girdthai *et al.*, 2010). Drought tolerance index (DTI) was useful in explaining how some genotypes had higher pod yield under drought. The crosses ICG11249 x JL24, ICG11249 x RRB, Tainan-9 X 55-437 and ICGVSM 99511 x 55-437 had the highest DTI values for SCMR, biomass and harvest index. Therefore, these crosses are promising drought tolerant progenies. Previous reports on inheritance of drought resistance traits suggested a predominant role of additive gene effects in SLA and HI inheritance (Nigam *et al.*, 2001; Surihan *et al.*, 2005). Painawadee *et al.*, (2009) reported that the water loss from cells might affect the concentration of chlorophyll. It could be hypothesized that groundnut genotypes with high SCMR have more photosynthetic machinery per unit leaf area and hence potential for greater assimilation under drought stress (Songsri *et al.*, 2009).

The significance of GCA mean squares indicated the importance of additive gene effect governing the inheritance pod yield, biomass, harvest index and SCMR. GCA mean squares for males and females were highly significant for pod yield and biomass. GCA mean squares for females were greater than males for pod yield and biomass indicating that the major contribution to additive variance for these traits was due the female parents.

SCA mean squares differed significantly for pod yield and harvest index indicating the importance of both additive and non-additive variance for these traits. The findings agree with Swe and Branch (1986) who found that estimates of general and specific combining abilities to be significant for biomass, harvest index, total pod weight. John *et al.*, (2011) indicated primarily non-additive gene action was important in the inheritance SCMR.

The variety 55-437 was the best general combiner for all physiological characters. RRB was the best general combiner for biomass and pod yield. The ICGV-SM99511 was the best general combiner for SPAD chlorophyll meter reading and pod yield while Tainan-9 was the best combiner for biomass and harvest index.

The estimates of phenotypic coefficient of variation (PCV) were greater than genotypic coefficients of variation (GCV) for all the physiological traits. PCV ranged from 7.27 to 40.20% and GCV from 2.71 to 15.91%. The traits pod yield, biomass and harvest index showed highest PCV estimates, respectively, 35.81, 26.91 and 40.20% and moderate GCV estimates 11.02, 14.12 and 15.91%, respectively, for the same traits. The low magnitude of difference between PCV (6.39%) and GCV (2.95%) observed with SPAD chlorophyll meter readings indicated that this trait was less influenced by the environment (Narasimhulu *et al.*, 2012). High values of GCV suggest that these traits can be easily improved by selection. Several authors reported comparable results where PCV values were higher than GCV values for all the traits which reflect the influence of environment on the expression of characters including Thirumala *et al.* (2012); Azharudheen *et al.* (2013) and Reddy *et al.* (2013).

Narrow sense heritability estimates for physiological traits were higher than for agronomic traits, and varied under both well-watered and end-of-season drought conditions. The heritability estimates for pod yield (0.26) and biomass (0.18) were low, but they were high for harvest index (0.78) and SPAD chlorophyll meter reading 0.71 and 0.68 respectively at 60 and 80 days after sowing. Fifty percent (50%) Plants flowering showed moderate heritability estimate of 0.56. End of-season drought decreased narrow sense heritability estimates for all the physiological traits. Heritability estimates decrease from 71.6% to 36.8% for SCMR60DAS; from 68.2% to 10.6% for

SCMR80DAS and from 78.9% to 37.8% for harvest index. Results agree with Songsri *et al.* (2008) who found high heritability estimates for physiological traits. End of-season drought stress decreased heritability estimates for all the physiological traits except for pod yield and biomass. These findings are similar with Girdthai *et al.*, (2012) who found increase of broad sense heritability for pod yield and biomass under drought stress conditions.

Highly significant positive association between pod yield and harvest index was found in both water regimes. The correlation coefficient was higher ( $r = 0.77$ ,  $P \leq 0.001$ ) under end of-season drought stress condition than under well watered conditions ( $r = 0.74$ ,  $P \leq 0.01$ ). Strong negative significant ( $P \leq 0.05$ ) correlation was found between biomass and harvest index under well watered and end of-season drought conditions  $r = -0.66$ ,  $-0.58$ , respectively. Weak positive and non-significant correlation was found between SCMR and pod yield, under well watered conditions ( $r = 0.38$ ). Wunna *et al.* (2009) reported moderate association between HI and biomass under early drought and irrigated condition. These results support the findings of Ravi Kumar *et al.* (2012) for SCMR, harvest index. Ahamed (1995), Abdalla *et al.* (2008) and Jayalakshmi *et al.* (2000) have reported similar results for harvest index.

In the past, breeders focused on earliness as a drought escape mechanism, particularly for the end-of-season drought that was easily predictable in the past. But, now with climate variability, this is changing. Rainfall is very erratic, floods are frequent, intermitted drought spells are frequent. Therefore, the drought escape strategy is not adequate because it is difficult to predict the end-of-season drought. However, drought escape mechanisms are still useful; for example, during rainy season 2013, most of groundnut growing areas in Niger experienced end-of-season drought. Interestingly, FESA seed Company reported that they had already harvested

the extra early variety identified in the study that matured in 75 days, before end-of-season drought. The manager of this seed company was very impressed with the potential of this variety and organized a field day to share his findings with farmers around his farm. On station the variety was planted 15th July and harvested September 30<sup>th</sup> 2013. The success of the variety ICIAR19BT to escape drought means that earliness as a drought avoidance mechanism remains supportable.

Promising early maturity and drought tolerant crosses were identified in this study and could be exploited to develop new varieties following their evaluation across several environments. Through conventional breeding, genetic variability for drought tolerance among groundnut cultivars can be identified and the genetic variation identified can be introduced through different mating designs into cultivars with good agronomic characteristics. Relationships that have been established between farmers and seed companies and INRAN's seed unit must be maintained to implement a viable groundnut breeding programme in Niger. Farmers' confidence in groundnut production should be restored by development of new improved early or drought tolerant groundnut varieties.

Conventional plant breeding is a highly time-consuming as well as a cost- and labor-intensive approach. When transferring desired genes from one plant to other through the conventional plant breeding, a number of undesired genes are also transferred. To achieve gains through traditional breeding, a number of selection and breeding cycles are required. The limited success in improving crop drought tolerance is because drought tolerance is controlled by multiple genes having additive effects and a strong interaction exists between the genes for drought tolerance and those involved in yield potential. Thus, there is a need to seek more efficient approaches for

genetically tailoring crops for enhanced drought tolerance. Through marker-assisted breeding (MAB), it is now possible to examine thousands of genomic regions of a crop under water limited regimes, which was, previously not possible (Ashraf, 2010). Drought tolerance QTLs have been reported, this information can be exploited to introgress drought tolerance related traits such as transpiration, TE, SLA, SCMR into elite early maturing variety. Ravi *et al.* (2010) reported a number of QTLs for drought tolerance related traits in groundnut, including transpiration (7 QTLs), TE (7), SLA (13), SCMR (29), Biomass (7), Pod yield (7), Seed weight (5), and Haulm (6).

From farmers' perceptions about earliness and drought tolerance, breeding efforts can be focused on "ideal" variety and can combine earliness, drought tolerance and high yielding. Development of ideal variety can be achieved more efficiently by using Marker assisted backcrossing. An extra early variety (ICIAR19BT) with good combining ability for most traits studied and drought tolerant varieties also have been identified. Molecular screening of the selected drought tolerant varieties will be crucial to identify genotypes carrying drought tolerance QTLs to facilitate marker assisted selection. Information generated from this study can be used to develop new groundnut varieties combining both traits.

In the context of climate change, breeding efforts should focus on drought and high temperatures in the near future. Therefore, prior to establishing a viable breeding programme, a better understanding of interactions between the abiotic stresses is required. In addition to this understanding, relationships between biotic and abiotic stress must be established.

## CHAPTER SEVEN

### 7.0. GENERAL CONCLUSIONS AND RECOMMENDATIONS

#### 7.1. General conclusions

Through this study, the main constraints to groundnut production and preferred varieties have been identified. Drought and low soil fertility were the most important constraints contributing to low groundnut production in the study areas. The most preferred varieties were 55-347, RRB, and JL24. These will be used in a breeding programme to develop new early maturing genotypes that are drought tolerant. It was also clear that drought is the major production constraint in both regions of the study. The information gathered is useful for groundnut breeders to develop good quality groundnut varieties that incorporate farmers' preferences.

The genetic variation found in the germplasm screened for early maturity and drought tolerance will help breeders to develop higher yielding early- maturing and drought- tolerant groundnut varieties adapted to the Sahelian environment characterized by a short crop period and intermittent drought spells. Two extra early varieties namely Chico and ICIAR19BT, and three early maturing varieties ICG3584, ICGV02022 and 796 were identified. Five drought tolerant varieties namely ICG6703, ICGV-SM 99551, Tainan-9, ICG11249 and ICGV-IS01820 were selected. These materials can be used as parental lines in a breeding programme to develop early maturing and drought tolerant varieties. The varieties ICIAR19BT and ICGV-SM 99511 were the best high yielding.

The results from the genetic analysis show that it is possible to select for both earliness and drought tolerance in early generations. This process could be enhanced using marker assisted selection schemes if and when QTLs/genes for the traits are found and markers are developed.

Additive gene effects primarily controlled the inheritance of pod yield, seed yield, pod length, and maturity index. Based on heritability of seed weight and pod length and their positive association with pod yield, these traits could be used to improve yield of groundnut. Maturity index, although giving a high heritability estimate, was not associated with the yield traits, but showed a strong correlation with days to emergence. It could be a good criterion for earliness selection.

Most physiological traits evaluated had high heritability, indicating that breeding progress should be possible. SPAD chlorophyll meter readings should be particularly useful as a selection criterion for drought tolerance in groundnut because of high heritability and the simplicity in gathering data. Groundnut lines with the ability to maintain high chlorophyll content and high biomass under drought conditions may also show better tolerance to drought. High heritability estimates for harvest index coupled with strong positive association with pod yield under both water regimes indicated the harvest index should also be considered as a selection criterion for pod yield.

The variety 55-437 contributed to superior pod yield, seed weight, number of seed, harvest index and SCMR. RRB and Chico contributed superior maturity index and days to emerge. ICIAR19BT was the best general combining ability for days to emergence, pod yield, seed weight, and pod length. ICGV-SM 99511 had the best general combining ability for SPAD chlorophyll meter reading and pod yield, while Tainan-9 was the best combiner for biomass and harvest index.

## 7.2. Recommendations

- Three farmers' varieties, 55-437, JL24 and RRB, should be used in further studies to combine earliness and drought tolerance to mitigate the effects of climate variability in Niger and similar environments in West Africa.
- One extra early maturing variety, ICIAR19BT (75 Days), and drought tolerant variety, Tainan-9, identified as high yielding and promising varieties among the parental lines should be widely evaluated in farmer participatory variety trials in the Niger groundnut main regions for release to boost groundnut production through increased productivity and contribute to smallholder farmers' livelihoods.
- QTLs for earliness and drought tolerance should be mapped in the population developed in this study. This would facilitate the application of marker assisted selection if large effects of QTL's will be found.
- A study should be carried out to combine earliness and drought tolerance traits to develop varieties that are capable of producing high yields to allow them to grow in harsher environments similar to those of Niger.
- The best specific crosses for earliness and drought tolerance should be advanced up to F5 before selection through bulk method to develop new pure lines varieties.

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## APPENDICES

## APPENDIX 1: check list of focus group discussion

Number	Check list of the Focus Group Discussion
<b>Varieties used and seeds sources</b>	
1.	<b>Varieties used</b> <b>a. Identification and characterization of varieties</b> - How many groundnut varieties do you use? - Can you describe each of those varieties? <b>b. Assessment of varietal change over time</b> - Varieties were cultivated for how many times before you change to a new variety?  <b>c. Varieties ranking</b> - Can you rank all the varieties that are used in your village?
2.	<b>Seed management:</b> <b>a. Seed selection</b> - How do you select groundnut seeds for next cropping season?  <b>b. Seed storage</b> - Are you having any problem of storage?
3.	<b>Seed access</b> - What are the sources of seeds used? - Are you having any problem to access seeds?
4.	<b>Socio-economic data</b> <b>a. Farmland size</b> - Can you tell us the size of land roughly allocated to groundnut production? <b>b. Equipment</b> - Which types of equipment do you use for groundnut cultivation?
5.	<b>Farming system</b> - Can you describe the farming system currently used in your village?
6.	<b>Planting &amp; harvesting time</b> - What are your groundnut planting times? - At which period is groundnut mostly harvested?
<b>Production constraints</b>	
7.	<b>Biotic stresses</b> - Do you have any biotic stresses in groundnut production? - How do you manage insects and diseases?
8.	<b>Abiotic stresses</b> - What are the major abiotic stresses that limit groundnut production? - Can you describe the methods used to manage drought locally?
9.	<b>Fertiliser application</b> - Do you apply fertilizer? - Which types do you apply?
10.	<b>Weeding</b> - How many times is weeding done in your groundnut field?
11.	<b>Constraints ranking</b> - Can you rank the main production constraints?
<b>Marketing</b>	
12.	- Are you having any difficulties to sell your production?

**APPENDIX 2: Performance of 150 genotypes**

Number	Entry	% EMERG 7DAS	ND 50% PF	MD	PY (g)	BIO (g)	HI	PH (cm)
1	796	100	24	80	560	2000	0.28	52.33
2	ICIAR 19BT GH	100	24	75	930	1570	0.59	54.33
3	J 11 Niger	100	24	85	390	1860	0.2	54.33
4	ICG 3584	96	24	80	570	2050	0.27	54.33
5	ICGV-IS01835	96	24	85	690	1700	0.4	48
6	ICG 3312	92	26	85	450	1220	0.36	44
7	ICGV-IS 01827	92	26	85	570	1258	0.45	44.66
8	ICGV-IS 01852	92	24	85	670	1930	0.34	56.66
9	TS 32 -1 Niger	92	24	85	300	2100	0.14	58.66
10	ICG 12879	92	24	90	570	720	0.79	31.66
11	55-437 Niger	92	24	90	570	1450	0.39	48
12	ICG 15380	87.5	22	85	740	2340	0.31	56.66
13	SHITAOCHI	87.5	26	85	710	1260	0.56	49.33
14	ICIAR 12AT	87.5	28	85	210	700	0.3	46
15	ICG 1487	87.5	24	85	580	2760	0.21	45.33
16	ICG 4764	87.5	24	85	600	1380	0.43	54.66
17	ICG 81	87.5	24	90	480	985	0.48	49.33
18	ICGV-IS01859	87.5	24	90	830	1900	0.43	53.33
19	ICG 8106	86	24	85	300	2000	0.15	43
20	ICG 02022	83	24	80	580	1580	0.36	50.33
21	ICIAR 19 BT NG	83	24	80	580	1100	0.52	54
22	T44 - 88	83	28	85	530	1830	0.28	49.33
23	T169 - 83	83	26	85	790	1560	0.5	46.66
24	ICG 10384	83	26	90	440	1930	0.22	47.33
25	ICG 2019	83	24	90	630	1680	0.375	55.33
26	ICG 3421	83	26	90	1210	2760	0.43	58.66
27	Dayo early	83	26	90	870	1700	0.51	48.66
28	T131 - 83	79	26	85	720	2354	0.3	43.33
29	ICG 1519	79	24	85	550	1420	0.38	50.66
30	T9 - 89	79	26	85	630	1380	0.45	52.66
31	ICG 405	79	26	85	760	1180	0.64	46
32	ICG 11249	79	24	90	810	1570	0.51	46.66
33	ICGV-SM 99507 Niger	79	24	91	930	1910	0.48	44.33
34	Chico	75	24	75	540	1860	0.29	39.33
35	ICG 1415	75	26	85	730	2100	0.34	44.66
36	ICG 9315	75	24	85	470	2520	0.18	55.33
37	ICGV-IS01836	75	28	90	750	2250	0.33	50.66
38	T6 - 96	75	24	90	1070	1400	0.76	44
39	Fleur 11 Niger	71	26	85	590	1760	0.33	43
40	ICG-3736	67	26	85	630	1250	0.5	48.66

41	ICG 15236	67	28	85	420	1090	0.38	48.66
42	T 177 - 83	67	26	90	800	1960	0.4	46.66
43	ICG 9809	67	24	90	890	2040	0.43	47.33
44	TX 903652	62.5	26	85	500	2330	0.21	42.33
45	ICG 14106	62.5	24	85	450	1050	0.42	51.33
46	ICG-12991	62.5	28	90	1000	1880	0.53	53.33
47	T127 - 83	58	26	85	480	1340	0.35	51.33
48	T2 - 2007	58	26	85	1240	1780	0.69	52
49	ICG 6703	58	22	90	650	1540	0.42	44
50	T13-89	54	28	85	720	1760	0.4	48.66
51	O-20	54	26	90	390	1720	0.22	54.66
52	T45 - 87	54	26	90	530	1470	0.36	44
53	T181 - 83	50	26	90	700	1940	0.36	47.33
54	T49-87	46	28	85	1220	1987	0.61	42.66
55	ICG 12921	46	24	85	350	1470	0.23	45.33
56	T119-83	46	26	91	690	1587	0.43	51.33
57	T4 -96	41	28	90	990	3040	0.32	48.66
58	ICG 4670	37.5	28	85	700	1820	0.38	52
59	ICG 9346	37.5	28	85	740	1360	0.54	55.33
60	ICG 1823	33	28	91	800	2230	0.35	46.33
61	ICG 4728	29	28	90	600	1850	0.32	48.66
62	ICG 2738	25	26	90	570	1790	0.31	50
63	IGC 3386	21	28	90	870	2540	0.34	60.33
64	ICG 3775	4	28	90	490	1660	0.29	45.33
65	CMA 8705	0	0	0	0	0	0	0
66	CMA 87111	0	0	0	0			
67	ICG-4747	0	0	0	0	0		
68	CMA 87082	0	0	0	0	0	0	0
69	CMA 87063	0	0	0	0	0	0	0
70	CMA 95044	0	0	0	0	0	0	0
71	CMA 87007	0	0	0	0	0	0	0
72	CMA 95006	0	0	0	0	0	0	0
73	CMA 92072	0	0	0	0	0	0	0
74	CMA 95008	0	0	0	0	0	0	0
75	ICG 434	0	0	0	0	0	0	0
76	RRB Niger	87.5	26	95	680	1460	0.46	42.66
77	ICGV-IS 96 -895	75	26	95	710	1860	0.38	41.33
78	ICGV 02266	54	26	95	620	2380	0.26	49.66
79	ICGV 97182	67	26	95	480	1520	0.31	42.66
80	KPANIELLI-ICGV90084	33	26	95	540	2570	0.21	50
81	ICGV-87281	41	30	95	650	1380	0.47	50
82	ICG 397	87.5	24	95	870	1580	0.55	40.33
83	ICG 1415	4	28	95	360	1320	0.27	39.33

84	ICGV-92101	67	26	95	430	976	0.44	44.66
85	ICG 7906	12.5	30	95	1100	2550	0.43	50.33
86	SH470P	71	26	95	1090	2040	0.53	42.66
87	ICG 3657	29	30	95	830	1720	0.48	51.33
88	ICG 3343	75	26	95	840	1350	0.62	52
89	ICGV - SM 99511	50	24	95	890	1980	0.44	48.33
90	ICG 1914	8	38	95	440	830	0.53	33.66
91	ICGV-87003	83	26	95	1330	1720	0.77	48.66
92	ICG 9777	29	30	95	220	890	0.24	43.66
93	T3 - 96	62.5	26	95	760	1460	0.52	50.66
94	ICG-6222	83	24	95	930	2500	0.37	62
95	ICG-476	4	32	98	700	1800	0.38	33.33
96	ICG 9666	29	28	98	550	2320	0.23	42.66
97	JL24	79	24	100	1160	1850	0.62	46.33
98	ICGV-87123	0	24	100	1290	1830	0.7	47.33
99	Te3	83	28	100	900	1940	0.46	42.66
100	GUSIE-BALIN(ICGV92099)	79	28	100	910	2460	0.36	42
101	Edorpo-Munikpa (SARGV 88001)	71	28	100	680	3080	0.22	50
102	ICG 9346	92	26	100	390	2300	0.16	56
103	T47 - 87	92	26	100	1110	1300	0.85	46
104	ICG 5494	12.5	28	100	440	1070	0.41	42.33
105	ICG 3746	58	28	100	450	2380	0.18	52.66
106	ICGV-IS 01850	75	24	100	1140	1900	0.6	48.66
107	T1 - 95	0.75	28	100	660	1080	0.61	50
108	ICGV-SM 99504 Niger	0.92	24	100	1080	1860	0.58	55.33
109	TX 903620	0.83	30	100	470	910	0.51	38
110	T5 - 96	71	26	100	960	2250	0.42	49
111	ICIAR 7B	92	26	100	830	1540	0.53	46.66
112	ICGV-IS01851	79	24	100	640	880	0.72	43.66
113	ICG 296	46	26	110	730	1760	0.41	47.33
114	ICG 7756	83	28	110	510	3500	0.14	48
115	ICG 76	54	32	110	470	2680	0.17	29.66
116	NC 7	71	28	110	890	1760	0.5	40.66
117	ICG 15232	0	30	110	430	900	0.47	39.33
118	MANIPINTAR	58	28	110	220	3580	0.06	47.33
119	ICGV-IS 96 -814	33	28	110	1020	2230	0.45	43.66
120	ICGV - SM 99505	71	24	110	600	1440	0.41	43.33
121	ICG 1142	0	42	110	100	520	0.19	47
122	ICG 3240	87.5	24	110	580	1930	0.3	45.33
123	ICG 2716	17	26	110	260	2630	0.09	50
124	ICGV-91225	92	28	110	590	3130	0.18	53.33
125	ICGV-IS01835	58	30	110	780	2190	0.35	47.66
126	ICG 15233	0	38	110	340	870	0.39	42

127	NKATIESARI	71	28	110	890	2360	0.37	43
128	ICG-10142 TIFFON-8	4	39	110	280	1960	0.142	30.33
129	ICGV(FDRS)-20X F-MIX-39	83	26	110	840	1870	0.44	40
130	ICG 6813	33	30	110	140	1560	0.08	32.66
131	ICG 5475	79	26	110	840	1500	0.56	50
132	Tainan - 9	4	30	110	720	1270	0.56	42
133	ICG 3027	33	32	110	560	1770	0.31	44.66
134	ICGV-IS92093	62.5	28	110	860	1620	0.53	44
135	ICG 1534	92	26	110	540	2710	0.19	51
136	ICGV-92087	54	28	110	630	2580	0.24	52.66
137	ICG 8751	87.5	26	110	510	810	0.62	38
138	MIX SINK 24	67	26	110	960	1540	0.62	40
139	ICG 297	62.5	28	110	650	1280	0.5	48
140	ICG 1703	0	30	110	150	250	0.6	33.33
141	ICGV-IS 01820	87.5	26	110	1000	1550	0.64	51.66
142	F-MIX	75	28	110	720	2000	0.36	39
143	ICG-3301	12.5	30	110	480	2520	0.19	47.33
144	ICG 1834	100	26	110	1000	1580	0.63	56.66
145	ICG-1697	8	32	110	660	1260	0.52	44.66
146	CMA 87073	0	38	110	50	120	0.41	26
147	ICG 862	46	30	110	540	1270	0.42	22.33
148	ICG 11088	0	38	110	30	420	0.07	22
149	ICG 6022	17	28	110	590	900	0.65	48.66
150	ICG 2773	54	32	111	410	2110	0.19	35.33

**% EMERG:** Percentage of emergence, **50% PF:** 50% plant flowering, **DM:** Date to maturity, **PY:** Pod yield, **BIO:** Biomass, **HI:** Harvest index, **PH:** Plant height

**APPENDIX 3: Mean performance of 100 genotypes under both water regimes**

Genotypes	Pod Yield		SCMR 45 DAS		SCMR 60 DAS		SCMR 90 DAS	
	WS	WW	WS	WW	WS	WW	WS	WW
Dayo Early	205.5	191	37.9	41.4	51.4	44.5	44.15	39.15
Edorpo-Munikpa (SARGV 88001)	97.5	134.5	42.3	39.7	51.05	46.35	47.25	44.45
F-MIX	128.5	111	38.5	38.7	46.15	44.85	43.75	43.6
Fleur 11 Niger	182.5	318	42.85	40.8	46.15	43.95	49.15	41.4
GUSIE-BALIN(ICGV92099)	102	128	40.05	36.35	49.95	42.7	45.35	45.95
ICG 11249	204	204	44.3	36.2	48.75	44.05	46.25	41.7
ICG 12879	119	305	40.15	34.6	48.15	39.95	45.85	36.05
ICG 14106	102.5	186.5	39.9	39.9	44.9	44.75	45.15	41.1
ICG 1415	137.5	224.5	38.75	40.3	49	41.85	48.35	43.95
ICG 1519	172.5	266.5	40.75	39.4	52.8	44.8	40.75	38.9
ICG 15232	146.5	164	41.75	40.85	53.7	50	45.45	47.35
ICG 15236	56.5	173	44.65	41.65	51.6	44.95	47.1	41.1
ICG 1534	224	264.5	34.55	32.05	40.65	38.45	45.25	37.8
ICG 15380	133.5	221.5	38.25	38	51.9	43	44.55	40.75
ICG 1823	160.5	253	39.6	39.85	47.2	46.25	45	41.8
ICG 1834	223	229.5	36.2	38.4	44.5	42.45	46.4	39.6
ICG 1914	116	233.5	46.25	40.5	51.15	49.5	47.45	43
ICG 2716	186	345.5	40.3	42.6	45.4	43.9	45.3	40.45
ICG 2738	326.5	191	36.85	40.35	47.75	44.95	45.7	41.8
ICG 2773	98.5	142.5	43.35	40.2	49.8	46.95	47.45	45.85
ICG 296	105	120	40.8	36.55	44.35	44.1	44.9	40.5
ICG 297	279	286.5	40.65	39.3	40.85	38.1	41.5	37.7
ICG 3027	234	146.5	41.15	42.35	49	49.1	46.75	39.55
ICG 3240	121	269.5	38.8	41.55	43.95	45.5	43.4	41.15
ICG 3343	213	280	43	41.3	51.25	43.35	46.8	40.7
ICG 3421	253.5	309.5	44.05	38.9	47.4	45.15	43.45	40.55
ICG 3657	167.5	301	42.25	37	50.7	44.9	43	42.5
ICG 3746	206	265.5	42.8	38.4	47.6	40.35	45.2	41.7
ICG 3775	63.5	242	41	38.55	49.05	44	45.75	42.55
ICG 397	204.5	291	38.85	37.7	42.6	41.25	39.7	38.2
ICG 405	138.5	267.5	44.2	41.5	50.4	46.25	47.05	45.25
ICG 4728	224.5	337.5	40.15	37.65	45.45	46.2	44.85	39.9
ICG 5475	261	335.5	40.1	42.55	46.1	46.75	46	41.5
ICG 5494	195.5	235	41.8	42.55	47.8	40.85	48.3	37.65
ICG 6022	300	218.5	42.35	39.75	44.4	42.25	44.25	38.25
ICG 6703	342	194	39.95	35.05	40.5	43.75	44.5	38.85
ICG 76	128.5	92	38.1	40.6	48.65	44.6	49.35	40.85
ICG 7756	63.5	105	45.1	41.25	48.9	53.5	48.75	46.45
ICG 7906	191	172.5	41.25	39.25	50.45	43.25	45.35	41.4

ICG 862	62	98	41.2	36.55	51.15	41.05	50.7	41.95
ICG 8751	197.5	283	36.6	37.85	42.05	45.5	45.05	39.65
ICG 9346	162.5	315	38.75	40.05	48.65	45.75	46.2	41.65
ICG 9666	206	94.5	41.5	41.55	47.15	44.85	50.5	43.25
ICG 9777	53.5	78	40.9	40.8	44.4	44.4	49.85	41.15
ICG 9809	163	138.5	42.6	40.4	50.55	44.9	46.75	46.25
ICG-10142 TIFFON-8	54.5	64.5	43.05	41.5	53.75	46.45	51.95	45.9
ICG-12991	207.5	196	40.5	38.55	48.6	45.05	43.05	41.35
ICG-1697	118	95.5	43.15	43.35	41.7	41.5	40.4	41.25
ICG-3301	236.5	188.5	36.05	36.65	44.55	43.4	41.05	38.8
ICG-476	110.5	321.5	36.65	34.45	40.95	42.95	41.45	38.55
ICG-6222	210	410	41.55	38.9	45.6	44.1	44.3	39.15
ICGV - SM 99505	161.5	302	40.7	40.1	43.55	46.8	44.7	40.35
ICGV - SM 99511	309	524	42.3	35.2	48.25	43.05	44.6	46.35
ICGV 02266	310	203.5	42.15	43.8	45.75	47.45	46.55	45.65
ICGV 97182	149.5	314.5	42.65	40.15	44.8	44.3	45.45	43.2
ICGV(FDRS)-20X F-MIX-39	82.5	194.5	41.7	41.3	50.2	45.75	46.15	42.4
ICGV-87003	138	261.5	39.9	36.4	45.8	44.3	44.3	38.8
ICGV-87123	302.5	192.5	40.85	37.3	50.35	43.4	41.5	42.6
ICGV-87281	207	213.5	41.2	39.25	41.9	40.6	43.95	40.3
ICGV-91225	194.5	155	36.65	38.7	47.15	45.3	46.5	45.25
ICGV-92087	91	73.5	37.6	37.7	47.1	45.9	45.5	44.1
ICGV-92101	87	172	47.2	40.55	50.5	45.45	47.6	46.35
ICGV-IS 01820	220	222.5	48.4	43.85	50.25	48	47.45	45.7
ICGV-IS 01850	115	335	43	40.6	52.1	48.45	46.15	41.65
ICGV-IS 01852	282.5	221	42.4	42.45	54.35	52.8	46.75	44.65
ICGV-IS 96 -814	65	69.5	42.85	39.1	47.25	37.7	46.95	41.45
ICGV-IS 96 -895	82	257.5	40.25	38.7	48.1	44.75	48.35	43.6
ICGV-IS01835	183	117	41.9	44.3	49.05	44	43.95	40.1
ICGV-IS01836	270.5	343	41.25	40.6	48.7	43.75	48.2	39.5
ICGV-IS01851	34.5	104	43.95	42.3	56.2	50	53.9	46.35
ICGV-IS01859	205.5	299	44.05	44.4	48.9	52.75	48.7	43.05
ICGV-IS92093	122	105	38	40.7	48.65	47.85	48.1	44.95
ICGV-SM 99504 Niger	194.5	260.5	43.25	40.65	51.2	42.6	45.65	40.9
ICGV-SM 99507 Niger	162	319	43.45	40.5	47.9	44.7	45.75	42.35
ICIAR 7B	106.5	298	41.3	41.4	45.6	46.8	49.6	43.95
IGC 3386	240.5	208	39.4	38.75	42.8	46.8	42.4	40.1
KPANIELLI-ICGV90084	59.5	114.5	40.55	41.55	46.35	45.25	45.45	43.7
MANIPINTAR	97.5	84.5	45.7	43	50.55	45.3	45.7	45.65
MIX SINK 24	118.5	129	39.85	35.7	42.5	42.1	46.95	43.9
NC 7	123	171.5	40.9	41.35	46.7	46.35	47.45	44.4
NKATIESARI	110	139	38.25	38.05	45.65	46.05	49.4	45.45
SH470P	164.5	327.5	41.05	39.55	47	45.35	44.5	38.75

SHITAOCHI	142	246	42.15	31.3	45.9	47.25	45.6	38.2
T1 - 95	165	205	42.65	40.3	51.7	41.8	47.5	40.45
T119-83	158	190.5	39.55	42.05	48.4	43.45	43.55	39.45
T13-89	274.5	315.5	40.4	38.45	46.95	44.6	51.15	40.8
T169 - 83	170	295	40.05	37.7	51.65	49.6	43.65	43.15
T181 - 83	136.5	238.5	39	39.35	46.8	45.4	46.65	39.8
T2 - 2007	145	283	40.15	40.5	49.55	42.4	47.5	40.1
T4 - 96	134.5	309.5	40.95	39.5	49	44.35	46.5	40
T45 - 87	133.5	271	43.3	39.75	53.05	46.2	46.95	40.75
T47 - 87	188	405.5	38.8	40.25	53.3	42.5	45.75	39.8
T49-87	179	265.5	39.45	38.15	44.9	39.45	45.6	40.65
T5 - 96	184	160	45.2	40.4	47.8	43.6	47.5	39.35
T6 - 96	119.5	233.5	48.7	38.7	48.2	48.35	45.3	41.8
T9 - 89	166	210	38.65	42.6	46.15	45.7	43.95	40.95
Tainan - 9	157	159	40.65	41.55	47.5	42.05	48.6	40.1
Te3	116	236.5	44.65	44.5	47.45	44.7	43.4	39.5
TX 903620	181.5	245.5	41.45	39.65	45.9	46.3	47.7	43.1
<b>Mean</b>	<b>165</b>	<b>222.6</b>	<b>41.16</b>	<b>39.66</b>	<b>47.78</b>	<b>44.77</b>	<b>45.97</b>	<b>41.75</b>
<b>CV %</b>	<b>46.11</b>		<b>7.03</b>		<b>8.59</b>		<b>6.06</b>	
<b>SE</b>	<b>89.37</b>		<b>2.841</b>		<b>3.973</b>		<b>2.658</b>	