Farmer perceptions and genetic studies of rosette disease in groundnut (*Arachis hypogaea* L.) in northern Mozambique

By

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THESIS ABSTRACT

Groundnut (*Arachis hypogaea* L.) is an important food and cash crop in Mozambique and production has been constrained by lack of high-yielding cultivars and disease infection. Objectives of this study were: 1) to identify farmers' major groundnut production constraints and their preferences for cultivars; 2) to determine genotypic variation among landraces for agro-morphological traits and resistance to groundnut rosette disease; 3) to determine agronomic performance and resistance to groundnut rosette disease among advanced groundnut lines; and 4) to determine the inheritance of resistance to groundnut rosette disease. The study was conducted in northern Mozambique from 2008/2009 to 2010/2011.

In attempt to identify farmers' major groundnut production constraints and their preferences in cultivars, a participatory rural appraisal (PRA) was conducted in Namuno and Erati districts in northern Mozambique. Results from the PRA showed that farmers were aware of the constraints affecting groundnut production and productivity in the study area. The major constraints included groundnut rosette disease, insect pests, lack of seeds and improved cultivars, low soil fertility and lack of infra-structure. Groundnut rosette disease was ranked the most important constraint, and it was widespread in the region. Selection criterion for groundnut cultivars used by women differed from that used by men within village and across villages. However, high yield and oil content were the most important traits preferred by farmers followed by pod and seed size, earliness, disease and insect pest resistance.

Fifty-eight groundnut landraces were collected from northern Mozambique (Nampula, Cabo Delgado, Niassa and Zambezia) and evaluated for variation in agro-morphological traits and resistance to groundnut rosette disease. The landraces showed high phenotypic diversity in agro-morphological traits. Clustering by nearest neighbour method indicated that the genotypes could be grouped into six clusters, indicating that agro-morphological diversity exists. The highest yielding genotypes were Pambara-4, Pambara-2, Pambara-6, Ile-1, Imponge-1-Tom and Gile-5. There was considerable genetic variability for resistance to groundnut rosette disease among the landraces. Four landraces (PAN-4, Imponge-4, Pambara-3, Metarica Joao) were classified as resistant. No significant correlation was observed between seed yield and groundnut rosette incidence.

Thirty-two improved lines were evaluated for performance in two growing seasons across three locations in northern Mozambique (Nampula, Namapa and Mapupulo). The results indicated that the highest yielding genotype was 23A and the highest yielding location was Namapa. There was a significant and negative correlation between seed yield and groundnut rosette disease indicating that the seed yield was negatively influenced by the disease. The results on stability analysis indicated that genotype 35B was the most stable across environments since it had coefficient of regression around unity (bi=1.024), high coefficient of determination (R^2=0.999), and small variance deviation (var-dev=162.8), and 13 % above average seed yield. It is, therefore, concluded that genotype 35A could be recommended for cultivation on diverse environments of northern Mozambique.

A trial was conducted using the parents and F_2 populations derived from a 7 X 7 diallel cross. The test materials were infected with groundnut rosette disease using the spreader-row technique. The results indicated that no genotype was immune to disease. The mean squares due to both general combining ability (GCA) and specific combining ability (SCA) were significant indicating that additive and non-additive gene actions were involved in the expression of resistance to groundnut rosette disease. The general predictability ratio (GCA:SCA) was 0.97, indicating the predominance of additive over non-additive gene action in the inheritance of the disease. The study also found that groundnut rosette disease was controlled by two recessive genes. However, some genetic modifiers may also be present and influence disease expression.

In general, the study revealed that breeding opportunities do exist, incorporating farmers preferred traits and major groundnut production constraints into new groundnut cultivars. Improving cultivars for resistance to groundnut rosette disease will be a major breeding focus, while selection for other traits and constraints will not be ignored. Resistance has been identified from local landraces. Advanced lines with high yields across environments were identified that can be recommended for release. The high significant additive effects observed for groundnut rosette disease implied genetic advance could be effective in the F_2 and later generations through selection, although modifiers could slow the progress.

DECLARATION

I, Amade Muitia, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

    a. Their words have been re-written but the general information attributed to them has been referenced

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5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the references sections.

Signed:

……...……..
Amade Muitia

As the candidate's supervisors, we agree to the submission of this thesis:

……
Dr. Githiri Mwangi (Supervisor)

……..……
Prof. Mark Laing (Co-Supervisor)

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DEDICATION

This thesis is dedicated to people closest to me who have always believed in me: my daughters (Clidemia and Edmonia), my sister (Julieta Miliano) and my late parents (Miliano Muitia and Aina Faquihi).

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GENERAL INTRODUCTION

Groundnut production in the world and Africa

Groundnut is an important food crop in the world. It is cultivated in more than 100 countries located in tropical, sub-tropical, and warm temperate regions of the world. Over two-thirds of global groundnut production occurs in seasonally dry regions, where drought is a potential constraint for crop production (Smartt, 1994). During 2009 it was harvested on about 23.39 million ha with an estimated total production of 36.46 million tonnes (groundnuts in shell) and an average yield of 1.52 t ha^{-1} (FAOSTAT, 2011).

Over one-quarter of the world groundnut production is in Africa with average yield of about 0.91 t ha^{-1} (Table 1), a figure that is far much lower than the world average of 1.52 t ha^{-1} (FAOSTAT, 2011). The ten major groundnut producing countries in Africa in 2009 were Nigeria, Senegal, Sudan, Ghana, Chad, Tanzania, DR Congo, Guinea, Mali and Burkina Faso. Mozambique was ranked among the top 25 major groundnut producing countries in Africa.

Table 1: World groundnut production in 2009

Region	Area (10^3 ha)	production (10^3 tonnes)	Yield (kg ha^{-1})	Relative contribution (%)
Africa	11024.08	10021.70	0.91	27.49
America	999.14	2936.10	2.94	8.05
Asia	11901.86	23465.62	1.97	64.37
Europe	10.47	8.43	0.81	0.02
Oceania	15.61	24.94	1.60	0.07
Rest of World	23951.16	36456.79	1.52	

Source: FAOSTAT (2011)

Groundnut production in Mozambique

Groundnut (*Arachis hypogaea* L.) is the third most important crop in Mozambique, after maize (Zea mays L.) and cassava (*Manihot esculenta* L.) (Walker et al., 2006). It is one of the major cash crops and the main source of protein and cooking oil for many Mozambican families (Muitia, 2005). Groundnut occupies the largest area among grain legumes in Mozambique (Arias and Libombo, 1994) and is the most important oilseed crop followed by cotton (*Gossypium hirsitun* L.) and sunflower (*Helianthus annuus* L.). However, the total production and the total area harvested (Table 2) were almost constant from 2001 to 2009 with very low yields (FAOSTAT, 2011).

Table 2: Groundnut production in Mozambique during the period 2001-2009

Year	Area (10^3 ha)	Production (10^3 tonnes)	Yield (kg ha^{-1})
2009	295.00	68.00	0.23
2008	295.00	94.45	0.32
2007	295.00	102.90	0.35
2006	295.00	86.00	0.29
2005	293.00	93.00	0.32
2004	293.90	90.23	0.31
2003	292.30	87.46	0.30
2002	279.78	101.07	0.36
2001	237.27	109.18	0.46

Source: FAOSTAT (2011)

Most of the groundnut production in the country is concentrated in the coastal areas of the northern provinces of Nampula, Cabo Delgado and Zambezia, region 7 (R7) and region 8 (R8), and the southern provinces of Inhambane, Gaza and Maputo region2 (R2) and region 3 (R3) (Table 3 and Figure 1). The rainy season in R7 and R8 regions begin in November to April with the total amount of rainfall of around 800-1200 mm year. The long rainy season favours the growth of late-maturing groundnut cultivars (Malithano, 1980). Groundnut production in these regions is basically for commercial purposes. R2 and R3 are characterized by constant droughts, uncertain and irregular rainfall and sandy soils. These regions receive total rainfall between 600 and 800 mm per year. Early-maturing cultivars are common in these regions since they can escape the end-of-season drought. The harvest from these regions is low and mainly for domestic consumption.

Groundnut is mainly grown by poor small scale farmers in Mozambique. Low yields and quality are realized by these farmers as a result of several constraints. The major production constraints include insect pests, poor cultural practices, diseases, drought, and post-harvest related issues (Malithano et al., 1984). The major insect pests are termites (Isoptera), aphids (*Aphis craccivora* Koch), thrips (*Frankiniella fusca)* and foliage feeding pests (*Aproarema modicella* Deventer) (Ramanaiah et al., 1988). Some of these pests (aphids) are vectors of groundnut rosette disease, the most destructive viral disease in sub-Saharan Africa.

Diseases constitute a major constraint to groundnut production in Mozambique. The most common diseases are early leaf spot (*Cercospora arachidicola*), late leaf spots (*Cercosporidium personatum* Berk and Curt), groundnut rosette disease and rust (*Puccinia arachidis*). Groundnut rosette disease can cause up to 100 % crop loss (Subrahmanyam et al., 1997; Subrahmanyam et al., 1998; Adamu et al., 2008). When the disease strikes, rural communities are greatly affected and they lose a very important source of protein, a valuable source of income and substantial amount of seed for next season of planting, leading to food insecurity. In order to prevent the disruption of rural economies, it is vital to prevent the epidemics of groundnut rosette disease by using host plant resistance to the pathogen or to the disease vector.

High yielding groundnut cultivars adapted to Mozambican conditions and preferred by farmers are yet to be developed. The National Research System in collaboration with ICRISAT-Malawi tested several groundnut populations in different agro-ecological zones of Mozambique. Some high yielding cultivars adapted to Mozambican conditions were identified. These cultivars were small-seeded and susceptible to groundnut rosette disease, and therefore not popular with farmers and buyers.

Table 3: Characteristics of the major groundnut producing regions of Mozambique

	R2	R3	R7	R8
Province	Coastal Gaza Inhambane Coastal Maputo	Gaza Northern Maputo	Central Zambezia Interior Nampula Central Tete Interior Cabo Delgado	Cabo Delgado Coastal Nampula Coastal Zambezia
Altitude	Below 200 m	Below 200 m	200 – 1000 m	Below 200 m
Rainfall	800-1000 mm ET0>1500 mm	500-800 mm ET0>1500 mm	800–1400 mm 1000<ET0<1400 mm	800–1400 mm 1000<ET0<1400 mm
Soil type	Sodic sandy red calcareous	Sandy black loam red Sodic Sandy loam	Deep brown loam Red loam	Sandy sandy loam loam

Key: ET_o = Evapotranspiration potential (Source: IIAM and UEM, 2010)

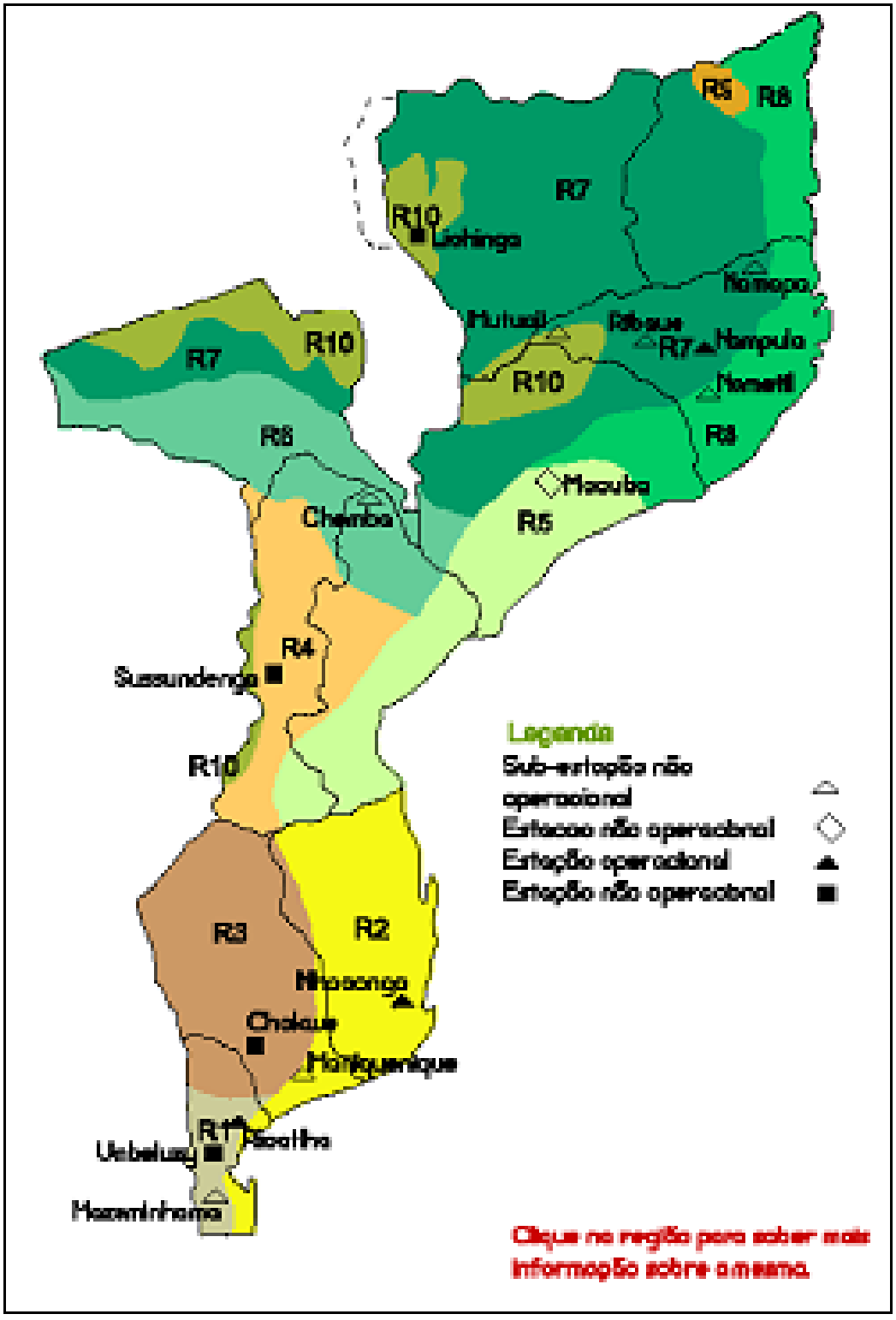

Figure 1: Agro-ecological zones of Mozambique (Codes for the zones are as defined in Table 3

Justification

Groundnuts constitute one of the major cash crops and the main source of cooking oil for many Mozambican families. The crop is grown all over the country by resource-poor small-scale farmers under rainfed conditions.

Groundnut rosette disease is one of the most important production constraint. Yield losses of up to 100% have been reported from various parts of the world (Naidu et al., 1998). Several methods for groundnut rosette disease management have been reported and include: insecticide application, manipulation of cropping systems and host plant resistance for both vector and virus (Naidu et al., 1998; Naidu et al., 1999). In sub-Saharan Africa, the use of host plant resistance is the most economically-effective and environmentally-beneficial method of controlling diseases. Resistant cultivars can easily fit into the resource-poor farmers' practices (Russell, 1978).

Many studies evaluated groundnut germplasm for resistance to groundnut rosette disease since 1907 when the disease was first reported, with no appreciable success. In 1952 significant resistance to the disease was identified in Burkina Faso (Nigam and Bock, 1990; Subrahmanyam et al., 1998; Olorunju et al., 2001). Since then, other sources of resistance have been identified from various parts of the world and used in breeding programmes to develop resistant cultivars. Such resistant cultivars have been successfully used in Burkina Faso, Malawi and Nigeria. Some resistant cultivars developed by ICRISAT were released in Mozambique but not widely accepted by farmers in the country.

There is a need to identify/develop farmer-acceptable groundnut cultivars for cultivation by Mozambican farmers. However, information on major groundnut production constraints, farmer preferences for groundnut traits and prevalence of groundnut rosette disease in Mozambique is limited. This study was undertaken to address some of these constraints.

Objectives of the study

The overall goal of the study was to improve food security and reduce the poverty of small scale farmers in the northern region of Mozambique by increasing groundnut production and productivity.

The specific objectives of the research were as follows:

i. To identify farmers' major groundnut production constraints and their preferences for groundnut traits.

ii. To determine genotypic variation among landraces for agro-morphological traits and resistance to groundnut rosette disease.

iii. To determine agronomic performance and resistance to groundnut rosette disease among advanced groundnut lines across locations in northern Mozambique

iv. To determine the gene action governing the inheritance of groundnut rosette disease resistance.

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I. LITERATURE REVIEW

1.0 Introduction

In this chapter, the literature on groundnut is reviewed in the following sections: origin and distribution; botany; production; groundnut rosette disease; breeding for resistance to groundnut rosette disease; methods for detecting groundnut rosette disease and mating design schemes. In addition, this section reviews groundnut production in Mozambique.

1.1 Origin and distribution of groundnut

Archaeological evidence suggests that groundnut has been cultivated for more than 3500 years, and was probably first domesticated in northern Argentina and eastern Bolivia (Singh and Simpson, 1994). It is believed that the cultivated type, *Arachis hypogaea,* originated in this region, since *Arachis monticola*, the only wild tetraploid species that is cross compatible with it, is found in this area (Stalker and Moss, 1987; Singh and Simpson, 1994). The crop was introduced to other parts of the world through various routes and reasons. Today, groundnut is grown worldwide (Figure 1.1) with China, India and the United States of America (USA) being the largest producers.

1.2 Groundnut botany

1.2.1 Taxonomy

The botanical name of groundnut is *Arachis hypogaea*. The name is derived from the Greek word *arachis* meaning 'legume' and *hypogaea* meaning 'below ground', referring to the formation of pods in the soil (Pattee and Stalker, 1995). Groundnut is a member of the family Leguminosae, tribe Aeschynomeneae, subtribe Stylosanthinae of genus *Arachis*. *Arachis hypogaea* is an annual herb of indeterminate growth habit which has been divided into two subspecies, *hypogaea* and *fastigiata,* each with several botanical cultivars (Holbrook and Stalker, 2003). Sub-specific and varietal classifications (Table 1.1) are mostly based on location of flowers on the plant, patterns of reproductive nodes on branches, numbers of trichomes and pod morphology (Krapovickas and Gregory, 1994).

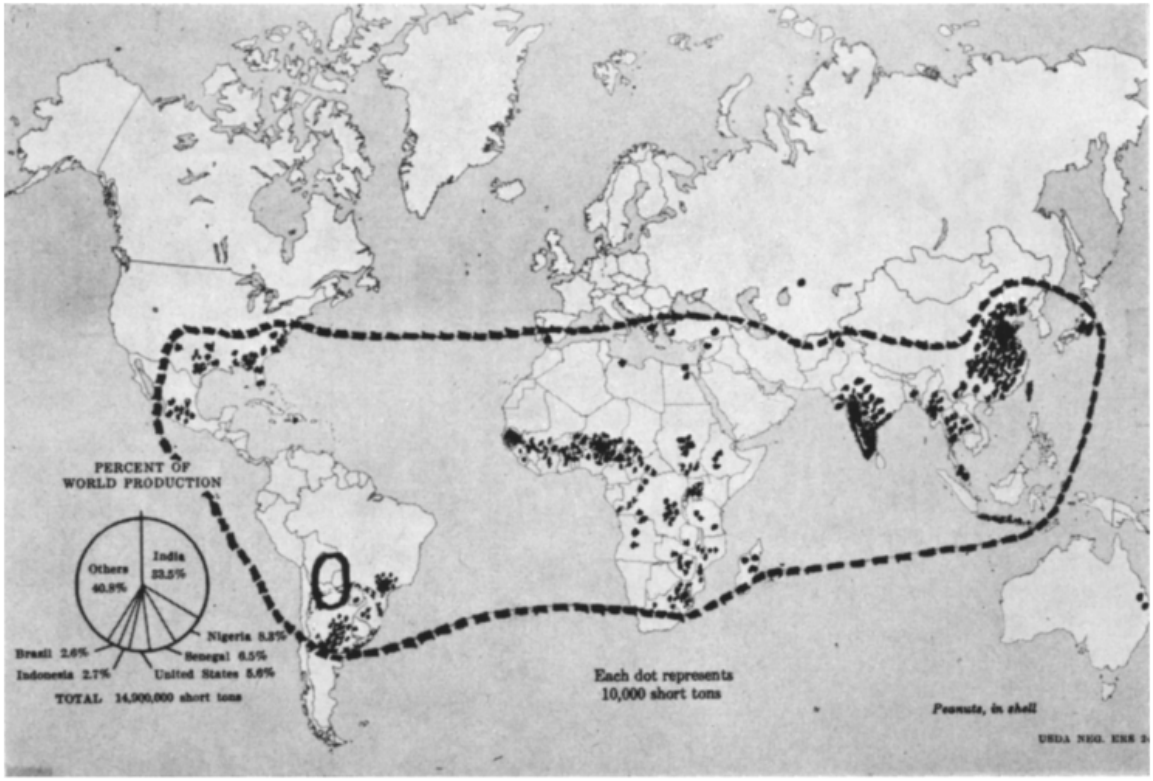

Figure 1.1: Center of origin (solid line) and area of intensive groundnut, *Arachis hypogaea*, cultivation (dotted line) in the world. (Source: Leppik (1970)).

Table 1.1 Subspecific and varietal classification of *Arachis hypogaea*

Subspecies	Botanical cultivar	Market type	Location where found	Important traits
Hypogaea	*Hypogaea*	-	Bolivia, Amazona	No flowers on the main stem; alternating pairs of floral and reproductive nodes on lateral branches; branches relatively short, and few trichomes
		Virgina	-	Large-seeded; less hairy
		Runner	-	Small-seeded; less hairy
	Hirsuta	Peruvian	Peru	More hairy; flowers on the main stem; sequential pairs of floral and vegetative axes on branches
Fastigiata	*Fastigiata*	Valencia	Brazil (Guaranian, Goias, Minas Gerais), araguay, Peru, Uruguay	Little branched, curved branches
	Peruviana	-	Peru	Less hairy; deep pod reticulation
	Aequatoriana	-	Ecuador	Very hairy; deep pod reticulation; purple stems; more branched and erect
	Vulgaris	Spanish	Brazil (Guaranian, Goias, Minas Gerais), araguay, Peru, Uruguay	More branched, upright branches

Adapted from Holbrook and Stalker (2003).

1.2.2 Reproduction in groundnuts

The groundnut flower is orange to yellow in colour, with standard, wing and keel, bisexual, zygomorphic, complete and sessile. It is produced above ground in the axils of leaves near the base of the plant about four to six weeks after planting, depending on genotype and environment, especially temperature (Holbrook and Stalker, 2003). The flower is inserted on top of a pedicel that curves downward and pushes the flower into the soil following pollination and fertilization where it produces seed (Stalker, 1997). Smith (1950) described the groundnut flower as having a curved beaked keel, with two petals fused along the dorsal edges to the apex but opened ventrally at the base.

As the stigma and the anthers are shielded within the flowers, self-pollination is most common with a high frequency (Murty et al., 1980), but cross-pollination may occur in the range of less than 1 % to 3.9 % (Rao and Murty, 1994). The cross-pollination in groundnuts is primarily induced by honeybees (Stalker, 1997; Maiti and Wesche-Ebeling, 2002), but other groundnut pests such as thrips can be vectors of groundnut pollen (Hammons and Leuck, 1966). (Stalker, 1997) reported that several wild species may require bees' visitation for pollination to occur. The groundnut flower contains 10 anthers with the staminal column surrounding the ovary, five of which are small and globular and five are oblong (Rao and Murty, 1994; Stalker, 1997). Rao and Murty (1994) stated that two of the 10 anthers are sterile while Stalker (1997) reported that one or more of the anthers is usually sterile and difficult to observe. Fertilization is complete in about 6 hours after pollination and within 5 to 6 hours the flower may wither (Rao and Murty, 1994). The flower petals droop and the fertilised ovary elongates after fertilization, forming the peg (Beattie and Beattie, 1943; Rao and Murty, 1994).

The peg grows down into the soil as a positively geotropic stalk-like structure (Coolbear, 1994), and the peg tip continues to enlarge, eventually forming a groundnut pod below the soil surface in 7 to 10 weeks (Gregory et al., 1951). The pegs which fail to contact and enter into the soil after expanding usually die. The number of kernels per pod may range from one to five and sometimes to six and is influenced by cultivar and environmental factors (Rao and Murty, 1994). However, members of subsp. *hypogaea* and subsp. *fastigiata* var. *vulgaris* always produce two-seeded pods (Stalker, 1997), and cultivars belonging to var. *fastigiata* are three or four-seeded (Rao and Murty, 1994).

1.2.3 Genetics of groundnuts

The cultivated species of groundnut, *A. hypogaea*, is tetraploid with 2n=4x=40 chromosomes. All wild species of section *Arachis* are diploid with 2n=2x=20 chromosomes, except for *A. monticola* (2n=2x=40) (Husted, 1933). In addition, there are rare species with 2n=2x=18 chromosomes, including *A. praecox* and *A. palustris* (Lavia, 1998). Husted (1936) identified a pair of small chromosomes and a pair of chromosomes with a secondary constriction and satellite, designating them as belonging to the A and B genomes respectively. Today, there are several proposed genomes within the genus *Arachis* (Table 1.2). Singh and Simpson (1994) stated that cultivated tetraploid *A. hypogaea* (AABB) could have originated via domestication of the wild tetraploid species *A. monticola*, which probably originated from amphidiploidization of an F_1 hybrid between a pair of diploid species containing A or B genomes.

Table 1. 2 Genomes within genus *Arachis*

Sections	Series	Genomes	Number of chromosomes
Arachis	1. Annuae	A, B, D	20
	2. Perennes	A	20
	3. Amphiploides	AB	40
Erectroides	1. Trifoliolate	E_1	20
	2. Tetrafoliolate	E_2	20
Procumbense	-	P	20
Caulorhizae	-	C	20
Rhizomatosae	1. Prorhizomatosae	R	20
	2. Eurhimatosae	2R	40
Extranervosae	-	Ex	20
Ambinervosae	-	AM	20
Triceminatae	-	T	20

Adapted from Singh and Simpson (1994).

1.3 Groundnut production

1.3.1 Importance of groundnut

Groundnut is one of the most important legume crops for several million people in the world and is a valuable cash crop for small-scale farmers in developing countries. It is an annual legume and grown primarily for its high quality edible oil and easily digestible protein in its seeds (Upadhyaya et al., 2006). Groundnut seeds are characterized by high contents of oil (40-50 %), protein (20-40 %), and a low percentage of carbohydrates (10-20 %) (Ahmed and Young, 1982; Maiti and Wesche-Ebeling, 2002). Groundnuts have a cultivar of uses, including human food (roasted, boiled, cooking oil), animal feed (pressings, straw, seeds), and industrial raw materials (soap, detergent, cosmetics) (Maiti and Wesche-Ebeling, 2002). Groundnut oil can be used in cooking, lighting, fuel and as a food constituent. A large percentage of the world production of groundnuts is used for edible oil, whereas in the USA, approximately 60 % of total groundnut production is used for human food (Ahmed and Young, 1982; Moss and Rao, 1995). The principal uses are groundnut butter, groundnut candy, in-shell, and shelled nuts. In some places, the vines with leaves are used as source of protein hay for horses and ruminant livestock; the shells can be used as feed for livestock and burned for fuel.

1.3.2 Groundnut production constraints in Mozambique

Groundnut yields realized by small scale farmers in Mozambique are quite low (400-600 kg ha^{-1}). The low yields have been attributed to several constraints. Some of the major groundnut production constraints include poor cultural practices, pests, weeds, drought, and diseases (Malithano, 1984). The poor cultural practices include low plant population, and delays in planting due to uncertainty of rainfall. Farmers plant groundnut in wide spacing leading to very low plant density. The low plant density may be attributed to lack of seed and to the mixed cropping systems practiced by the farmers. Most of farmers use their own seed for sowing in the following season because groundnut prices at the beginning of growing season are quite high and most of the farmers do not afford. Mixed cropping system is common for many farmers in Mozambique. The system reduces the risk of crop loss due to adverse conditions thereby ensuring substantial yield advantages and harvests as compared to sole cropping.

The major pests affecting groundnut include termites, aphids (*Aphis cracivora*), thrips (*Frankliniella* fusca) and foliage feeding pests (Ramanaiah, 1988). Termites are a major pest at all stages of crop growth and they feed on pods, seeds and plant foliage. Aphids are a major pest at seedling stage and they suck plant sap. Thrips attack flower buds and consequently contribute to low seed set. Foliage feeding pests attack the crop during vegetative growth. They reduce photosynthetic area. Some of these pests (i.e. aphids) are vectors of the most destructive virus diseases in sub-Saharan Africa, such as groundnut rosette disease. Besides groundnut rosette disease, aphids are also vectors of peanut mottle, peanut stripe, peanut stunt and peanut chlorotic streak (Kokalis-Burelle et al., 1997). The control measures applied by farmers to reduce insect pest infestation include cultural practices and insecticide application. Cultural practices include early planting, such that the crop matures before the period of peak pest population, and mixed cropping. Insecticides are effective in killing insects. However, they should be applied only if economically sustainable since they are expensive.

Weeds constitute a major problem for groundnut during the first few weeks after planting and at the harvesting. Failure to control weeds can result in reduced crop yields since they compete with the groundnut crop for nutrients and water. In addition, they interfere with the harvesting process. Furthermore, they harbour pests and disease vectors. Cultural practices such as good land preparation and crop rotation are the most recommended control measures for weeds. In addition, herbicide application, when available, is also recommended for weed control (Kokalis-Burelle et al., 1997).

Drought stress may affect the crop at different stages during the growing season. In groundnut, drought stress during flowering and pod filling stage is critical for yield and agronomic characters. Drought at these stages leads to reduction in crop yield by affecting the number of pods per plant (Boote et al., 1982), and irregular and scarce rainfall at pod filling reduces the yield greatly (Malithano, 1980). Not only the yield of groundnut but also the quality of products decreases under drought stress (Rucker et al. 1995). When drought occurs in the last 20-40 days of the season, pre-harvest infection by *Aspergillus flavus* is increased and consequently, aflatoxin concentration increase. found that genotype selection for drought tolerance may improve aflatoxins resistance, and under drought stress conditions, drought tolerant cultivars yield more than susceptible (Cole et al., 1989; Sanders et al., 1993 and Arunyanarka et al., 2010).

Diseases constitute a major constraint to groundnut production. Early leaf spot (*Cercospora arachidicola* Hori) and late leaf spot (*Cercosporidium personatum* Berk and Curt), rust (*Puccinia arachidis* Speg.) and groundnut rosette disease virus are very common and can cause significant losses to the crop. Leaf spots and rust damage the crop by reducing the photosynthetic area through lesion formation and stimulating leaflet abscission. The shedding of the leaflets results in premature ageing of the crop, and therefore, yields loss. Crop rotation, use of tolerant cultivars and use of fungicides are some control measures for these diseases. Groundnut rosette disease alone can cause up to 100 % crop loss (Subrahmanyam et al., 1997; Subrahmanyam et al., 1998; Adamu et al., 2008). When the disease occurs, rural economies that depend on groundnuts are completely disrupted since smallholder farmers in sub-Saharan Africa, grow groundnut for both subsistence and as cash crop (Naidu et al., 1999). When a disaster such as groundnut rosette disease strikes, rural farmers lose a very important source of protein, a valuable source of income and substantial part of seed for next planting leading to food insecurity (Naidu et al., 1998). Consequently, suggested that cultivars with resistance to the pathogens would be needed to suppress the two leaf spot diseases even if fungicides controlled the diseases (Holbrook and Stalker, 2003). In the case of rosette disease, it is vital to prevent the epidemics of the disease by using host resistance to the pathogen or to the disease vector. Other control measures for diseases include crop rotation, deep ploughing, removal of debris and planting on time and insecticide application against disease vectors.

1.4 Groundnut rosette disease

Groundnut rosette disease was first described in 1907 by Zimmermann in Tanzania Naidu et al. (1998). It is the most destructive virus disease of groundnuts in sub-Saharan Africa (Nigam and Bock, 1990; Naidu et al., 1998; Olorunju and Ntare, 2008). Today, the disease is widely distributed in sub-Saharan Africa and offshore islands, including Madagascar (Nigam and Bock, 1990; Naidu et al., 1998).

Groundnut rosette disease is caused by a complex of three agents namely: groundnut rosette assistor virus (GRAV), groundnut rosette virus (GRV) and a satellite RNA (sat RNA) (Murant et al., 1988; Naidu et al., 1998). It is transmitted by an aphid vector, *Aphis craccivora* Koch, in a persistent manner. In order for the aphid to be able to successfully

transmit the disease, all three agents must be present together in the host plant (Subrahmanyam et al., 1998). Subrahmanyam et al. (1992) reported three types of groundnut rosette namely chlorotic, green and mosaic, while Naidu et al. (1999) reported that there are two predominant symptom types of groundnut rosette disease namely chlorotic and green rosette. Chlorotic rosette is widely distributed in sub-Saharan Africa; green rosette is most prevalent in West Africa while mosaic type of rosette is found in Eastern, Central and Southern Africa (Naidu et al., 1998).

Different variants of the satellite RNA of groundnut rosette virus are responsible for the chlorotic and green forms of groundnut rosette disease (Murant and Kumar, 1990). In chlorotic rosette, the leaves show a bright yellow chlorosis (the limb of the leaves is chlorotic with green spots and the veins are green and conspicuous) which may affect the whole leaf or only parts of the leaf. The symptoms may appear over almost the entire plant, or only in parts of the plant. In addition, the leaves are twisted and distorted. In green rosette the leaves are darker green than normal or show light green or dark green mosaic, and are much reduced in size. In mosaic rosette, young leaflets show conspicuous mosaic symptoms. In both forms of rosette, plants are stunted and give limited or no yield.

1.5 Resistance to groundnut rosette disease

Many studies have evaluated groundnut germplasm for resistance to groundnut rosette disease since its description in 1907. The existence of significant resistance within *A. hypogaea* germplasm was first reported in 1952 from Burkina Faso when an epidemic of groundnut rosette disease destroyed a large collection of germplasm (Nigam and Bock, 1990; Subrahmanyam et al., 1998; Olorunju et al., 2001). Some germplasm accessions from Burkina Faso survived the epidemic and were resistant to the disease. Later it was determined that the resistance is controlled by two independent recessive genes (Berchoux de, 1960; Bock et al., 1990; Nigam and Bock, 1990). However, from a cross between RMP-12 and M1204.78I, it was detected that resistance is controlled by one dominant gene (Olorunju, 1990).

Three mechanisms of resistance to rosette disease were suggested by Olorunju (1990) namely: resistance to initial infection, restriction of virus movement, and restricted production of sat RNA. In the last two decades, existing resistant germplasm and

breeding lines were susceptible to groundnut rosette virus assistor, and the resistance in these lines was to groundnut rosette virus and indirectly against its satellite RNA Olorunju et al. (1991) and (Subrahmanyam et al., 1998). Such genotypes are not immune, do not develop symptoms and can be overcome under high disease pressure or adverse environmental conditions (Bock et al., 1990).

1.6 Breeding for resistance to groundnut rosette disease

The discovery of sources of resistance of groundnut rosette disease in 1952 was a major step forward for groundnut improvement (Olorunju et al., 1992). These sources formed the basis for the rosette resistance breeding programmes throughout Africa (Subrahmanyam et al., 1998; Olorunju et al., 2001) leading to the development of several groundnut rosette disease resistant cultivars.

Subsequent studies in other parts of the world have been able to identify additional sources of resistance to groundnut rosette (Olorunju et al., 1992; Subrahmanyam et al., 1998). These attempts resulted in the development of long-duration cultivars such as RMP-12, RMP-40 and RG-1 (140-150 days) and early-maturing cultivars (90 days) Spanish such as KH-149A and KH-241C (Bockelée-Morvan, 1983). Resistance among these cultivars were effective against both chlorotic and green rosette (Berchoux de, 1960).

ICRISAT launched a program in Malawi in the early 1980s and in West Africa in the late 1980s with the objective of developing cultivars which are suitable for small-scale farmers in semi-arid tropics of Africa by combining groundnut rosette resistance, early maturity and high-yielding (Olorunju et al., 2001). These two programs have produced a wide range of early-, medium- and late-maturing cultivars suitable for various cropping systems in semi-arid tropics of Africa (Ntare et al., 2008).

1.7 Methods for detecting groundnut rosette virus

Diagnostic techniques for viruses in general fall into two broad categories that were comprehensively described by Naidu and Hughes (2008). They include: biological properties related to the interaction of the virus with its host and/or vector (e.g.,

symptomatology and transmission tests) and intrinsic properties of the virus itself (coat protein and nucleic acid).

Groundnut rosette disease has for a long time been identified in groundnut cultivars based on visual symptoms in the field. Recent advances in diagnosis have been achieved through the development of improved diagnostic methods including triple antibody sandwich enzyme-linked immunosorbent assay (TAS-ELISA), dot blot hybridization assay (DBH) and reverse transcription-polymerase chain reaction (RT-PCR) (Naidu et al., 1998; Naidu et al., 1999). The new techniques enable the detection of the complex of the three agents involved in the groundnut rosette disease namely GRV, GRAV and sat RNA (Naidu et al., 1999).

The field screening technique that is based on virus symptoms on the host plants is the most commonly used method for screening groundnut genotypes for resistance to groundnut rosette disease. The technique involves planting one infector row of the highly susceptible cultivar after every two adjacent rows of test lines at the onset of rains such that every test rows is adjacent to one infector row (Bock and Nigam, 1988). A large number of seedlings of a susceptible groundnut cultivar is raised in the greenhouse and inoculated with GRV, using a greenhouse viruliferous culture of *Aphis craccivora* which has been maintained on susceptible groundnut cultivar (Bock et al., 1990; Olorunju et al., 1991; Olorunju et al., 2001). About one week after emergency of the seedlings in the field, rosette-disease plants reared in the greenhouse, heavily infested with *A. craccivora* are transplanted at 1.5 to 2.0 m intervals into infector rows (Bock et al., 1990; Nigam and Bock, 1990; Olorunju et al., 2001). The aphids migrate from the transplanted plants onto to infector rows and later onto the test material. Single plants from each genotype are monitored for presence or absence of virus symptoms at regular interval. Disease incidence (DI) is determined by calculating the percentage of plants with rosette symptoms for each genotype.

1.8 Groundnut rosette management

Several methods for groundnut rosette disease management have been suggested which include insecticide application, cultural practices and breeding for both vector and virus resistance (Naidu et al., 1998; Naidu et al., 1999). Insecticide application reduces the vector population in the field thereby reducing the chances of disease spread.

Insecticide application is not the best approach for the farmers of sub-Saharan Africa region due to the high costs of the chemicals, while improper use of these chemicals may result in development of insecticide-resistant biotypes (Naidu et al., 1999) as well as death of natural enemies.

Cultural practices have been found to be effective in reducing the incidence of groundnut rosette disease (Ntare et al., 2007). Commonly used cultural practices include early planting and high plant density of the groundnut crop. In case of early planting, the crop escapes the period of high pest population that occurs late in the season. In case of plant density, aphids have been reported to prefer widely spaced plants over closely spaced ones. However, farmers do not follow these recommendations for several reasons including crop priority, lack of adequate quantities of seed and uncertainty of rainfall.

In sub-Saharan Africa, the use of host plant resistance is the best way of controlling diseases (Russell, 1978) because it is the most economically-effective and environmentally friendly. The use of resistant cultivars to groundnut rosette disease could allow groundnut growers to save money which would otherwise be used for purchase and application of insecticide. Likewise, the reduction in use of insecticide could avoid pollution of environment as well as allow the increase of natural enemies of virus vectors.

1.9 Mating design

Mating designs are used to generate genetic pedigrees, germplasm that can be used in breeding programs and genetic information such as pedigrees and gene effects (Dabholkar, 1992). The choice of mating designs depends on the objectives and the overall breeding strategy of the particular breeding program. The most common objectives of mating designs are: a) to provide information for evaluating parents; b) to estimate genetic parameters; c) to produce a base population for advanced generation selection; and d) to estimate realized gain directly (McKinley, 1983). The most common mating designs are the biparental, diallel, and the North Carolina designs (Comstock, 1952). Genetic components of variance estimated from the mating designs are translated to covariances among related individuals and portioned into additive,

dominance, and epistatic genetic components (Becker, 1984; Christie and Shattuck, 1992).

1.10 The diallel cross

A diallel cross involves *n* parents producing n^2 possible single crosses and selfs (Griffing, 1956). The diallel analyses differ depending on whether the selfed parents and/or the reciprocal F_1's have been included and each of them necessitates a different form of analysis (Griffing, 1956; Becker, 1984; Dabholkar, 1992). Half diallel is when the reciprocal crosses have been excluded, while a modified diallel is one in which the parents have been excluded (Griffing, 1956).

The practical choice of using reciprocals depends on the convenience, the availability of resources and the genetics of the material under study. Reciprocals are excluded in case of limitations of time, space, labour to manage the large crosses, and for crops in which maternal effects are known to be smaller or non-existent (Christie and Shattuck, 1992). Including reciprocals has been a problem since synchronised flowering is often a major problem (Stuber, 1980).

Two genetic models; model 1 (random effects i.e. cultivar and block are random), and model 2 (fixed effects i.e. cultivar and block are constant) are commonly used by plant breeders and quantitative geneticists (Griffing, 1956; Dabholkar, 1992). The analytical and interpretation aspects of breeding experiments follow these models. In model 1 the genotypic effects are considered random variables and in the second model they are fixed.

There are three levels at which diallel analyses can be conducted: the combining ability analysis; genetic variance component analysis; and complete genetic analysis. The combining ability level of analysis is generally preferred as it is purely statistical in nature and therefore needs none of the restrictive genetical assumptions (Christie and Shattuck, 1992). Estimation of the genetic components of GCA and SCA also requires the assumptions of no epistasis and the independent distribution of genes in the parents to be made (Griffing, 1956). For the level genetic variance component analysis, the population should be in Hardy-Weinberg equilibrium with respect to individual loci, and linkage equilibrium with respect to all pairs of loci. A complete genetic analysis can be

made if further assumptions concerning the parents are made. If homozygosity of the parents is assumed, and the assumption of no-multiple allelism is also made, then the additive genetic variance can be subdivided into further components (Mather and Jinks, 1971). Such subdivision provides information on the gene action and gene frequencies.

1.11 Combining ability analysis

In the diallel mating design, the estimation of genetic variances is made in terms of the combining ability (Griffing, 1956). In the combining ability analyses, the cultivar effects are considered in terms of GCA and SCA effects. A relatively larger GCA/SCA variance ratio demonstrates the importance of additive genetic effects and the lower ratio indicates predominance of dominance and/or epistatic gene effects (Christie and Shattuck, 1992). Furthermore, the GCA effects are calculated only when mean squares for GCA is found to be significant (Dabholkar, 1992). Parent with larger GCA, or more significant is referred to as a best combiner. Thus, these significant parental lines are chosen for hybridisation. The same is done for SCA and this is based on whether the crosses have one parent in common or not. In this case breeders can choose best crosses.

1.12 Combining ability studies in groundnut

Genetic studies conducted in groundnut were reviewed by Singh and Oswalt (1991). Hariprasanna et al. (2008) used full diallel to examine the combining ability and to understand the type of gene action governing shelling percentage, 100-pod weight, 100-seed weight, number and proportion of mature seeds in groundnut. They found that the expression of majority of the traits was controlled predominantly by additive gene action, and non-additive gene action was important on seed size. These results were complemented by Anderson et al. (1992) on F_1 and F_2 populations for pod and seed sizes. Mothilal and Ezhil (2010) found the magnitude of specific combining ability variances much greater than those of general combining ability for plant height, number of mature pods plant^{-1}, pod yield, seeds yield plant^{-1} and shelling percentage.

Layrisse et al. (1980) studied the combining ability from F_2 generation of ten groundnut lines from South American centres of diversity for yield, pod, seed protein and oil

content. They found that both GCA and SCA were significant for all traits, except for the SCA estimates for protein, and that GCA component was larger than the SCA for all traits. Additive and non-additive gene action was reported by Sangha and Labana (1982) for number of pods and yield.

Using half diallel, Jayalakshmi et al. (2002) studied from F_1 generation the gene action of morphological and physiological attributes (specific leaf area, secondary nodes plant^{-1}, ill and immature pods plant^{-1}, pod yield, root dry mass shoot bio-mass, seed yield) influencing groundnut yield. They found that both additive and non-additive gene actions were important in the expression of the most of traits.

A diallel analysis of six groundnut parents was conducted by Redona and Lantican (1985) to examine the general and specific combining abilities for seed and pod yield plant^{-1}, weight seed^{-1}, weight pod^{-1}, number of pods and seeds plant^{-1}, and height of main axis. They found that both GCA and SCA mean squares were significant, and estimates of GCA effects were greater than the SCA estimates for all traits, this indicating that additive gene action was important in the expression of all traits.

General and specific combining abilities for resistance to peanut bud necrosis tospovirus (PBNV) were examined to understand the gene action controlling the disease from F_1 and F_2 populations resulting from six parent diallel crosses (Pensuk et al., 2002). It was observed that both GCA and SCA effects were significant, but the magnitude of GCA was greater than of that of SCA, suggesting that additive gene effect was mainly responsible for the expression of the disease. A diallel analysis of four groundnut parents was conducted by Varnam et al. (1989) to examine the genetics of F1 populations for rust resistance. From this experiment, it was detected that resistance was governed by both additive and non-additive gene effects but additive being predominant.

Ouedraogo et al. (1995) studied the combining ability for components of resistance to early leaf spot (latent period, lesion diameter and amount of sporulation) and yield components (pod weight plant^{-1}, seed weight plant^{-1} and 20 seed weight) of groundnut lines. They found that both GCA and SCA were significant for all traits, but the GCA and SCA ratios indicated that additive gene action was effective on controlling lesion diameter and amount of sporulation. Similar results were reported by Dwivedi et al.

(2002) when studying the combining ability of components of resistance (latent period, lesion leaf^{-1}, lesion diameter, sporulation index, percentage of leaf area damaged, percentage of leaf defoliation and disease score).

Adamu et al. (2008) studied the general and the specific combining abilities for groundnut rosette disease resistance and other traits in groundnuts (early maturity, haulm yield, pod yield, shelling percentage, days to 50% flowering) on F_2 and F_3 populations. They found that GCA and SCA estimates were significant for all traits, except SCA estimates for haulm yield and shelling percentage in F_2 populations, while SCA estimates in F_3 populations were significant for groundnut rosette resistance. They added that the magnitude of GCA estimates was greater than SCA for all traits in both generations, and they suggested that additive gene action was more important than the non-additive effects on the expression of the disease.

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II. GROUNDNUT (*ARACHIS HYPOGAEA* L.) PRODUCTION CONSTRAINTS FARMERS PREFERRED TRAITS AND GROUNDNUT ROSETTE DISEASE INCIDENCE IN THE NORTHERN REGION OF MOZAMBIQUE

Abstract

Groundnut is an important crop in Mozambique. However, yields have remained low, regardless of the availability of improved cultivars. The objectives of this study were to obtain farmers' groundnut (*Arachis hypogaea* L.) cultivar selection criteria and production constraints which could be important for breeding programmes. The study was conducted Namuno (13° 36' 39" S, 38° 48' 15" E and 200-500 m.a.s.l) in Cabo Delgado and Erati (13° 43' 41" S, 39° 50' 41" E and 200-500 m.a.s.l.) in Nampula province. Open-ended interviews with a group of farmers and guided by a questionnaire were undertaken to obtain detailed information on groundnut production in the region. The main issues addressed in the study were major crops grown, farmers' groundnut cultivar selection criteria, cropping systems, groundnut production constraints, and farmers' awareness of groundnut rosette disease. The study established that the main crops grown in the region were maize (*Zea mays* L.), groundnut, cassava (*Manihot esculenta)*, cowpea (Vigna unguiculata) and sorghum (*Sorghun bicolour*). Groundnut was the third most important crop after cassava and maize. The major constraints for groundnut production were diseases, insect pests and a lack of suitable improved cultivars. About 27 % of women and 41 % of men reported that diseases, specifically groundnut rosette disease, were the most important constraint affecting groundnut production. In Namuno, 100 % of farmers grew local landraces and recycled their own seed every growing season, but in Erati about 56 % of farmers had replaced landraces with improved cultivars. In some cases, selection criterion for groundnuts was dependent on sex and villages. However, farmers in this region preferred erect or runner, red seeded testa groundnut cultivars that are medium to large in size, early to medium maturing, medium to high yielding, high oil content, tolerant to drought, diseases and insect pests. Over 60 % of fields evaluated in the region were infested by groundnut rosette disease and over of 50 % of these fields had between 10 and 30 % of disease incidence. Therefore, there is need to develop groundnut cultivars that are resistant to biotic and abiotic stresses aforementioned.

Keywords: Mozambique, groundnut (*Arachis hypogaea*), rosette disease, participatory rural appraisal

2.1 Introduction

Groundnut (*Arachis hypogaea* L.) is an important crop in northern Mozambique where it is grown more as a cash crop than a food crop. The demand for seed is high especially at planting time. In the 1990s, the National Research System of Mozambique in collaboration with ICRISAT-Malawi released high-yielding and adapted cultivars to the region. However, recent surveys in farmers' fields and local markets have indicated that the level of adoption of the new released cultivars was very low. Some of the reasons for the low adoption were that farmers had little exposure to improved groundnut cultivars and/or cultivars did not satisfy farmers' preferences and needs. Similar reasons for low adoption of new groundnut cultivars were reported by Ntare et al. (2007) in West Africa. The adoption rates of new technology have a tendency of being low particularly in areas where farmers are not involved in development of the technology (Tripp, 1982; Maurya et al., 1988), which might be the case of northern Mozambique.

Governmental and non-governmental institutions have recognised the need to move away from the top down flow of extension information to more participatory approaches of identification of needs and technology development. The participatory approaches involve supporting communities in their bid to set and accomplish their own developmental goals (Hagmann et al., 1999).

The involvement of the farmers in the process of developing new and resistant cultivars is very important for the adoption of these new cultivars among farmers (Adu-Dapaah et al., 2004; Dorward et al., 2007; Gyawali et al., 2007; Morris and Bellon, 2004). This has been in response to the widespread perception that conventional breeding approaches have not been as successful as they might in high stress and diverse environments (Atlin and Witcombe, 2002). During the process, farmers assess the cultivars under their own conditions, preferences and management practices (Sperling et al., 1993; Witcombe et al., 1996; Sperling et al., 2001; Witcombe et al., 2005; Witcombe et al., 2006).

The use of participatory tools and techniques, such as key informant interviews, transect walks, matrix scoring and ranking can promote exchange of ideas between researchers and villagers leading to improvement of the efficiency and impact of the research (Chambers, 1992). Yield increases attributable to the adoption of new cultivars resulting

from participatory plant breeding programmes were reported in South and Southeast Asia (Witcombe et al., 2002), Colombia, India, Nepal, Namibia, Rwanda (Witcombe et al., 1996), Andean region (Danial et al., 2007), and West Africa (Ntare et al., 2007) in grain legumes, potato (*Solanum tubercosum*), rice (*Oryza sativa*), wheat (*Triticum aestirum* L.), barley (Hordem vulgare), pearl millet (*Pennisetum typhoides*) and maize (*Zea mays*).

It was, therefore, a good opportunity to test the participatory plant breeding approach in Mozambique by conducting, first, a participatory rural appraisal (PRA) to obtain baseline information that could be used by the groundnut breeding programme in Nampula. The objectives of the PRA were to: 1) identify major constraints limiting groundnut production; 2) identify groundnut traits that are preferred by farmers. In addition, a survey was conducted to determine the prevalence of groundnut rosette disease in the region.

2.2 Materials and methods

2.2.1 Study area

The PRA was conducted in 2009 in Namuno (13° 36' 39" S, 38° 48' 15" E and 200-500 m.a.s.l) in Cabo Delgado province and Erati (13° 43' 41" S, 39° 50' 41" E and 200-500 m.a.s.l.) in Nampula province (Figure 1), northern Mozambique. In Namuno the annual precipitation is between 800 and 1200 mm from October to April, with heavy rains occurring in January and February. The district experiences an annual average temperature between 20 and 25^{o} C (MÉTIER, 2005b). Erati receives annual precipitation between 800 and 1200 mm from October to April, with heavy rains occurring in January and February. Annual average temperature in the district is between 20 and 25^{o} C. Soils in the two districts are intermediate to heavy textured and are characterized as being sandy loam, deep and well-drained (MÉTIER, 2005a). The two districts were selected since they are located in the northern groundnut belt of Mozambique. Three villages (Milipone, Napuri and Ncoela) in Namuno district and two villages (Namicore and Muloco) in Erati district were selected for the PRA study.

In addition, a groundnut rosette disease survey was conducted in the region between March and early April in 2010/2011 growing season. A total of 126 fields were visited in 13 districts; four in Nampula province (Meconta, Monapo, Nacaroa and Erati), four in Cabo Delgado (Chiure, Montepuez, Balama, and Namuno), two in Zambezia (Gile and Maganja da Costa) and three in Niassa (Nipepe, Maua and Metarica) (Figure 2.1).

2.2.2 Data collection

The PRA tools used to gather information included interviews using a semi-structured questionnaire (Appendix 1), transect walk, problem listing, and focused group discussion. Data gathered from transect walk, problem listing and focused group discussion were used to support and validate the information obtained from the semi-structured questionnaire. Other supporting information was obtained through reports and other sources such as Ministry of Agriculture and National Institute of Statistics. Key informants, community leaders and local extension officers were contacted in the process to validate the data.

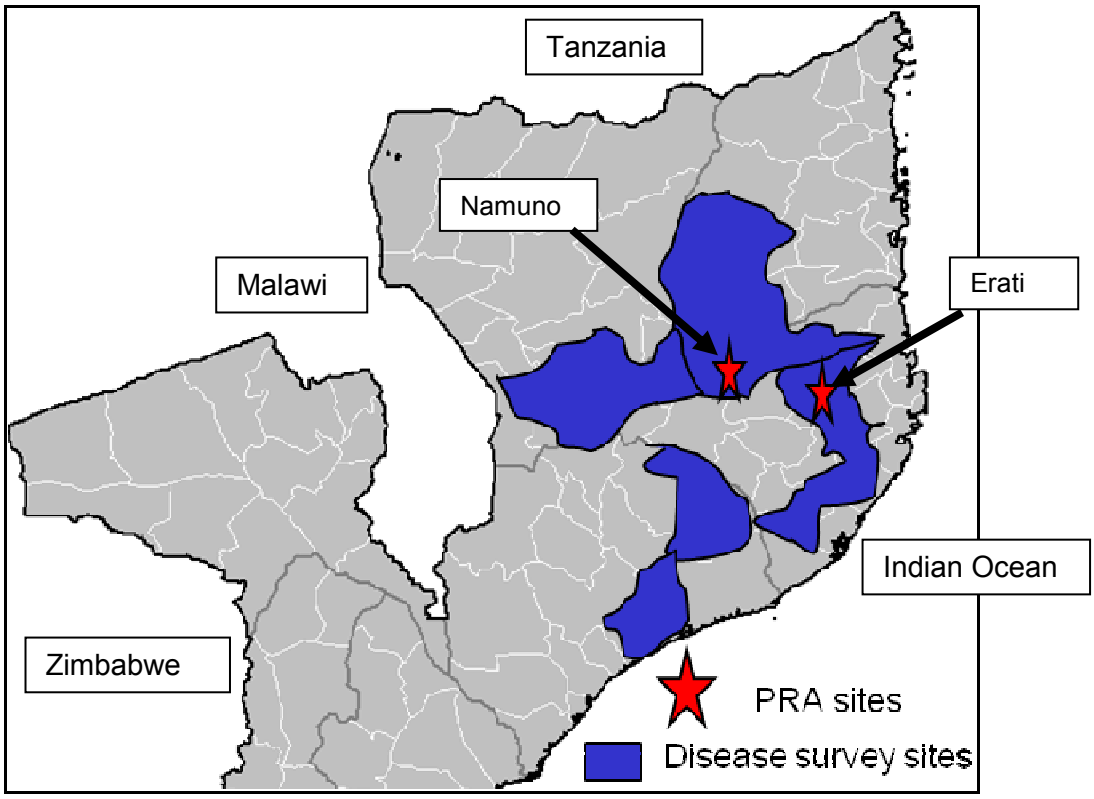

Figure 2.1: Map of northern Mozambique showing participatory rural appraisal and disease survey sites

Selection of farmers was done at community level with the assistance of agricultural extension officers and local leaders. The participants in the study included local leaders, innovative farmers, women and men, poor farmers with limited resources and community based organization members.

The semi structured questionnaire (Appendix 1) was used to obtain relevant information from the farmers about their villages and needs. In each village, twenty five farmers were randomly selected and interviewed. The information collected in these interviews included major food and cash crops grown; number of the household members and their ages; farmers' groundnut cultivar selection criteria (such as seed size, seed colour, taste, plant characteristics, maturity, pest and disease tolerance); groundnut production practices (planting methods, rotation, single or multi-cropping systems); groundnut production constraints (abiotic, biotic and socio-economic); and farmers' awareness of groundnut rosette disease and disease management strategies.

A transect walk was done by walking through and making direct observations on 10 to 15 fields in each village. Information collected from these direct observations included major food and cash crops grown, soil type, land use, cropping pattern, acreage allocated to groundnut, incidence and prevalence of groundnut rosette disease.

A focused-group discussion was conducted with a group of community members in each village. The group comprised of about 20 to 25 members and included key informants, elders, women group representatives, community based organization representatives, farmers, village leaders and religious leaders. These farmers were identified based on their interest in the groundnut crop, knowledge of groundnut production, knowledge of the village history and farmers' influence in the village. In these discussions, farmers provided information on their farming systems, crop production practices, groundnut production constraints, and important traits used by the communities for groundnut cultivar choices.

Groundnut rosette disease survey was conducted through direct visits to farmers' fields. Observations were recorded in groundnut fields located at 30-50km intervals. Visual disease symptoms (presence or absence) were recorded for each field from a sample of 50 plants using diagonal approach. Disease incidence (DI) was determined by recording the percentage of plants with rosette symptoms from each field (Waliyar et al., 2007), and disease prevalence was determined by the relation between the number of fields with disease symptoms over the total fields visited in each district.

2.2.3 Data analysis

Statistical analyses for both quantitative and qualitative data were performed in SPSS (Release 19.0) computer package. Data were classified as nominal or ordinal when entering into the SPSS spreadsheet. For exploring relationships, frequencies and descriptive statistics were computed for data collected in each village. Charts were constructed in Microsoft Office Excel 2007.

2.3 Results

2.3.1 Gender and age distribution

Percentage of women and men participating in the interviews is presented in Figure 2.2. On average over 70 % of the participants were males and less than 30 % were females. In Muloco and Napuri the gap between males and females participating in the study was big since males were over 80 % and females were less than 20 %. In Namicori, the male and female participants were almost equal (55 % male:45 % female).

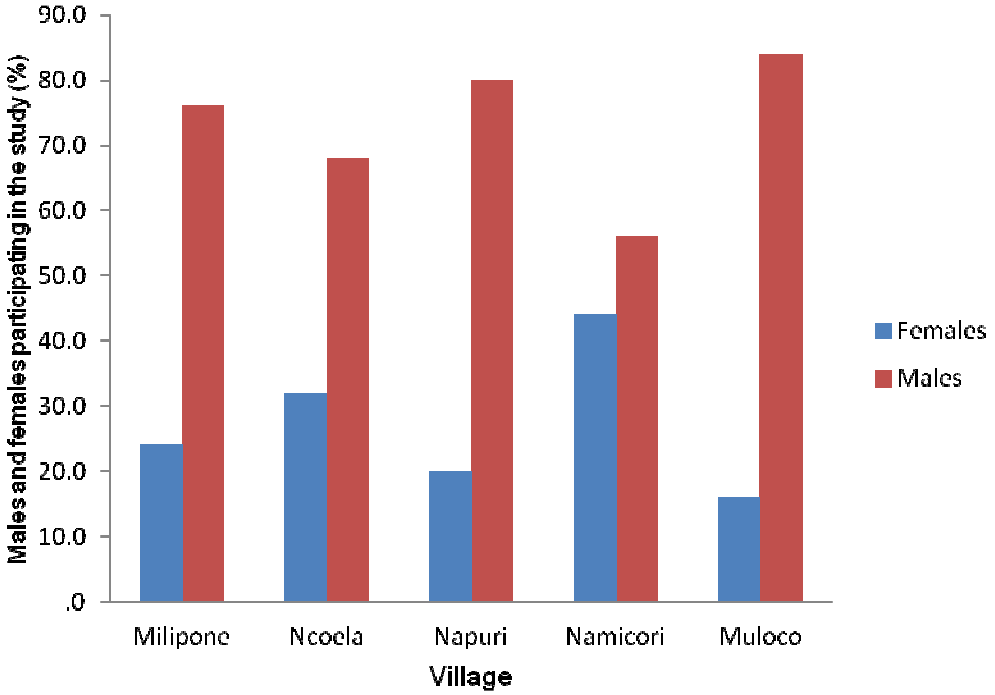

Figure 2.2: Percentage of males and females participating in the PRA in the study area

About 40 % of the respondents ranged between 31 to 40 years of age. Over 50 years of age ranged on average between 1.0 to 5 %, being 4.8 % for age interval of 51 to 60 and 1.6 % of the age over 70 (Table 2.1).

Table 2. 1: Percent distribution of respondents agewise in the study area

Age interval (years)	District					Total
	Namuno			Erati		
	Milipone	Ncoela	Napuri	Namicori	Muloco	
<30	4.0	12.0	56.0	32.0	12.0	23.2
31-40	44.0	60.0	24.0	32.0	48.0	41.6
41-50	48.0	20.0	12.0	32.0	28.0	28.0
51-60	4.0	8.0	0.0	4.0	8.0	4.8
61-70	0.0	0.0	0.0	0.0	4.0	0.8
>70	0.0	0.0	8.0	0.0	0.0	1.6

Percent distribution of the number of persons per household in the study area is presented in Figure 2.3. About 45 % of the total household in the two districts comprised of more than 4 people and only about 5 % of the households comprised of 2 people. Within villages, in Milipone and Ncoela, most of the households, over 33 %, comprised of more than 4 persons while in Muloco about 40 % of the households consisted of 3 persons and other 40% of more than 4 persons.

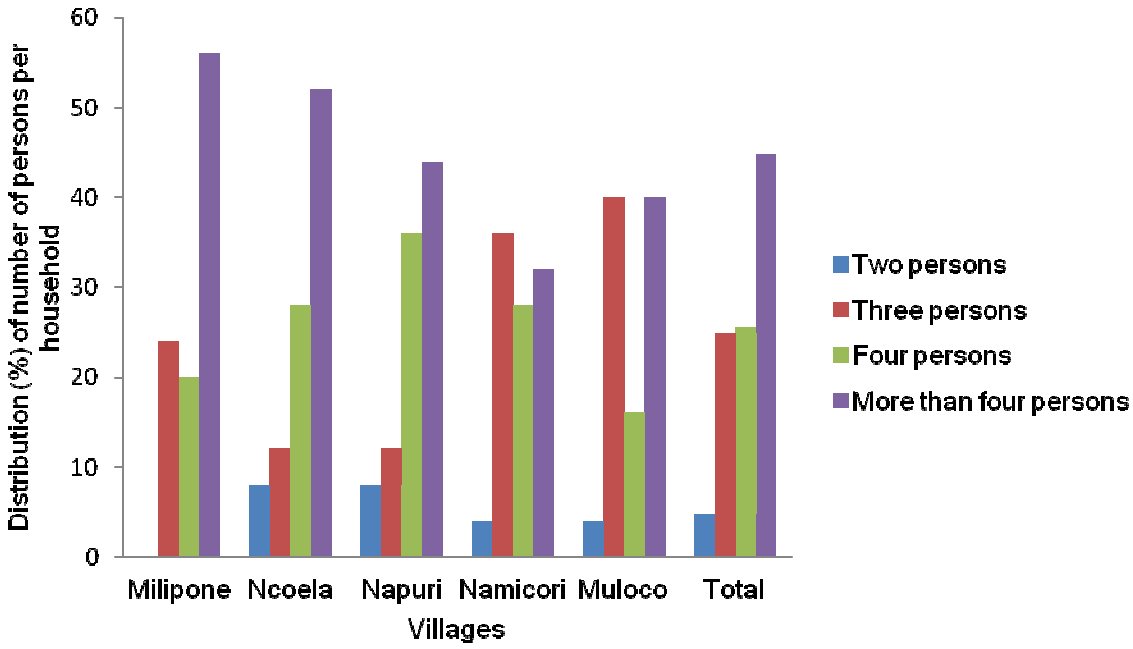

Figure 2. 3: Percent distribution of number of persons per household in the study area

2.3.2 Area under cultivation and crops grown

About 53 % of farmers cultivated all their crops in more than 1.0 ha and only 13 % of respondents cultivated less than 0.5 ha (Table 2.2). Within villages, in Ncoela, 60 % of respondents cultivated their crops in areas between 0.5 and 1.0 ha, while in Napuri, 68 % of farmers cultivated areas over 1.0ha. In Namicori, over 80 % of the farmers cultivated areas more than 1.0 ha.

Table 2. 2: Percent distribution of farm size in the two districts

District	Village	Area (ha)		
		less than 0.5	between 0.5 and 1.0	More than 1.0
Namuno	Milipone	20.0	52.0	28.0
	Ncoela	12.0	60.0	28.0
	Napuri	16.0	16.0	68.0
Erati	Namicori	0.0	16.0	84.0
	Muloco	16.0	28.0	56.0
Total		12.8	34.4	52.8

According to the farmers, most of the crops are grown during the rainy season (October to April) and a few crops are grown during the dry season, along river basins. The main crops grown during the rainy season included cassava, groundnuts, sorghum, maize, sesame (*Sesamum indicum*), cowpea, sweet-potatoes (*Ipomea batatas*), cotton, (*Gossypium hirsutum*) green-gram (*Vigna radiata*), pigeon-pea (*Cajanus Cajan*), rice, sugar-cane (*Saccharum officinarum*) and bambara-groundnuts (*Vigna subterranea*) (Table 2.3). Groundnut was ranked third after cassava and maize, while sweet potato was ranked last in importance. The few crops grown during the dry season (May to September) included tomato (Lycopersicon esculentum), cabbage (*Brassica oleracea*) and onion (*Allium cepa*).

Table 2. 3: Percent distribution of the respondents by major crops grown in five villages in the study

Crop	Village					Mean	Rank
	Milipone	Ncoela	Napuri	Namicori	Muloco		
Cassava	22.2	17.5	19.7	23.7	29.8	22.6	1
Maize	22.5	17.8	18.2	19.4	17.2	19.0	2
Groundnut	18.5	17.8	16.9	16.3	16.3	17.2	3
Sorghum	4.9	5.8	4.9	5.2	4.6	5.1	5
Cowpea	4.3	6.2	5.8	4.5	5.2	5.2	4
Sesame	4.6	4	3.1	5.2	2.5	3.9	9
Cotton	4.9	6.8	3.7	3.1	3.4	4.4	7
Bambara nut	4.6	4.6	4.3	3.1	3.7	4.1	8
greengram	3.7	5.2	5.8	5.2	3.1	4.6	6
Sugar cane	4.0	3.1	4.0	3.0	2.6	3.3	13
Rice	1.8	3.7	4.9	3.7	3.1	3.4	12
Sweet potato	3.4	2.8	4.3	3.4	3.7	3.5	11
Pigeon pea	0.6	4.6	4.3	3.7	4.6	3.6	10
Others	0.0	0.1	0.1	0.5	0.2	0.2	14

2.3.3 Groundnut production

In this study, groundnut was grown by every household across the two districts. It was ranked the third most important crop after cassava and maize (Table 2.3). In Namuno district (Milipone, Ncoela and Napuri), 100 percent of the farmers (Figure 2.4) grew local landraces which matured after 150 days with yields varying between 500-700 kg ha^{-1}. On the contrary, about 56 % in Namicori and 60 % in Muloco, villages in Erati district, grew improved groundnut cultivar Nametil instead of landraces. Nametil matures around 90 days and its yield can reach up to 1200 kg ha^{-1}.

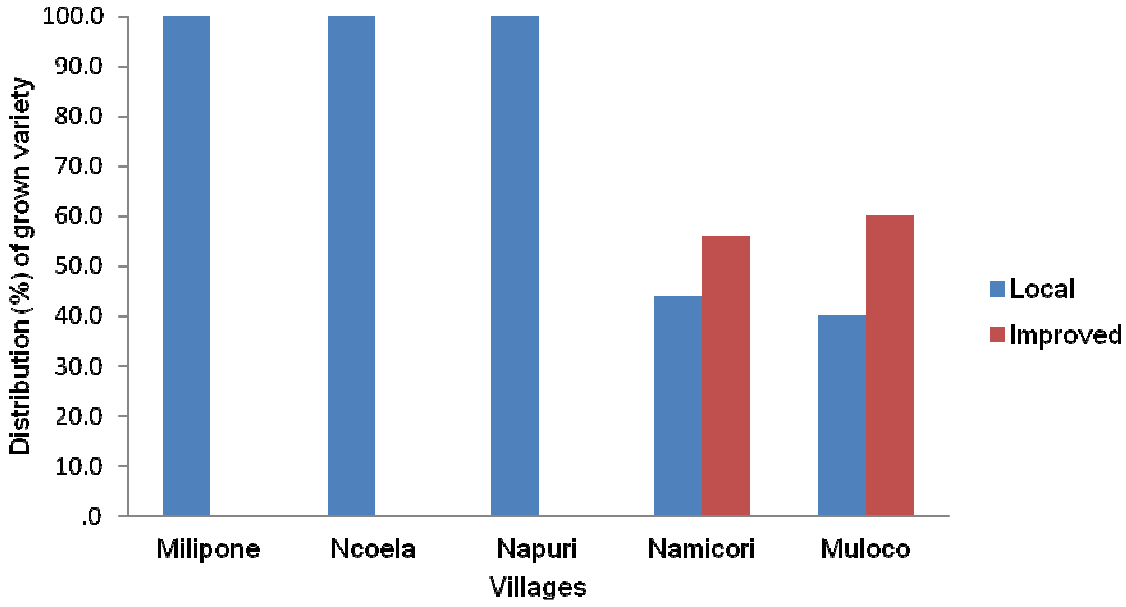

Figure 2. 4: Percent distribution of respondents by type of groundnut cultivar grown in Namuno and Erati districts

2.3.4 Preferred traits for groundnut cultivars

In this study, farmers selected groundnut cultivars for production on the basis of seed colour, seed size, market price, yield potential, palatability, earliness, oil content, and tolerance to pests and diseases (Table 2.4). In some of the cases, the selection criterion used by women differed from that used by men within village and across villages. For example, in Milipone, Namuno, about 42 % of women preferred cultivars with small pods and small seeds, 25 % preferred medium pods and seeds and 33 % big pods and seeds. On the other hand, about 11 % preferred small pods and seeds, 34 % medium and 55 % big pods and seeds. About all respondents in the two districts preferred cultivars with red seed. But slightly over 20 % of farmers in Erati preferred cultivars with tan seed, and about 5 % of respondents in Ncoela and Napuri (Namuno) preferred cultivars with any seed colour.

Preference for groundnut maturity was different across villages. In Namuno district, 16 %, 35 % and 65 % of the men in Milipone, Ncoela and Napuri villages, respectively preferred medium maturing cultivars. In Erati, about 14 % of men in Namicori and 29 % in Muloco preferred medium maturing cultivars.

Overall, females preferred erect cultivars, except in Ncoela and Napuri where 63 % and 40 % of females preferred runners, respectively. Males preferred runners, except 50 % and 62 % of males in Namicori and Muloco who preferred erect types. Big pod and seed sizes were preferred by both males and females, except 42 % of females in Milipone and 50 % of males in Muloco who preferred small pod and seed sizes. Red primary seed colour was preferred by both males and females. Early maturing cultivars were preferred for both males and females, except 40% females and 65 % of males in Napuri who preferred medium maturing and 42 % of males in Milipone who preferred late maturing cultivars. Both males and females preferred high yielding cultivars, except 50 % of females in Muloco who preferred medium yielding. Both males and females preferred high resistant cultivars to insect pests, diseases and drought. High oil content cultivars were preferred by both males and females, except 50 % of females in Muloco who preferred medium oil content cultivars.

Table 2.4: Percent distribution of preferred traits in groundnut cultivars by gender in Namuno and Erati districts in Mozambique

Trait	Gender	Preference	District					Mean
			Namuno			Erati		
			Milipone	Ncoela	Napuri	Namicori	Muloco	
Growth habit	Females	Erect	50.0	25.0	20.0	81.8	75.0	50.4
		Bunch	33.3	12.5	40.0	0.0	0.0	17.2
		Runner	16.7	62.5	40.0	18.2	25.0	32.5
	Males	Erect	10.5	41.2	10.0	50.0	61.9	34.7
		Bunch	10.5	0.0	20.0	21.4	14.3	13.2
		Runner	78.9	58.8	70.0	28.6	23.8	52.0
Pod and seed size	Females	Small	41.7	12.5	0.0	31.8	12.5	19.7
		Medium	25.0	31.3	40.0	27.3	37.5	32.2
		Big	33.3	56.3	60.0	40.9	50.0	48.1
	Males	Small	10.5	20.6	2.5	28.6	50.0	22.4
		Medium	34.2	23.5	35.0	21.4	21.4	27.1
		Big	55.3	55.9	62.5	50.0	28.6	50.5
Seed colour	Females	Red	100.0	100.0	60.0	72.7	100.0	86.5
		Tan	0.0	0.0	0.0	27.3	0.0	5.5
		Any	0.0	0.0	40.0	0.0	0.0	8.0
	Males	Red	100.0	88.2	85.0	78.6	76.2	85.6
		Tan	0.0	5.9	10.0	21.4	23.8	12.2
		Any	0.0	5.9	5.0	0.0	0.0	2.2

Table 2.4: Continued

Trait	Gender	Preference	District					Mean
			Namuno			Erati		
			Milipone	Ncoela	Napuri	Namicori	Muloco	
Maturity	Females	Early	100.0	87.5	40.0	100.0	75.0	80.5
		Medium	0.0	12.5	40.0	0.0	25.0	15.5
		late	0.0	0.0	20.0	0.0	0.0	4.0
	Males	Early	42.1	64.7	20.0	71.4	71.4	53.9
		Medium	15.8	35.3	65.0	14.3	28.6	31.8
		late	42.1	0.0	15.0	14.3	0.0	14.3
Yield	Females	Low	0.0	0.0	0.0	0.0	0.0	0.0
		Medium	16.7	0.0	20.0	0.0	50.0	17.3
		High	83.3	100.0	80.0	100.0	50.0	82.7
	Males	Low	0.0	0.0	0.0	0.0	0.0	0.0
		Medium	36.8	11.8	10.0	0.0	19.0	15.5
		High	63.2	88.2	90.0	100.0	81.0	84.5
Disease, pest and drought Resistance	Females	Low	0.0	0.0	40.0	6.1	0.0	9.2
		Medium	5.6	4.2	6.7	0.0	33.3	10.0
		High	94.4	95.8	53.3	93.9	66.7	80.8
	Males	Low	3.5	0.0	8.3	4.8	0.0	3.3
		Medium	35.1	15.7	6.7	0.0	15.9	14.7
		High	61.4	84.3	85.0	95.2	84.1	82.0
Oil content	Females	Low	0.0	0.0	20.0	0.0	0.0	4.0
		Medium	16.7	0.0	0.0	0.0	50.0	13.3
		High	83.3	100.0	80.0	100.0	50.0	82.7
	Males	Low	0.0	0.0	0.0	0.0	0.0	0.0
		Medium	36.8	0.0	10.0	0.0	14.3	12.2
		High	63.2	100.0	90.0	100.0	85.7	87.8

2.3.5 Groundnut production constraints

Several production constraints affecting groundnut production were mentioned by farmers in the two districts (Tables 2.5). The major constraints included diseases and insect pests, low soil fertility and lack of groundnut seed. There was a difference in the way men and women perceived the main constraints affecting groundnut production within and across villages. For example, low soil fertility was ranked fifth main constraint affecting groundnut production by women in Ncoela, Namuno, but the men in the same villages ranked this constraint second. On the other hand, soil fertility was ranked third, fourth and fifth, in Napuri, Milipone and Ncoela, in Namuno district, respectively, while Namicori was ranked fourth and Muloco fifth.

Diseases and insect pests were ranked first and third, respectively by both women and men. About 35 % of women and 33 % of men in the study area reported that diseases were the most important constraints for groundnut production and productivity. On the other hand, about 9 % of women and 9 % of men mentioned that insect pests were responsible for low groundnut production and productivity in the region.

Lack of new improved cultivars and seed are some of important constraints that contribute to low yields and yield lose in groundnut production. Lack of seed was ranked third by women as a constraint for groundnut production while men rank lack of seed fourth as an important problem for groundnut production. Lack of new improved cultivars was ranked fifth by about 8 % of women and sixth by about 9 % of men as problem affecting groundnut production in the two districts.

In addition, farmers also reported that lack of buyers, labour, infra-structure and drought negatively influenced groundnut production. Inadequate infrastructure was ranked second by about 10% of women and seventh by men in the study area as problem affecting groundnut production, and labour was ranked fourth and fifth by women and men, respectively.

The perception of the problems affecting groundnut production in the study area was different within and across villages as well as between men and women within village. However, some of the constraints were perceived the same way by both women and men.

Table 2.5: Percentage of farmers reporting groundnut production constraints in Namuno and Erati districts in Mozambique

Gender	Problem	Namuno			Erati		Total	Overall Rank
		Milipone	Ncoela	Napuri	Namicori	Muloco		
Females	Drought	7.4(3)*	6.9(4)	4.4(5)	9.1(3)	5.6(6)	7.2	6
	Low soil fertility	5.6(4)	5.6(5)	8.9(3)	7.1(4)	8.3(5)	6.9	7
	Diseases	37.0(1)	43.1(1)	31.1(1)	29.3(1)	33.3(1)	34.6	1
	Insect pests	9.3(2)	6.9(4)	8.9(3)	10.1(2)	11.1(4)	9.2	3
	Lack of seed	9.3(2)	6.9(4)	8.9(3)	9.1(3)	13.9(2)	9.2	3
	Lack of improved cultivars	5.6(4)	5.6(5)	8.9(3)	10.1(2)	8.3(5)	7.8	5
	Lack of market	7.4(3)	8.3(3)	8.9(3)	7.1(4)	0.0(7)	6.9	7
	Lack of labour	9.3(2)	6.9(4)	6.7(4)	9.1(3)	11.1(3)	8.5	4
	Lack of infra-structure	9.3(2)	9.7(2)	13.3(2)	9.1(3)	8.3(5)	9.8	2
Males	Drought	5.8(8)	9.2(4)	6.1(6)	6.3(6)	7.4(7)	7.0	8
	Low soil fertility	8.8(5)	10.5(2)	8.9(2)	10.3(2)	9.5(4)	9.5	2
	Diseases	34.5(1)	20.9(1)	41.7(1)	42.1(1)	24.9(1)	32.5	1
	Insect pests	9.9(3)	10.5(2)	8.9(2)	7.9(4)	9.0(5)	9.3	3
	Lack of seed	9.4(4)	9.2(4)	6.7(5)	8.7(3)	11.6(2)	9.2	4
	lack of improved cultivars	11.1(2)	9.8(3)	6.7(5)	5.6(7)	9.5(4)	8.7	6
	Lack of market	5.3(9)	9.2(4)	5.6(7)	4.8(8)	9.5(4)	7.0	8
	Lack of labour	8.2(6)	10.5(2)	8.3(3)	7.1(5)	10.6(3)	9.0	5
	Lack of infra-structure	7.0(7)	10.5(2)	7.2(4)	7.1(5)	7.9(6)	7.9	7

*Number in parenthesis represents constraint rank

2.3.6 Groundnut rosette disease prevalence in the Northern region of Mozambique

From this study, the results showed that all districts visited had over 50 % of the fields that had groundnut were infected with groundnut rosette disease. Balama district had the lowest number of groundnut fields infected with this disease with slightly over 50% and Nipepe had the highest with over 80 % (Figure 2.4).

Disease incidence in the 2010/2011 growing season in various districts studied ranged from 0 to 40% (Table 2.6). Most of the fields visited had disease incidence between 10 and 30 %. Nipepe had the highest number of fields (80 %) infected with groundnut rosette disease while Balama had the lowest (44 %) number of infected fields.

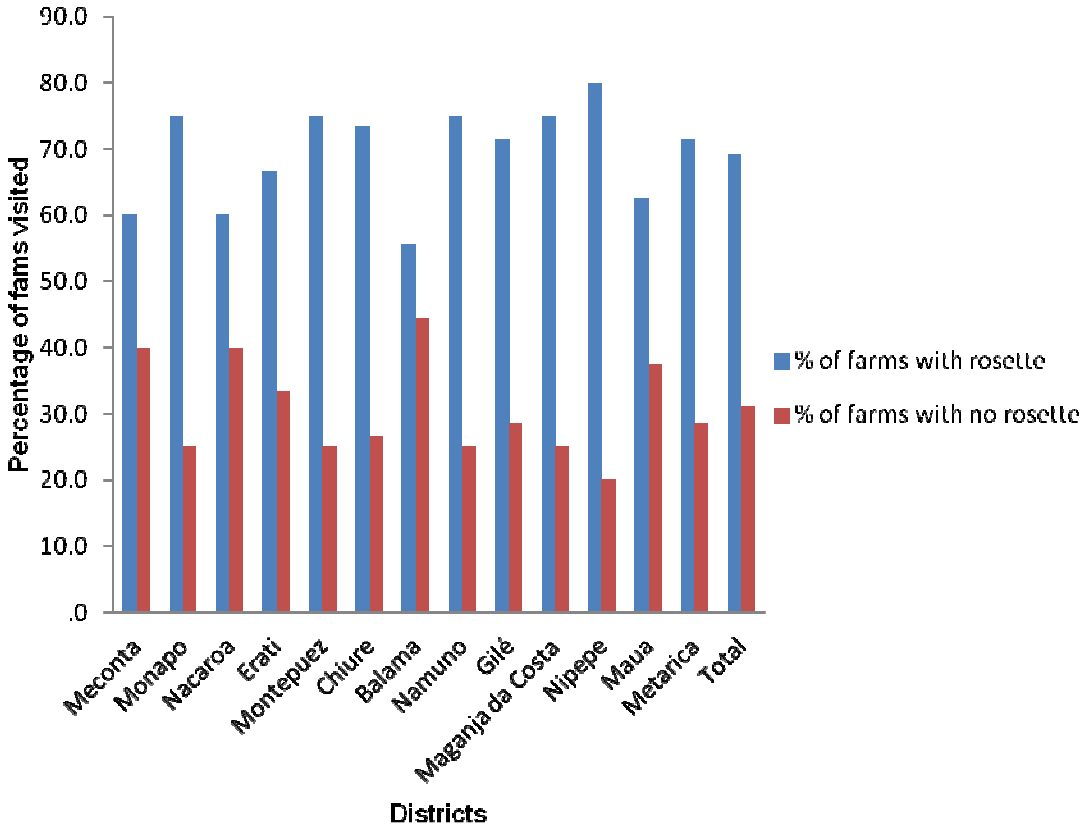

Figure 2.5: Groundnut rosette disease prevalence in the northern region of Mozambique

Table 2.6: Gorundnut rosette disease incidence in the northern region of Mozambique during the 2010/2011 growing season

Province	District	Number of fields observed	Disease incidence intervals (%)		
			0-10	10-30	>30
Nampula	Meconta	10	40.0	50.0	10.0
	Monapo	8	25.0	50.0	25.0
	Nacaroa	10	40.0	40.0	20.0
	Erati	15	33.3	46.7	20.0
Cabo Delgado	Montepuez	12	16.7	58.3	25.0
	Chiure	15	26.7	53.3	20.0
	Balama	9	44.4	33.3	22.2
	Namuno	12	25.0	58.3	16.7
Zambezia	Gilé	7	42.9	42.9	14.3
	Maganja da Costa	8	25.0	50.0	25.0
Niassa	Nipepe	5	0.0	80.0	20.0
	Maua	8	12.5	62.5	25.0
	Metarica	7	28.6	57.1	14.3
	Total	126	28.6	51.6	19.8

2.4 Discussion

Farmers in Erati and Namuno districts cultivated small fields that were less than five hectares. This is probably due to lack of labour since most of the farmers use household

labour. The mean number of persons per households was four and varied from two to just above four members in the two districts. According to the farmers, a household of two members was basically the wife and husband, and no children. This type of household had limited labour, and therefore, cultivated areas less than one hectare. A household of three, in general, consisted of grandparents and a grandchild. They produced their crops in small fields with very limited labour. Households of four or more members were wife and husband and two or more children. These households had more labour and cultivated areas over two hectares. These findings were confirmed by Davies (1997) while describing Niassa, Mozambique, farming system. The study also showed that active farmers were between 30-50 years old in both districts. This was because people of less than 30 years of age had alternative jobs in the nearest towns or they were selling goods within the villages.

The main crops cultivated in the two districts in order of decreasing importance were cassava, maize, groundnut, sorghum, sesame, cowpea, sweet-potato, cotton, green-gram, pigeon-pea, rice, sugar-cane and bambara-groundnut. Groundnut was grown for food and cash. Other crops such as cassava, maize, sorghum and cowpea were grown specifically for food security. As a food crop, farmers used groundnut as a source of cooking oil or snack (roasted or boiled).

Intercropping (mixed cropping) was found to be the most common cropping system practiced by farmers in the two districts. Most of the fields had mixtures of cassava, groundnut, cowpea and pigeon pea, and a few farmers practised mono-cropping of groundnut in small plots. Groundnut was the only crop which appeared in all inter-cropping systems. Métier (2005a, b) confirmed that groundnut was grown in all three main cropping systems described in Namuno and Erati, which is an indication of the importance of groundnut crop in the region. By intercropping several crops including groundnut, farmers improved their food security status because if one crop failed farmers could still harvest others.

About 47 % of respondents cultivated small fields that were less than one hectare in size, while 53% of respondents cultivated fields that were 1-5 ha. This is an indication that crops grown in the region, even though important for food security, were grown in small fields.

It is very important for breeders to know the characteristics of groundnuts that farmers prefer when developing a new cultivar. Most of the farmers in this region preferred large-seeded, erect, early maturing, high yielding, high insect pest, disease and drought resistant, and high oil content groundnut cultivars. However, there were some differences on preference between males and females within and across villages. Kitch et al. (1998) pointed out that farmer preferred cultivars with particular traits, such as large-seeded and red-coloured cultivars, that give the best price.

The results of this study indicated that farmers were aware of the constraints affecting their crops. Constraints such as diseases, insect pests, and lack of new and improved cultivars were reported to be limiting factors for groundnut production in the region. The most important groundnut disease mentioned by farmers was groundnut rosette disease. They used descriptive names for symptoms, such as stunted plants, deformed leaves, yellowing of leaves in order to indicate the disease. For example, farmers compared groundnut rosette disease with leprosy disease in humans: the affected plants were stunted just as with fingers of persons suffering from leprosy. They noted that this disease was sporadic, but it could destroy an entire crop when it occurred. Other diseases mentioned by farmers were leaf spots and leaf rust. Farmers related leaf spots and rust diseases with crop maturity since the diseases appeared late in the season when the crop was about to mature, however they were not aware of the real impact of these diseases. The most important insect pests mentioned by farmers were termites and white grubs. According to the farmers, termites attacked groundnut crop from emergence to harvest, while white grubs attacked plants during the seedling stage, causing wilting and death.

In Namuno, all farmers grew local landraces, which were large-seeded, low-yielding and susceptible to groundnut rosette disease. This indicated that improved cultivars that had been released in the area were not adopted by the farmers due to possession of small pods and seeds which required more labour for shelling. The farmers were aware of the advantages of growing improved cultivars which were high yielding. However, they continued growing the landraces for two main reasons: 1) lack of buyers at the local level for the small-seeded improved cultivars and 2) high labour demand for the shelling process. The farmers indicated that they did not have means to transport their produce to the nearest major town and the stockists in the rural areas did not buy small-seeded cultivars.

On the contrary, farmers in Erati had replaced local landraces with improved groundnut cultivar, Nametil, which is resistant to groundnut rosette disease, high-yielding, early-maturing, small-seeded with high oil content. The main reason for this replacement was because Erati district is close to a big town (Nampula) and is traversed by a major road which links two big urban areas of northern Mozambique, Pemba and Nampula. In these two towns, small-seeded groundnuts are preferred.

Another constraint mentioned repeatedly was the selling price. According to farmers, most of the produce was sold to individuals, local markets and fellow farmers. Farmers sold their groundnuts at prices ranging between 10 and 12 Mozambican currency (about US$0.40) per kg during the harvesting period from May to September, while toward the onset of rains when groundnut seed was in high demand, prices reached up to 50 Mozambican currency (about US$2.0 per kg).

Groundnut rosette disease was recorded in all districts surveyed. Its incidence was generally low but varied from one district to another. Serious disease incidence occurred in Nipepe and Maua, Niassa province. Groundnut rosette disease is known to cause occasional epidemics under favourable conditions (Haciwa and Kannaiyan, 1995). Therefore, even with low disease incidence in the 2010/2011 growing season, the groundnut breeding programme must aim at developing rosette disease tolerant high yielding cultivars with other preferred traits.

This study initiated dialogue between farmers and researchers which helped understand the main constraints for groundnut production faced by farmers in the northern region of Mozambique. This dialogue, through the participatory approach, confirmed that farmers were aware of the various issues affecting their daily lives including crop production. Biggs (1978) confirmed that farmers have valuable knowledge and they can contribute to agricultural research.

During this study, farmers of both districts mentioned that they did not participate in research programmes occurring in their regions, which lead to low adoption of new technologies. Farmer participation is important because it empowers them (Sperling et al., 1993) and increases the efficiency of the research by orienting it to their needs (Witcombe, 1996; Witcombe et al., 1996; Witcombe et al., 2005; Witcombe et al., 2006). Biggs (1989) opined that farmers must be consulted in order to diagnose problems and

modify research plans. They have to sense that they are active partners in the research, and they have to lead the direction of research.

2.5 Conclusions

Based on the results obtained from the PRA, it is concluded that farmers were aware of the constraints affecting groundnut production and productivity in the study area. The major constraints included groundnut rosette disease, insect pests, lack of seeds and improved cultivars, low soil fertility and lack of infra-structure. Selection criterion used by women differed from that used by men within village and across villages. However, high yield and oil content were the most important traits followed by pod and seed size, earliness and disease and insect pest resistance. Farmers did not accept groundnut rosette resistant cultivars since they were not suitable for local needs. Those near major towns accepted since they can market their produce. Farmers were aware of groundnut rosette disease and it was ranked the most important constraint by both women and men. Groundnut rosette disease was found in all districts surveyed. Its incidence was generally low, but varied among the districts. The most serious disease incidence occurred in Niassa province.

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III. EVALUATION OF NORTHERN MOZAMBIQUE GROUNDNUT (*ARACHIS HYPOGAEA* L.) LANDDRACES FOR RESISTANCE TO GROUNDNUT ROSETTE DISEASE AND SELECTED AGRO-MORPHOLOGICAL TRAITS

Abstract

Groundnut (*Arachis hypogaea* L.)is an important cash and food crop for many families in Mozambique. No information is available on the diversity of groundnut landraces present in the country. The objective of this study was to evaluate the groundnut landraces with respect to rosette disease and selected morphological traits. Fifty-eight local groundnut landraces collected from northern Mozambique were evaluated in the 2008/2009 and 2009/2010 growing seasons for agro-morphological traits and 2010/2011 growing

season for groundnut rosette disease incidence at Nampula Research Station. In this study, flower colour of yellow-orange group was observed. Two main primary seed colours (purple and tan) were found; both colours varied from light to dark. Four types of growth habit pattern were recorded being decumbent-1, decumbent-2, decumbent-3 and erect. Green and purple main stem colours were found; some genotypes had a mixture of the two colours. Leaflet shapes were classified as obovate, lanceolate, wide-elliptic and oblong-elliptic. Three pod sizes (small, medium and big) were recorded, and pod constriction varied between very deep, deep, moderate, slight and none. Pod beak was classified as prominent, moderate and slight. Most landraces gave low mean seed yield, similar to that obtained by Mozambican groundnut producers of 600 to 800 kg ha^{-1}. The highest yielding genotypes were Pambara-4, Ile-1, Imponge-1-Tom, Pambara-2, Imponge-42, Gile-5 and Pambara-6 with over 800 kg ha^{-1}. For 100 seed weight, the landraces were grouped into three different classes: (i) less than 30 g, (ii) between 30 and 45 g and (iii) more than 45 g. The average number of pods $plant^{-1}$ was 107, and the average pod length was 2.5 cm with the largest of 3 cm and the shortest of 2 cm pod length. Four genotypes, PAN-4, Imponge-4, Pambara-3 and Metarica Joao were classified as resistant to groundnut rosette disease. There was no significant ($P>0.05$) correlation between seed yield and groundnut rosette disease incidence. The Clustering of the genotypes by the nearest neighbour method based on agro-morphological traits gave six Clusters which indicated that there was wide diversity among landraces, suggesting that they could be useful for a breeding programme.

Keywords: Mozambique, landraces, groundnut, *Arachis hypogaea*, Morphological characterization, groundnut rosette disease.

3.1 Introduction

Groundnut (Arachis hypogaea L.) is the third most important crop in Mozambique after maize (Zea mays) and cassava (Manihot esculenta) (Walker et al., 2006). It is a major cash crop and the main source of cooking oil for many Mozambican families (Muitia, 2005). In terms of production, groundnut occupies the largest area among the grain legumes in the country (Arias and Libombo, 1994). The crop is mainly grown by small scale farmers under rainfed conditions. Low groundnut yields that are of poor quality are realized by farmers in Mozambique as a result of several constraints. The major

constraints include: diseases (i.e., groundnut rosette disease, early and late leaf spots), drought, insect pests (e.g., leaf borers), and post-harvest related issues (i.e., aflatoxins).

Groundnut rosette is the most destructive viral disease of groundnut in Sub-Saharan Africa and can cause up to 100 % crop loss (Bock et al., 1990; Naidu et al., 1998; Naidu et al., 1999). The disease is manifested in the form of mosaic, chlorosis or green where by leaves show mosaic symptoms, yellow chlorosis and dark green, respectively. The identification of genotypes with resistance to groundnut rosette disease would be an important component of the genetic improvement of groundnut in Sub-Saharan Africa, including Mozambique, where the disease is endemic. Sources of resistance to groundnut rosette disease have been identified at ICRISAT (ICRISAT, 1991; Ntare et al., 2007). These resistant cultivars are not popular with Mozambican farmers since they have small pods and seeds which are laborious to shell. Such resistance, on the other hand, could be incorporated into popular but susceptible local landraces through breeding.

Groundnut has been cultivated by farmers in Mozambique since the 16th century when the crop was first introduced by portuguese. There is a wide range of landraces currently grown by farmers in the country. Some of these landraces may already carry genes for resistance to rosette disease, in addition to other traits. Hence, there is a need to evaluate a number of landraces in order to identify genotypes with desirable traits such as resistance to groundnut rosette disease, medium to big seed size, early maturity and high oil content. The objectives of this study were to evaluate groundnut landraces collected from northern Mozambique for variation in selected agro-morphological traits and to identify groundnut germplasm sources resistance to groundnut rosette disease for future use in breeding programmes.

3.2 Materials and methods

3.2.1 Groundnut genotypes

Fifty-eight local groundnut landraces were collected from the northern region of Mozambique (Nampula, Cabo Delgado, Niassa and Zambézia). The genotypes were labelled with the names of the villages or regions where they were collected (Table 3.1).

3.2.2 Study area

The study was conducted at Nampula Research Station (PAN), which is located about 7 km east of Nampula in northern Mozambique (15º 09' S, 39º 30' E) and is elevated at 432 m above sea level. The soil type is sandy loam and the vegetation is predominantly grassland. The average rainfall is slightly over 1000 mm which starts around November/December up to April/May with its peak in January. The maximum temperature in the region is about 39^{o} C and the minimum temperature is 19^{o} C.

3.2.3 Field establishment

The study was carried out in the 2008/2009, 2009/2010 and 2010/2011 growing seasons. During the first two growing seasons (2008/2009 and 2009/2010), the genotypes were evaluated for agro-morphological characteristics at low disease pressure. Since Nampula is a hotspot for groundnut rosette disease, the experiment was planted in December of each growing season so that the plants could escape the period of heavy disease infection late in the season. The 58 genotypes were planted in an α-resolvable design (29 blocks containing 2 row plots each) with two replications. The replicates were separated by 2 m alleys. Two replications were used in order to keep the experiment in a manageable size because of the number of accessions and the design of the infector row where by each test line is surrounded by infector made the experiment quite big. An individual genotype was planted in a 4 m single row at a spacing of 0.6 m between rows (genotypes) and 0.2 m within rows. The seeds were sown at a depth of 5 cm. The field was kept weed free by hand weeding. No fertilizer, pesticides or supplementary water were applied because fertilizers and pesticides are not available and farmers do not user fertilizers non pesticides on their crop.

In the 2010/2011 growing season, the genotypes were evaluated at high disease pressure in Nampula and Namapa for groundnut rosette disease screening. The experiment in Namapa was destroyed by heavy rains occurred by mid February of 2011 and is not reported in this thesis. The experiment was planted in late January in order to expose the genotypes to high disease pressure. The 58 genotypes were planted in a α-resolvable design (29 blocks containing 2 row plots each) with two replications. The replicates were separated by 2 m alleys. An individual genotype was planted in a 4 m single row at spacing of 0.6 m between rows (genotypes) and 0.2 m within rows. Blocks

were flanked with two rows of a susceptible cultivar. Care was taken to ensure uniform planting. The field was kept weed free by hand weeding. No fertilizer, pesticides or supplementary water were applied.

The genotypes were infested with disease using the spreader-row technique. This was done by planting the tester genotypes (landraces) in single row plots adjacent to a susceptible cultivar (JL-24), that was planted 15 days earlier to provide large population of aphids and groundnut rosette disease inoculum (Figure 3.1)..

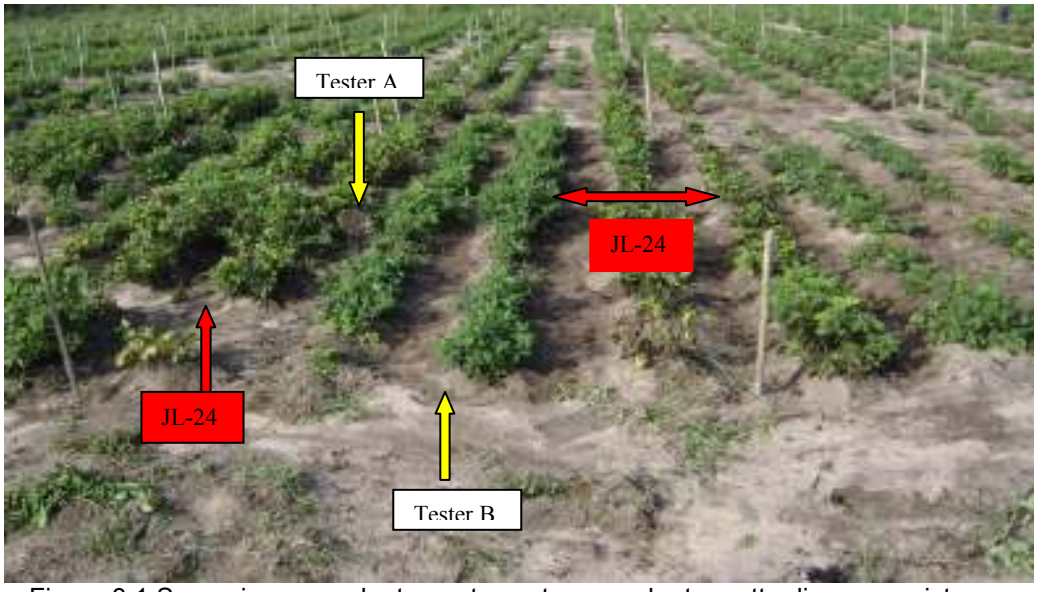

Figure 3.1 Screening groundnut genotypes to groundnut rosette disease resistance

Table 3.1: Local groundnut landraces evaluated for yield, yield components and resistance to groundnut rosette disease in 2008/2009, 2009/2010 and 2010/2011 growing seasons at PAN, Nampula, Mozambique

Genotype*	Origin	Source	Genotype*	Origin	Source
1A	Nampula	Breeding program	Molocue-2	Zambézia	Market-Mixture
35B	Nampula	Breeding program	Mualia	Cabo Delgado	Village-Mixture
41A	Nampula	Breeding program	Mualia-1	Cabo Delgado	Village-Mixture
75B	Nampula	Breeding program	Mualia-2	Cabo Delgado	Village-Mixture
Erati Mercado	Nampula	Market-Mixture	Mualia-3	Cabo Delgado	Village-Mixture
Erati Omar	Nampula	Omar's home-Mixture	Nacate	Cabo Delgado	Field-single plant
Erati Sede	Nampula	Market-Mixture	Nacate_3	Cabo Delgado	Field-single plant
Impong_1_Tom	Nampula	Village-Mixture	Nacate-1	Cabo Delgado	Field-single plant
Imponge_2	Nampula	Village-Mixture	Nacate-2	Cabo Delgado	Field-single plant
Imponge_3	Nampula	Village-Mixture	Namuno-1	Cabo Delgado	Market-Mixture
Imponge_4	Nampula	Village-Mixture	Ncoela	Cabo Delgado	Field-single plant
Imponge_4/2	Nampula	Village-Mixture	Ncoela-1	Cabo Delgado	Field-single plant
Imponge_5	Nampula	Village-Mixture	Ncoela-2	Cabo Delgado	Field-single plant
Imponge-2A	Nampula	Village-Mixture	Ncoela-3	Cabo Delgado	Field-single plant
Imponge-4/3	Nampula	Village-Mixture	Ncoela-4	Cabo Delgado	Field-single plant
PAN-1	Nampula	Breeding program	Ncoela-5	Cabo Delgado	Field-single plant
PAN-2	Nampula	Breeding program	Ncoela-6	Cabo Delgado	Field-single plant
PAN-3	Nampula	Breeding program	Pambara-1	Cabo Delgado	Village-Mixture
PAN-4	Nampula	Breeding program	Pambara-2	Cabo Delgado	Village-Mixture
PAN-5	Nampula	Breeding program	Pambara-3	Cabo Delgado	Village-Mixture
JL-24	Nampula	Nampula-Cultivar	Pambara-4	Cabo Delgado	Village-Mixture
Gile_4	Zambézia	Market-Mixture	Pambara-5	Cabo Delgado	Village-Mixture
Gile-1	Zambézia	Market-Mixture	Pambara-6	Cabo Delgado	Village-Mixture
Gile-2	Zambézia	Market-Mixture	Pambara-7	Cabo Delgado	Village-Mixture
Gile-3	Zambézia	Market-Mixture	Unhaphatenha	Cabo Delgado	Field-single plant
Gile-5	Zambézia	Market-Mixture	Cuamba Lurio Eugenio	Niassa	Market-Mixture
Ile-1	Zambézia	Market-Mixture	Lurio Miguel	Niassa	Market-Mixture
Ile-2	Zambézia	Market-Mixture	Metarica Joao	Niassa	Market-Mixture
Molocue-1	Zambézia	Market-Mixture	Metarica Mutara	Niassa	Market-Mixture

*The names of the genotypes represent the villages from where they were collected

3.2.4 Data collection

Some groundnut descriptors reported by the International Board for Plant Genetic Resources (IBPGR) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were used (IBPGR and ICRISAT, 1992) for evaluating the genotypes during 2008/2009 and 2009/2010 growing seasons (Table 3.2). The traits evaluated included qualitative traits (primary seed colour, flower colour, leaflet shape, growth habit, pod size, pod constriction, pod beak, stem colour) and quantitative traits (seed yield, 100 seed weight, pods plant^{-1} and pod length). Yield was determined for each groundnut genotype at the end of the maturity period by shelling and weighing the sun dried seeds. Seed weight, measured in gm^{-2}, was converted to kg ha^{-1}.

In the 2010/2011 growing season, single plants from each genotype were monitored for presence or absence of virus symptoms at 60 days after planting. Disease incidence (DI) was determined by calculating the percentage of plants with rosette symptoms for each genotype (Waliyar et al., 2007).

3.2.5 Data analysis

The data on yield, morphological characteristics and disease incidence were analyzed using the Genstat 14 Statistical program (Payne et al., 2011). The following statistical model was used to analyse data:

$$Y_{ijkl}=\mu+E_i+Y_j+EY_{ij}+R_{k(ij)}+G_l+GE_{il}+GY_{jl}+GEY_{ijl}+\varepsilon_{ijkl}$$

Where: Y_{ijkl} = observed landrace response; μ = overall population mean; E_i = Effect of the ith environment; G_l = Effect of the l^{th} genotype; Y_j = Effect of the j^{th} year; EY_{ij} = Interaction effect of the i^{th} environment and the j^{th} year; $R_{k(ij)}$ = Effect of the k^{th} replication in the i^{th} environment; GE_{il} = Interaction effect of the l^{th} genotype and the i^{th} environment; GY_{jl} = Interaction effect of the l^{th} genotype and the j^{th} year; GEY_{ijl} = Interaction effect of the l^{th} genotype, i^{th} environment and j^{th} year; ε_{ijkl} = Experimental error.

Where G was considered as fixed effect and E, Y, GY, GE and GEY were considered as random effects.

Mean separation for yield and disease incidence data was performed using Fisher's protected least significant difference (LSD) for each season separately and for combined data. Phenotypic correlations between disease incidence and yield and yield components were determined using Pearson's Correlation procedure. Cluster analysis was performed for the morphological characteristics, yield, and yield components using SPSS for Windows 19 (SPSS, Inc., 2010, Chicago, IL, www.spss.com) for combined data. Hierarchical cluster analysis was carried out using nearest neighbour method and applying squared Euclidean distance as the similarity measure.

This experiment was conducted in two locations (Nampula and Namapa), but only data from one location (Nampula) will be presented since the trial from the other site was washed out by heavy rains which occurred in mid-February, 2011.

Table 3.2: Descriptors used in the evaluation of Mozambican groundnut landraces grown at Nampula Research Station

Descriptor	Category definition	Remarks
Qualitative traits		
Primary seed colour	1=white; 2=off-white; 3=yellow; 4=very pale tan; 5=pale tan; 6=light tan; 7=tan; 8=dark tan; 9=grey orange; 10=rose; 11=salmon; 12=light red; 13=red; 14=dark red; 15=purplish; 16=light purple; 17=purple; 18=dark purple; 19=very dark purple; 20=other	Recorded from dry, mature and wrinkle free seeds
Flower colour	1=white; 2=lemon yellow; 3=yellow; 4=orange-yellow; 5=orange; 6=dark orange; 7=garnet/brick red; 8=other	Colour of front face of the stand petal of fresh and opened flowers
Leaflet shape	1=cuneate; 2=obcuneate; 3=elliptic; 4=oblong-elliptic; 5=narrow-elliptic; 6=wide-elliptic; 7=suborbicular; 8=orbicular; 9=ovate; 10=obovate; 11=oblong; 12=oblong-lanceolate; 13=lanceolate; 14=linear lanceolate; 15=other	Shape of fully expanded, apical leaflet of the third leaf on the main stem
Growth habit	1=procumbent-1; 2=procumbent-2; 3=decumbent-1; 4=decumbent-2; 5=decumbent-3; 6=erect; 7=other	Taken at podding stage (45-60 days after planting)
Pod size*	1=small; 2=medium; 3=big	Recorded from fully mature pods
Pod constriction	0=none; 3=slight; 5=moderate; 7=deep; 9=very deep	Taken from fully mature pods
Pod beak	0=absent; 3=slight; 5=moderate; 7=prominent; 9=very prominent	Recorder from fully mature pods
Stem colour*	1=purple; 2=green; 3=mixture of the two	Recorded on the main stem of mature plants (45-60 days after planting)
Quantitative traits		
100 seed weight		weight of 100 random, mature and wrinkle-free seeds
pods per plant		Total number of pods recorded from 5 random plants
pod length		Recorded from a mean of 20 fully mature pods selected randomly
Rosette disease incidence	HR=<10%; R=11-30%; MR=31-50%; S=>50%	

*Not included on the IBPGR descriptor. HR=High resistant; R=Resistant; MR=Moderate resistant; S=Susceptible

3.3 Results

3.3.1 Phenotypic variation among groundnut landraces

The genotypes studied differed with respect to pod size, pod constriction, primary seed colour, pod beak, leaflet shape and growth habit (Figure 3.2, Figure 3.3 and Appendix 2). They were, however, similar for yellow-orange flower colour. Pod size comprised of small, medium and big. Seventy-nine percent of the genotypes evaluated had medium pod size, 9 % were big-seeded and 12 % were small-seeded. Pod constriction varied from very deep to none. Most of the genotypes, over 75 %, had moderate pod constriction and 14 % had deep pod constriction. The landraces studied had seeds with various shades of purple primary colour (light, pale and deep purple) or tan primary colour (light, pale and dark). Thirty-one percent of the genotypes had purple, and 30 % had pale tan, as primary seed colours, respectively. Their pod beaks varied from prominent to slight, with moderate pod beak being the most common, in 57 % of the genotypes. Leaflet shape varied between obovate, lanceolate, wide-elliptic and oblong elliptic. Over 40 % of the genotypes had wide-elliptic leaflet shape followed by obovate leaflet shape with about 24 % of the genotypes, and growth habit varied from erect to decumbent-3 (Figure 3.3). Over 50 % of the landraces evaluated had a decumbent-2 growth habit and only 10 % were erect. Sixty per cent of the landraces had green stem colour, while 28 % and 12 % of the landraces had purple and mixed stem colours, respectively.

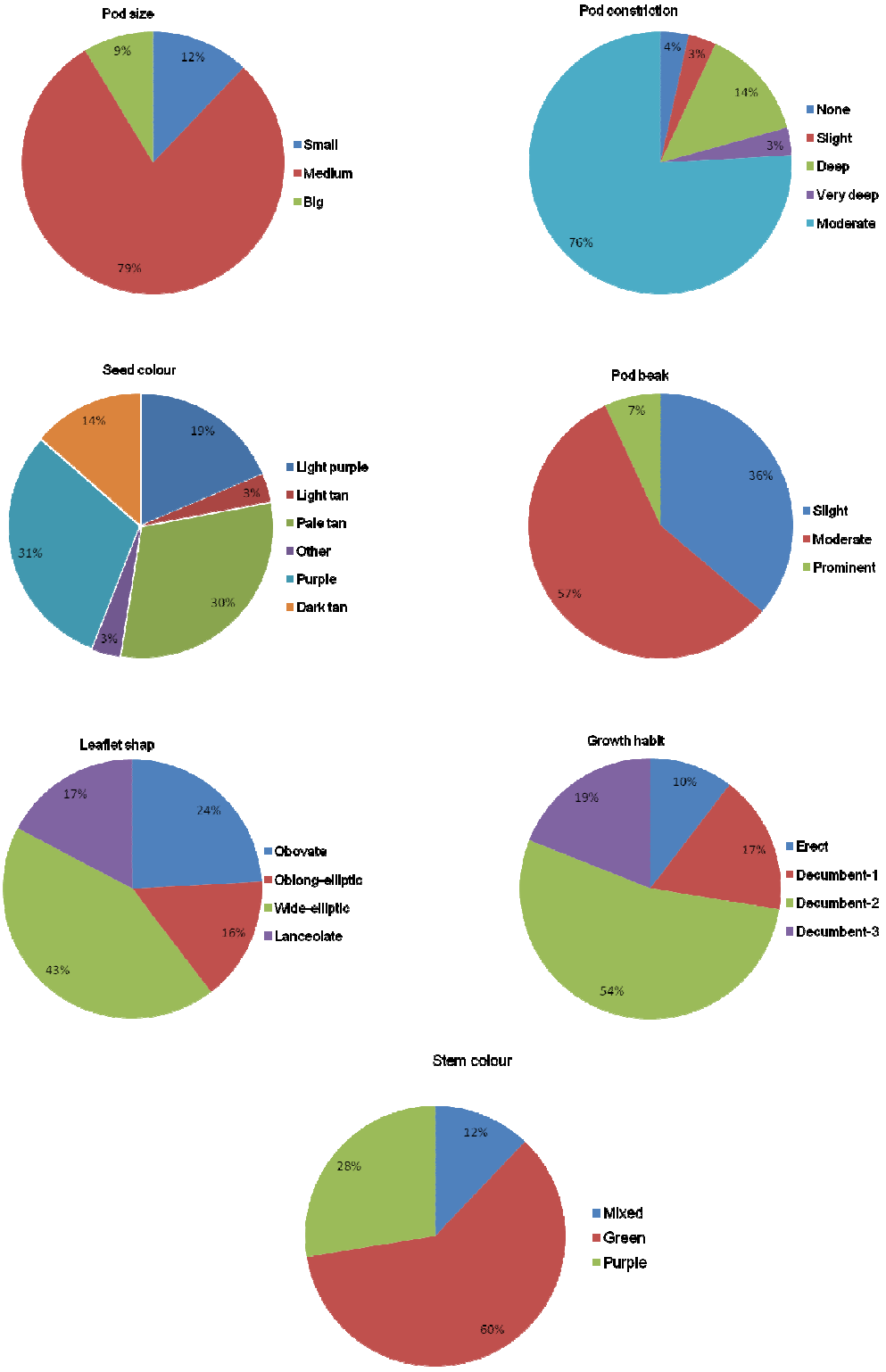

Figure 3.2: Frequency distribution (%) of 58 groundnut landraces for selected agro-morphological traits

Figure 3.3a: Pod constriction, pod beak and primary seed colours recorded in groundnut landraces grown in Mozambique. A1: No pod constriction, A2: Moderate pod constriction, A3: Very deep pod constriction, B1: Moderate pod beak, B2: Prominent pod beak and C: Primary seed colours.

Figure 3.3b: Growth habits of groundnut landraces grown in Mozambique. A: Decumbent-1, B: Decumbent-3, C: Erect, and D: Decumbent-2

3.3.2 Yield and yield components

The mean yield and yield components were significantly ($P \leq 0.05$) different among the groundnut genotypes (Table 3.3 and Appendix 3.). The mean yields ranged between 441.7 and 952 kg ha^{-1}. The highest yielding genotype across the two seasons was Pambara-4 (952 kg ha^{-1}). In the 2008/2009 growing season, the highest yielding genotype was Gile-5 (906 kg ha^{-1}), and in 2009/2010, the highest yielding genotype was Ncoela-5 with 1039.5 kg ha^{-1}.

The lowest yielding genotype across the two seasons was Erati Omar with 441.7 kg ha^{-1}. The lowest yielding genotype in the 2008/2009 growing season was Erati Omar with mean of 214.1 kg ha^{-1}, and the lowest yielding genotype in 2009/2010 was Gile-2 with mean of 263.5 kg ha^{-1}. The 2008/2009 growing season gave a higher mean yield of 681.0 kg ha^{-1} compared to that of 2009/2010 growing season (743.0 kg ha^{-1}).

The 100 seed weight ranged from 28.1 to 61.3 g. Over 55 % of the genotypes had a 100 seed weight of more than 45.0 g, about 16 % less than 35.0 g and about 28 % between 35.0 and 45.0 g. Genotype Gile-2 had the highest 100 seed weight (61.3 g) and genotype Erati Omar had the lowest (26.6 g).

The mean number of pods plant^{-1} ranged from 91 to 153, with genotype Imponge-42 having the highest number (153) and genotypes Gile-2, PAN-1, Mualia-1, Nacate-3, Erati Mercado and Unhaphatenha having the lowest number of pods per plant (91). Most of the genotypes had over 100 pods per plant.

All genotypes had pods over 2.0 cm long, except Pambara-6 and Ncoela-2 with 1.8 and 1.7 cm, respectively. Genotype Ncoela-2 had the shortest pod length (1.7 cm) while genotype Metarica Joao had the longest pod length (3.0 cm).

Table 3.3: Yield and yield components of 58 groundnut genotypes evaluated at Nampula in 2008/2009 and 2009/2010 growing seasons*

Genotype**	Seed yield (kg ha^{-1})			100 seed weight (g)			Number of pods plant $^{-1}$			Pod length (cm)		
	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined
Top 10 landraces												
Pambara-4	874.4	1029.5	952.0	46.2	47.4	46.8	91.0	91.0	91.0	2.4	2.1	2.2
Ile-1	852.5	918.0	885.2	55.0	48.6	51.8	149.0	113.0	131.0	1.5	1.9	1.7
Impong_1_Tom	808.3	957.1	882.7	40.5	33.6	37.1	91.0	131.0	111.0	2.3	2.9	2.6
Pambara-2	853.6	858.6	856.1	50.7	49.9	50.3	91.0	93.5	92.3	2.4	2.8	2.6
Imponge_42	865.3	832.9	849.1	38.7	37.4	38.0	126.5	100.0	113.3	2.9	2.6	2.7
Gile-5	906.0	761.7	833.9	46.0	40.5	43.3	97.5	97.0	97.3	2.2	2.1	2.1
Pambara-6	817.6	785.0	801.3	41.8	42.1	41.9	91.0	134.5	112.8	2.8	2.4	2.6
PAN-5	786.5	788.4	787.4	40.6	39.1	39.8	121.5	156.5	139.0	2.8	2.7	2.8
1A	816.1	735.2	775.6	40.0	40.0	40.0	92.0	91.0	91.5	2.1	2.6	2.3
Namuno-1	839.0	692.1	765.5	44.9	49.1	47.0	111.5	91.0	101.3	2.1	2.2	2.2
Bottom 10 landraces												
Cuamba Lurio Eugenio	476.3	435.7	456.0	33.7	35.2	34.5	131.0	91.0	111.0	2.7	2.6	2.6
Pambara-7	404.3	425.7	415.0	34.8	35.9	35.4	134.5	91.0	112.8	2.6	2.6	2.6
Imponge-2A	363.8	456.6	410.2	26.9	36.8	31.8	91.0	93.5	92.3	2.6	2.1	2.3
Pambara-3	393.1	412.0	402.5	36.8	38.4	37.6	93.5	91.0	92.3	2.8	2.1	2.5
Molocue-2	433.6	357.2	395.4	42.5	48.6	45.5	95.5	113.0	104.3	2.6	2.9	2.8
Erati Mercado	398.4	385.1	391.7	44.8	29.3	37.0	91.0	91.0	91.0	2.2	2.5	2.3
Lurio Miguel	503.7	263.5	383.6	35.0	23.2	29.1	131.0	96.5	113.8	2.6	2.4	2.5
Ncoela-3	484.9	270.6	377.7	39.8	38.4	39.1	99.5	112.5	106.0	2.7	2.6	2.6
Gile-1	326.2	349.8	338.0	47.4	50.0	48.7	111.0	92.5	101.8	2.7	1.8	2.2
Erati Omar	214.1	447.1	330.6	32.4	23.8	28.1	123.0	119.5	121.3	2.6	2.6	2.6
Check												
JL-24	804.5	681.2	742.8	41.3	37.6	39.4	126.0	91.0	108.5	2.3	2.2	2.2
Mean	682.0	498.0	587.0	41.7	40.6	41.1	107.3	97.4	101.0	2.5	2.5	2.5
LSD(5%)	227.7	223.4	141.0	12.4	10.1	14.1	25.5	24.7	32.9	0.8	0.8	0.6
CV(%)	21.6	19.1	17.2	15.3	18.7	11.0	13.3	11.8	16.4	10.7	12.1	14.6

*Genotypes sorted based on the combined yield; **whole list of genotypes given in Appendix 3.2

3.3.3 Clustering based on agro-morphological traits

Genotypes were clustered using both qualitative (primary seed colour, flower colour, leaflet shape, growth habit, pod size, pod constriction, pod beak, stem colour) and quantitative (seed yield, 100 seed weight, pods per plant and pod length) traits (Figure 3.4). At twenty units of distance of similarity, genotypes were grouped into six different clusters (Table 3.4). The distribution pattern indicated that the maximum number of genotypes (29) were in Cluster III followed by Cluster II (11), Cluster I (7), Clusters IV and V (5) each and Cluster 6 (1).

Table 3.4: Distribution of 58 groundnut landraces in six clusters on the basis of agro-morphological traits.

I (7)	II (11)	III (29)	IV (5)	V (5)	VI (1)
Gile-2	Metarica Joao	Erati Mercado	Pambara-6	Imponge-42	Lurio Miguel
Nacate-2	Mualia	Ncoela-3	JL-24	Pambara-2	
Imponge-4	Gile-4	Imponge-2A	PAN-5	Imponge-1-Tom	
PAN-4	Metarica Mutara	Imponge-3	Imponge-2	1A	
PAN-2	Molocue-1	Ncoela-1	Ile-1	Pambara-4	
Nacate-1	PAN-3	Ncoela-2			
Gile-5	Mualia-2	Molocue-2			
	PAN-1	Gile-1			
	Namuno-1	Pambara-7			
	Nacate-3	Pambara-3			
	Imponge-43	Cuamba Lurio Eugenio			
		Mualia-1			
		Erati Omar			
		35B			
		Unhaphatenha			
		Erati Sede			
		Nacate			
		Imponge-5			
		75B			
		Mualia-3			
		Ncoela			
		41A			
		Ile-2			
		Ncoela-4			
		Pambara-5			
		Pambara-1			
		Ncoela-6			
		Ncoela-5			
		Gile-3			

3.3.4 Correlations among quantitative traits

The phenotypic correlations among quantitative traits are given in Table 3.5. Correlations between 100 seed weight and seed yield (*r=0.3624, P≤0.001*), and number of pods per plant and pod length (*r=0.1559, P≤0.01*) were significant and positive. The rest of the correlation values were not significant.

Table 3.5: Phenotypic correlation among selected quantitative traits recorded in groundnut landraces grown at Nampula, in 2008/2009 and 2009/2010 growing seasons

	Seed yield	100 seed weight	Pod length	Number of pods plant^{-1}
Seed yield	1			
100 seed weight	0.3624***	1		
Pod length	-0.0409	0.0375	1	
Number of pods plant^{-1}	0.0491	0.0118	0.1559**	1

** Significant at P = 0.01; ***Significant at P = 0.001;

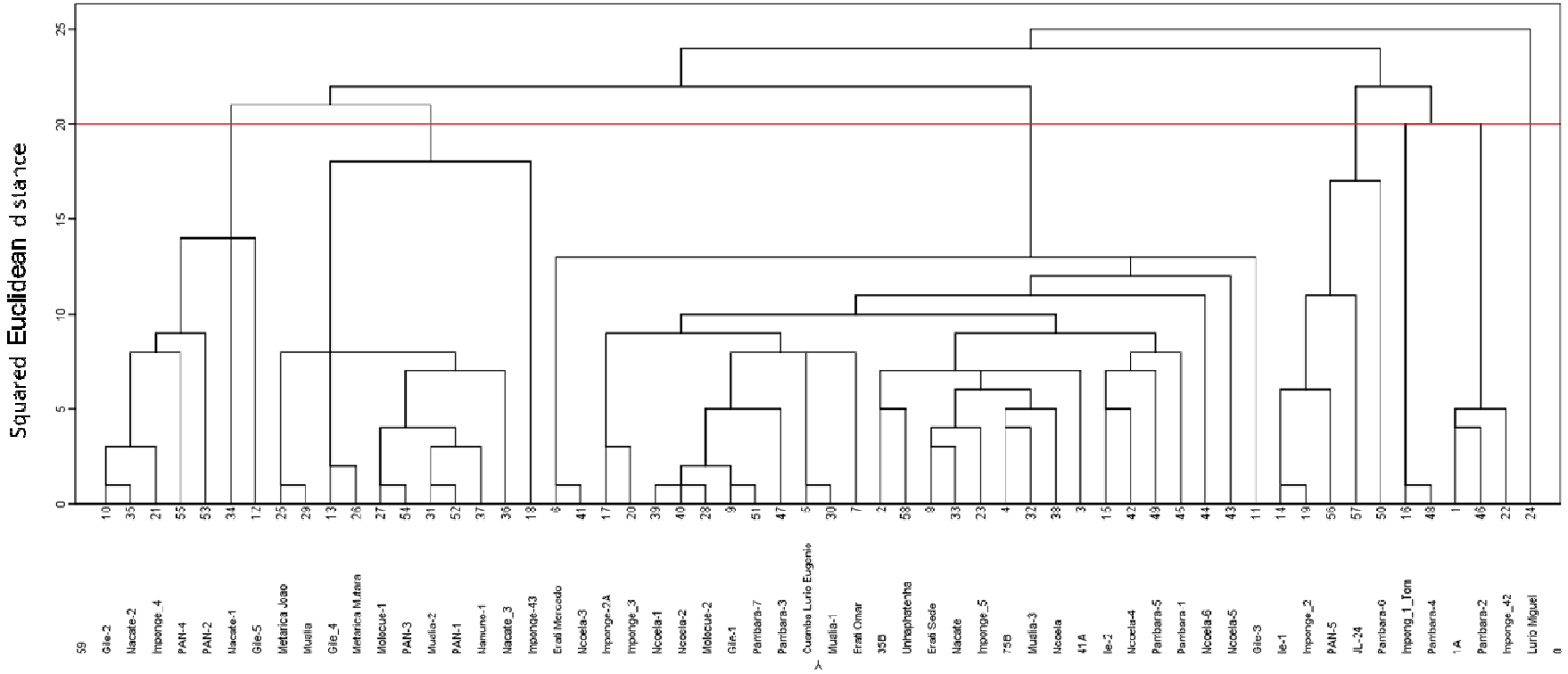

Figure 3.4: Dendogram of 58 landraces based on hierarchical cluster analysis using nearest neighbour method and squared Euclidean distance as distance measure.

3.3.5 Evaluation under high groundnut rosette disease pressure

The infector row technique was efficient in spreading the virus among the groundnut genotypes. The reactions recorded on the genotypes included symptomless plants, leaf deformation, stunted plants and chlorotic plants (Figure 3.5). There were significant ($P \leq 0.05$) differences among genotypes for incidence of groundnut rosette disease (Table 3.6 and Appendix 4). Groundnut rosette disease incidence ranged from 6.2 to 80 %. Four genotypes (PAN-4, Imponge-4, Pambara-3 and Metarica Joao) had groundnut rosette disease incidence less than 10 %. Sixteen of the genotypes had less than 30 % disease incidence, 21 genotypes had less than 50 % and 19 had more than 50 % of disease incidence. Genotype Namuno-1 had disease incidence of 80 %.

The mean seed yield for the genotypes ranged from 64.3 to 844.7 kg ha^{-1}. Genotype Nacate-1 had the highest mean seed yield of 844.7 kg ha^{-1} and Lurio Miguel had the lowest seed yield (64.3 kg ha^{-1}). About 46 % of the genotypes yielded less than 500.0 kg ha^{-1} in the 2010/2011 growing season and only 3 genotypes had over 700.0 kg ha^{-1}.

The 100 seed weight ranged from 23.2 to 54.0 g. Twenty four genotypes had a 100 seed weight less than 35.0 g and only 10 genotypes had a 100 seed weight of more than 45.0 g. Genotype Imponge-3 had the highest 100 seed weight with a mean of 54.0 g and genotype Lurio Miguel had the lowest (23.2 g). The mean number of pods $plant^{-1}$ ranged from 71 to 142. Genotype Erati Omar with the highest number with of 142 and 16 genotypes had the lowest number of pods per plant with a mean of 71.

All genotypes had pods that were over 2.0 cm long, except Ncoela-3 and Gile-2 with 1.8 and 1.7 cm, respectively. Genotype Gile-2 had the shortest pod length with a mean of 1.7 cm while genotype Pambara-2 had the longest pod (3.1 cm).

Figure 3.5: Symptoms of groundnut rosette disease observed on different genotypes. A. Health groundnut plant. B. Infected plant accompanied with leaf yellowing and plant stunting. C. Severe rosette infection showing leaf deformation and plant stunting.

Table 3.6: Groundnut rosette disease incidence at 60 days after planting, yield and yield components of groundnut landraces grown at Nampula, in 2010/2011 growing season

Genotype*	Disease incidence (%)	Seed yield (kg ha^{-1})	100 seed weight (g)	Number of pods plant $^{-1}$	Pod length (cm)
Top 20 landraces					
PAN-4	6.2	739.8	39.0	105.5	2.8
Imponge_4	9.2	423.1	41.1	71.0	2.1
Pambara-3	9.2	240.7	38.4	71.0	2.1
Metarica Joao	9.9	432.0	30.5	77.0	2.1
Imponge-43	11.1	322.4	34.4	103.0	2.5
Pambara-6	12.9	565.3	42.1	76.0	2.4
Pambara-4	14.3	522.0	47.4	91.5	2.5
Pambara-5	15.6	149.1	28.2	106.0	2.5
Impong_1_Tom	19.6	661.3	33.6	71.0	2.2
Pambara-1	23.9	337.5	40.5	71.0	2.2
Ile-2	25.0	455.9	30.5	78.5	2.6
Gile-2	25.9	535.7	30.5	81.5	2.4
PAN-2	27.5	688.2	38.2	87.5	2.5
Nacate	29.2	299.8	39.3	79.5	2.8
35B	29.8	425.3	32.8	103.5	2.2
Pambara-7	29.8	272.7	35.9	71.0	2.5
1A	30.2	767.3	40.0	71.0	2.2
75B	30.9	338.2	30.0	72.5	1.8
Mualia	31.3	498.0	49.7	71.0	2.3
Imponge_3	33.6	271.3	38.3	71.0	2.3
Bottom 20 landraces					
Erati Omar	50.0	539.5	23.8	82.5	2.9
Molocue-2	50.7	252.4	30.5	78.0	2.1
Metarica Mutara	51.7	585.0	28.9	123.0	2.4
Gile_4	52.4	315.4	30.5	112.0	2.1
Pambara-2	52.5	559.5	49.9	71.0	2.3
Ncoela-4	53.9	333.2	47.6	71.0	2.5
Nacate-2	55.0	469.5	50.3	71.0	2.6
Imponge_42	55.7	570.9	37.4	72.0	2.0
Gile-3	57.3	334.1	30.5	71.0	2.6
PAN-3	61.0	501.5	31.5	82.0	2.4
Molocue-1	61.4	461.4	30.5	91.5	3.0
Nacate_3	62.4	342.0	30.5	97.0	2.6
Imponge_2	63.1	656.7	42.9	114.0	2.7
Gile-5	63.7	266.7	30.5	71.0	2.1
Lurio Miguel	64.8	64.3	23.2	77.5	2.3
Mualia-1	65.8	280.6	40.3	104.0	2.6
Cuamba Lurio Eugenio	70.0	270.1	35.2	71.0	2.2
Ncoela-5	70.9	341.9	50.8	117.0	3.1
Unhaphatenha	71.5	441.3	38.0	111.0	2.6
Namuno-1	80.0	374.0	44.1	107.0	1.7
Check					
JL-24	32.6	585.2	37.6	114.5	2.4
Mean	41.0	419.0	37.3	87.3	2.4
LSD (5%)	24.5	231.7	19.3	26.8	0.8
CV (%)	26.6	15.3	23.1	21.9	12.4

*Genotypes sorted based on the disease incidence, and whole results in appendix 3.3

3.3.6 Correlations among quantitative traits under disease pressure

The phenotypic correlations among agro-morphological traits for the 58 groundnut landraces under rosette disease pressure are given in Table 3.7. The correlation between seed yield and 100 seed weight (*r=0.2199, P≤0.05*) was significant and positive. The rest of the correlations were not significant.

Table 3.7: Correlation between disease incidence, seed yield, 100-seed weight, number of pods plant^{-1} and pod length in the local landraces grown at Nampula, in 2008/2009 and 2009/2010 growing seasons

	Disease incidence	Pod length	Number of pods plant^{-1}	100 seed weight
Pod length	-0.1517			
Number of pods plant^{-1}	0.0261	0.0782		
100 seed weight	-0.0917	-0.0823	-0.0574	
Seed yield	0.0101	-0.1536	0.1512	0.2199*

*Significant at P = 0.05

3.3.7 Classification of genotypes with respect to resistance to groundnut rosette disease

The classification of genotypes into various groups on the basis of final disease incidence (DI) is given on Table 3.8. The genotypes that had DI values less than 10 % and from 11 to 30 % were considered resistant and moderately resistant, respectively. The genotypes ranging from 31 to 50 % DI were considered susceptible and those genotypes with more than 50 % DI were considered highly susceptible.

Table 3.8: Classification of groundnut genotypes into groups based on disease incidence (DI)

Resistant	Moderately Resistant	Susceptible	Highly Susceptible
PAN-4	1A	Mualia	Molocue-2
Imponge-4	35B	JL-24	Metarica Mutara
Pambara-3	75B	Imponge-3	Gile-4
Metarica Joao	Ile-2	Ncoela-6	Pambara-2
	Gile-2	Erati Sede	Ncoela-4
	Imponge-Tom-1	Mualia-3	Imponge-42
	Imponge-43	Erati Mercado	Gile-3
	Nacate	Ncoela-1	Molocue-1
	Pambara-1	Ile-1	Nacate-3
	Pambara-4	41A	Imponge-2
	Pambara-5	Imponge-5	Gile-5
	Pambara-6	Imponge-2A	Lurio Miguel
	Pambara-7	Ncoela-2	Mualia-1
	PAN-2	PAN-5	Cuamba Lurio Eugenio
		Gile-1	Ncoela-5
		Mualia-2	Unhaphatenha
		Ncoela-3	Namuno-1
		Nacate-1	
		PAN-1	
		Ncoela	
		Erati Omar	

3.4 Discussion

Significant variation was observed amongst the landraces for most of the traits studied, except flower colour where all the 58 landraces had yellow-orange flowers. The landraces had stems with green, purple or a mixture of the two colours. Leaflet shapes of these landraces were classified as obovate, lanceolate, wide-elliptic and oblong-elliptic. Pod beak was classified as prominent, moderate and slight. Pod constriction varied between very deep, deep, moderate, slight and none. Most of the genotypes had moderate pod constriction. Growth habit varied from erect to decumbent-3. Most of the genotypes had decumbent-2 growth habit. The seed colour, pod size and 100 seed weight data indicated that in the northern region of Mozambique, various groundnut market types are present. Most of the genotypes in this region had either big pods or small pods and purple seed colour. This variation of morphological characteristics suggested that landraces grown in Mozambique come from different

gene pools. Groundnut in Mozambique is believed to have been introduced from Brazil and India by the Portuguese (Higgins, 1951; Krapovickas and Gregory, 1994; Upadhyaya et al., 2006).

Under low disease pressure, the positive correlation between seed yield and 100 seed weight was significant (*r=0.3624, P≤0.001*), which indicated that high yielding genotypes also had high 100 seed weight. The positive and high correlation between pod size and pod length (*r=0.6874, P≤0.001*) found in this study suggested that the size of a pod is dependent on its length, and the correlation between 100 seed weight and growth habit (*r=-0.1601, P≤0.001*) suggested that a weight of 100 seeds could be dependent on the growth habit. Upadyaya (2005) and Upadyaya et al. (2006) found positive correlation between 100 seed weight and pod yield per plot when studying the variability for drought resistance related traits in the mini core collection and sources of early maturity in a core collection of groundnut, respectively.

In this study and based on selected characteristics, 6 different clusters were identified at a 20-distance of level of dissimilarity among genotypes. This suggests that the genotypes show high phenotypic diversity and can therefore be used in the hybridization and selection programmes for various traits (Swamya et al., 2003) in addition to groundnut rosette disease resistance.

There was a low mean seed yield obtained from most of the groundnut genotypes evaluated. Almost all landraces attained about the average yield obtained by Mozambican smallholder groundnut producers of 600 to 800 kg ha^{-1}. These yields are quite low compared to the African average yield (900 kg ha^{-1}) and the American average yield of about 3000 kg ha-1 (FAOSTAT, 2011). These low yields suggest that there are opportunities for groundnut improvement in Mozambique, in order to raise presently attained yields.

The groundnut genotypes were categorized into resistance groups based on disease incidence (Waliyar et al., 2007). The reactions of the genotypes observed during the experiment consisted of symptomless plants, deformed leaves, stunted plants and chlorotic plants (Dollet et al., 1986). The levels of infection varied significantly among the genotypes.

The genotypes were grouped into four groups on the basis of percentage of disease incidence: resistant (0-10 %); moderately resistant (11-30 %); susceptible (31-50 %) and highly susceptible (>50 %). Based on this grouping, genotypes PAN-4, Imponge-4, Pambara-3, Metarica Joao were classified as resistant to groundnut rosette disease. However, these results do not suggest that the resistant category was absolute even for plants with no visual rosette symptoms because seasonal effects associated with temperature and relative humidity can have an effect on the disease development in the plant (Schuerger and Hammer, 1995). In addition, groundnut plants that show no symptoms may be infected by one or more components of the virus complex (Bock et al., 1990) since these symptoms are associated with infection by groundnut rosette disease but are caused by a satellite RNA (Murant et al., 1988; Murant and Kumar, 1990).

3.5 Conclusion

There was high phenotypic diversity among evaluated landraces. This variation on morphological characteristics suggested that landraces grown in Mozambique come from different gene pools and can, therefore, be used in the hybridization and selection programmes. The results showed considerable genetic variability for resistance to groundnut rosette disease among genotypes. In this respect, four landraces were classified as resistant and could be used in breeding programmes as sources of groundnut rosette disease resistance. There was no association between seed yield and groundnut rosette disease incidence. The lack of correlation between yield and disease incidence does not suggest that the disease did not influence the yield. It may be that yield was already affected due to late planting, and other factors which could not be isolated.

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IV. MULTILOCATIONAL EVALUATION OF ADVANCED GROUNDNUT LINES IN NORTHERN MOZAMBIQUE

Abstract

Groundnut (Arachis hypogaea L.) is one of important legumes grown for cash crops in Mozambique. However, most of groundnut producers use local landraces in part due to lack of improved cultivars. The objective of the present study was to determine yield stability of advanced groundnut lines response to environments. Thirty-one advanced groundnut lines developed by the local breeding programme and the check cultivar, Nametil, were evaluated in the 2009/2010 and 2010/2011 growing seasons in randomized complete block design at three locations (Nampula, Namapa and Mapupulo). Three main primary seed colours (off-white, tan and purple) were found. Genotypes were significantly (P≤0.01) different for all traits. Effects due to Year and Environment were significant (P≤0.01) for seed yield, rosette, maturity and 100 seed weight. Genotype effects were significant (P≤0.01) for seed yield, rosette, maturity, 100 seed weight and plant height. Genotype X Environment interactions were significant (P≤0.01) for rosette and 100 seed weight. The average plant height was 21.4 cm. Genotype 26B was the tallest (40.2 cm) and genotype 32A was the shortest (14.7 cm). All genotypes had a 100 seed weight over 30.0 g, except 41A and 75B which had a 100 seed weight less than 30.0 g. Genotype 40A had the highest 100 seed weight (44.6 g). Over 90 % of the lines had 1 -2 seeds per pod. About 2/3 of the genotypes had over 60 % pod maturity. Genotype 72B had the highest pod maturity (90.6 %) and genotype 27A had the lowest (44.4 %). The mean yield was 1811.0 kg ha^{-1} and ranged between 1353.3 and 2165.9 kg ha^{-1}. The highest yielding genotype was 23A (2165.9 kg ha^{-1}) while 75B (1353.3 kg ha^{-1}) gave the lowest yield. Twelve genotypes outyielded the check cultivar (Nametil). The groundnut rosette disease incidence across environments in general was very low (0.4 and 6.5 %). Seed yield was positively correlated to 100 seed weight (*r=0.368, P≤0.01*), and negatively correlated to groundnut rosette disease (*r=-0.127, P≤0.01*). Genotype 35B was the most stable across environments since it had coefficient of regression around unity (bi=1.024), high coefficient of determination (R^2=0.999) and above average yield (13 % above average seed yield). Therefore, genotype 35B is ideal for cultivation across northern Mozambique.

Keywords: Mozambique, *Arachis hypogaea*, groundnut rosette disease, biplot, stability GGE, and G X E interaction

4.1 Introduction

Groundnut (*Arachis hypogaea* L.) occupies the largest area among the grain legumes in Mozambique (Arias and Libombo, 1994). It is the most important oilseed crop followed by cotton (*Gossypium hirsutum*) and sunflower (*Helianthus annuus*). It is estimated that groundnut is cultivated on about 332.000 hectares, which correspond to about 9 % of the total cropped area in Mozambique (INE, 2005), and it is the third most important crop after maize (*Zea mays* L.) and cassava (*Manihot esculenta*). The main producing province is Nampula, followed by Cabo Delgado, Zambezia, Inhambane and Gaza. Groundnut is one of the major cash crops and the main source of vegetable proteins for over 90% of rural families in Mozambican (ADAP-SF, 2006). Groundnut production in Mozambique fluctuates annually due to uncertain rainfall pattern and sensitive behaviour of the genotypes to different environmental conditions. Stability performance of groundnut cultivars is required for successful cultivation across different environments. Identification of superior cultivars incorporating stability and yield is important for the purpose of selecting cultivars which will give better yields consistently.

A number of concepts of stability and techniques for computing simultaneously high yield and stability parameters have been proposed, compared and used in various crops by many scientists. The technique most often used in measuring and comparing cultivar stabilities is regression analysis whereby the genotypic mean is regressed on the environmental means (environmental index) and the coefficient of regression of a cultivar measures the sensitivity or response of the cultivar to changes of environments (Zhang and Geng, 1986).

Several versions of this technique have been proposed, and some include deviations from the fitted regression as measure of stability (Finlay and Wilkinsons, 1963; Eberhart and Russell, 1966; Perkins and Jinks, 1968). In this model, regression coefficient (b=1)) is considered as measure of response and deviation mean square ($S^2d=0$) as measure of stability. Recently, genotype main effect plus genotype by environment interaction (GGE) biplot analysis has been proposed as graphical method to study stability (Yan et al. 2007). The main objective of the present study was to determine yield stability and the pattern of response of advanced lines across environments in northern Mozambique.

4.2 Materials and methods

4.2.1 Study area

The study was carried out at three locations (Nampula, Namapa and Mapupulo) in northern Mozambique in the 2009/2010 and 2010/2011 growing seasons. Nampula Research Station is located about 7 km east of Nampula town and lies at 15º 09' 00''S, 39º 30' E and 432 m.a.s.l. The soil type is sandy loam and the vegetation is predominantly grassland. The annual precipitation is slightly over 1000 mm from November/December to April/May with its pack in January. The maximum temperature in the district is about 39.9^{o} C and the minimum temperature is 19^{o} C.

Namapa Research Station is located about 8 km west of Nampa town in Erati district about 250 km north of Nampula and lies at 13° 43' 41" S, 39° 50' 41" E and 500 m.a.s.l. The soils are sandy loam, deep and well-drained. It receives annual precipitation between 800 and 1200 mm between October to April, with heavy rains occurring in January and February. Annual average temperature is between 20 and 25^{0}C.

Mapupulo is located about 12 km west of Montepuez town about 200 km west of Pemba, which lies at 13^{o} 13' S, 39^{o} 03' E and 535 m.a.s.l. The soils are clay loam and deep brown loam. It receives annual precipitation of 1200 mm in average from November/December to April/May, and the average temperature is between 20 and 25^{o} C.

4.2.2 Groundnut genotypes evaluated

A total of thirty-two genotypes (31 advanced lines and 1 check) were used in the study. The advanced lines resulted from crosses made in the USA in 2002 between two Spanish-type low Oleic/Linoleic ratio groundnut cultivars (PI 268573 and PI 268673) and one Spanish-type high oleic peanut cultivar (OLin) and one runner type high oleic cultivar (Tamrun OL01) in order to develop groundnut populations with high oleic fatty acid content and adapted to Mozambique. The two low oleic cultivars were introduced from Zambia into the USA and obtained from the Southern Regional Plant Introduction Station in Griffin, GA; the two high oleic cultivars were from the USA. Cultivars from Zambia were used because no homozygous groundnut cultivars from Mozambique were available, and Zambian cultivars are generally adapted to Mozambique. Both high oleic cultivars were released in 2002 (Simpson et al., 2003a; Simpson et al., 2003b) by the

Texas A&M University. The procedure described by López et al. (2001) was used for oil analysis and the F_2 progeny having Oleic/Linoleic ratio values of 9:1 or higher were selected in 2004 for evaluation in Mozambique starting in 2005. In the 2009, when this study began, these lines were in the F_7 generation.

4.2.3 Field establishment

The study was carried out during two growing seasons (2009/2010 and 2010/2011) Nampula, Namapa and Mapupulo. The test materials were evaluated using a randomized complete block design with four replications. The replicates were separated by 2 m alleys. An individual genotype was planted in 6 m long and 6 row plots at spacing of 0.45 m between rows and 0.15 m within row. The experiments were established between 15th December and 5th January at the onset of the rains. The seeds were sown at a depth of 5 cm. The fields were kept weed free by hand weeding. No fertilizer, pesticides or supplementary water were applied, and no seed treatment before planting was applied.

4.2.4 Data collection

Data were collected on plant height, 1-2 seeds pod^{-1}, primary seed colour, 100 seed weight, pod maturity, seed yield, and groundnut rosette disease incidence. Plant height (cm) was taken at 70 days after emergence from soil surface to top of the main axis of plant.

A random sample of 50 pods genotype-*1* was taken and pods were divided into two groups: one group with pods containing 1 or 2 seeds; the other group with pods containing 3 or more seeds. The number of pods in each of the two groups was counted and the data converted into percentage.

Primary seed colour was recorded from dry, mature and wrinkle-free seeds for each genotype. Colours were assigned based on the descriptors for groundnut that were described by IBPGR and ICRISAT (1992). The 100 seed weight was obtained from a random sample of 100 mature seeds for each genotype.

The internal shell-out method was used to estimate genotype maturity. Fifty randomly selected pods were shelled and sorted into white, yellow, orange, brown and black

categories, depending on the colour on the inner side of the shell wall. Mature pods were considered to be those with some orange, brown or black colouring inside the shell, while immature pods had white or yellow colouring inside the shell.

Yield was determined for each advanced line at the end of the maturity period by shelling and weighing the dried seeds. Seed weight, measured in kg m^{-2}, was converted to kg ha^{-1}.

Individual plants from each advanced line were monitored for presence or absence of virus symptom at 60 days after planting. Disease incidence (DI) for each genotype was calculated as the percentage of plants with rosette symptoms (Waliyar et al., 2007).

4.2.5 Data analysis

The data on yield, yield-related traits and groundnut rosette disease incidence were analyzed using the Genstat 14 statistical software (Payne et al., 2011). The following statistical model was used to analyse the combined data:

$$Y_{ijkl}=\mu+E_i+Y_j+EY_{ij}+R_{k(ij)}+G_l+GE_{il}+GY_{jl}+GEY_{ijl}+\varepsilon_{ijkl}$$

Where: Y_{ijkl} = observed landrace response; μ = overall population mean; E_i = Effect of the ith environment; G_l = Effect of the l^{th} genotype; Y_j = Effect of the j^{th} year; EY_{ij} = Interaction effect of the i^{th} environment and the j^{th} year; $R_{k(ij)}$ = Effect of the k^{th} replication in the i^{th} environment; GE_{il} = Interaction effect of the l^{th} genotype and the i^{th} environment; GY_{jl} = Interaction effect of the l^{th} genotype and the j^{th} year; GEY_{ijl} = Interaction effect of the l^{th} genotype, i^{th} environment and j^{th} year; ε_{ijkl} = Experimental error.

Where G was considered as fixed effect and E, Y, GY, GE and GEY were considered as random effects.

Mean separation was performed using Fisher's protected least significant difference (LSD) where the main effects were significant of 95 % of confidence level. GGE analysis was performed using yield data to determine the genotype x environment relationship among test environments and among genotypes (Gauch and Zobel, 1997; Yan et al., 2001; Yan and Rajcan, 2002).

Linear regressions were carried out for each of the cultivar based on the Eberhart and Russell (1966) method whereby each advanced line was regressed over the means of the three environments which are considered as environmental indices. According to this method, regression coefficient (b=1) and deviation from regression or variance deviation (var-dev=0) indicates stability. In this analysis, var-dev is the error mean square of the regression analysis as suggested by Alwala et al. (2010).

Phenotypic correlations between disease incidence and yield components were determined using Pearson's correlation procedure in SPSS 19 to determine whether there is causal relationship between the two.

4.3 Results

4.3.1 Combined data across locations and seasons

4.3.1.1 Analysis of variance

Results on analysis of variance across years and locations are presented in Table 4.1. The results indicated that there were highly significant differences (P≤0.001) among genotypes for most traits studied, except groundnut rosette disease incidence which was significantly different at P≤0.01. The effects due to year and environment were significant (P≤0.001) for seed yield, maturity and 100 seed weight. However, significant (P≤0.001) effects due to environment were also observed for rosette. In this study, the genotypic effects were significant (P≤0.001) for seed yield, rosette, 1-2 seeds pod^{-1}, maturity, 100 seed weight and plant height. In the first order of interaction effects due to year by environment interaction were significant (P≤0.001) for seed yield, maturity and 100 seed weight while the genotype by environment interaction were significant (P≤0.001) for rosette and 100 seed weight.

4.3.1.2 Phenotypic variation

Morphological variation of percentage of 1-2 seeds per pod, plant height and primary seed colour of groundnut genotypes across years and locations are presented in Table 4.2. The percentage of 1-2 seeds per pod ranged between 63.1 and 100 %. Twenty genotypes had 100% of pods with 1-2 seeds. Genotype 52B had the lowest percentage (63.1 %) of 1-2 seeds per pod.

Mean plant height was 21.4 cm and ranged between 14.7 and 40.2 cm. Genotype 75A had the highest plant height (40.2 cm) and genotype 41A had the lowest (14.7 cm). Three primary seed colours (off-white, tan and purple) were present and identified with 3, 26 and 3 genotypes, respectively. The most frequent seed colour was tan. The check cultivar had off-white primary seed colour.

Table 4.1: Combined analysis of variance for seed yield, groundnut rosette disease incidence, pod maturity, 100 seed weight and plant height of groundnut advanced lines evaluated across 3 environments over 2 years

		Mean squares					
Source of variation	df	Seed yield	Rosette	1-2 seeds	Maturity	100 seed weight	Plant height
Year (Y)	1	125907299.1***	11.1	1.2	5002.1***	716.9***	1.3
Environment (E)	2	13335503.2***	2241.5***	3.5	15006.3 ***	602.9***	3.9
Y X E	2	44809843.4***	12.8	1.2	5002.1***	1228.5 ***	1.2
Rep(Y X E)	18	15479953.5	137.3	81.9	878.6	194.9	476.8
Genotype (G)	31	1032106.8***	64.5**	3142.7***	2670.0***	268.7 ***	876.3***
G X E	62	356516.5	60.3***	13.9	404.2	45.8***	0.2
G X Y	31	871316.5**	6.9	4.7	134.7	22.7	0.1
G X E X Y	62	308893.1	2.1	4.7	134.7	24.6	0.1
Pooled error	558	457365.6	34.1	82.2	373.5	21.9	57.1
CV (%)		37.4	27.2	9.2	29.4	12.9	35.3

** Data significant at P = 0.01; ***Data significant at P = 0.001

Table 4.2: Morphological variation of 1-2 seeds per pod, plant height and primary seed colour of groundnut genotypes combined over two seasons and three locations

Genotype	1- 2 seeds per pod (%)	Plant height (cm)	Seed colour
19A	95.0	23.4	8.0 (Dark tan)
32A	100.0	21.9	2.0 (Off-white)
21A	100.0	15.9	8.0 (Dark tan)
75B	88.8	19.6	8.0 (Dark tan)
31A	100.0	17.9	8.0 (Dark tan)
45B	100.0	25.4	5.0 (Pale tan)
34A	100.0	16.4	8.0 (Dark tan)
26B	100.0	14.8	8.0 (Dark tan)
52B	100.0	14.8	5.0 (Pale tan)
1A	100.0	16.5	5.0 (Pale tan)
17A	100.0	23.5	5.0 (Pale tan)
23A	68.1	19.4	6.0 (Light tan)
6A	85.0	40.2	5.0 (Pale tan)
35B	96.9	14.9	6.0 (Light tan)
24A	100.0	26.8	6.0 (Light tan)
41A	100.0	16.4	8.0 (Dark tan)
15A	100.0	14.7	8.0 (Dark tan)
37A	100.0	18.8	8.0 (Dark tan)
72B	100.0	21.2	8.0 (Dark tan)
27A	100.0	33.1	6.0 (Light tan)
8A	100.0	16.7	5.0 (Pale tan)
16A	95.0	20.6	5.0 (Pale tan)
13A	100.0	21.4	5.0 (Pale tan)
10A	64.4	26.9	17.0 (Purple)
28A	100.0	21.5	6.0 (Light tan)
4A	63.1	30.2	17.0 (Purple)
33A	99.4	16.8	8.0 (Dark tan)
20A	100.0	18.1	8.0 (Dark tan)
25B	100.0	23.8	2.0 (off-white)
40A	70.6	32.0	17.0 (Purple)
Nametil	99.4	20.6	5.0 (Pale tan)
5A	88.1	20.1	2.0 (Off-white)
Mean	94.3	21.4	7.1
LSD	4.6	3.7	2.1
CV(%)	6.15	16.7	0.8

4.3.1.3 Yield, yield components and rosette disease incidence

Mean seed yield, 100 seed weight, pod maturity and groundnut rosette disease incidence are presented in Table 4.3 and appendix 5. The results showed that genotypes were significantly different (P≤0.05) for all traits. The mean yield across the three locations over two years was 1811 kg ha^{-1} and ranged between 1353.3 and 2165.9 kg ha^{-1}. The highest yielding genotype was 23A (2165.9 kg ha^{-1}), and the lowest was 20A (1353.3 kg ha^{-1}).

The mean 100 seed weight over across locations over the two years was 36.4 g and ranged between 29.9 and 44.6 g. All genotypes had a 100 seed weight over 30.0 g, except 41A and 75B which had a 100 seed weight less than 30.0 g. Genotype 40A had the highest 100 seed weight (44.6 g) and genotypes 41A and 75B had the lowest 100 seed weight (29.9 g).

Most of the genotypes across the three locations and two seasons had over 60% mean pod maturity, and it ranged between 90.6 and 44.4 %. Genotype 72B had the highest pod maturity (90.6 %) and genotype 27A had the lowest (44.4 %).

The groundnut rosette disease incidence across the three locations over two years was generally very low and it ranged between 0.4 and 6.5 %. Genotype 15A had the highest disease incidence (6.5 %) and genotype 75B had the lowest (0.4 %).

Table 4.3: Mean seed yield, 100 seed weigth, pod maturity and groundnut rosette disease incidence of advanced lines across locations and two seasons

Genotype	Seed yield (kg ha^{-1})	100 seed weight (g)	Maturity (%)	Rosette incidence (%)
10A	1457.0	36.3	71.3	4.1
13A	2013.9	29.9	81.9	0.8
15A	1704.9	39.1	73.8	3.3
16A	1782.4	44.6	56.3	6.5
17A	1690.6	37.5	50.6	2.5
19A	2066.9	37.9	66.9	1.6
1A	2099.3	38.6	58.1	2.2
20A	2045.8	37.5	63.1	0.4
21A	1868.9	36.5	68.8	5.4
23A	2165.9	36.6	68.1	3.0
24A	1626.8	31.9	67.5	4.3
25B	1702.6	33.5	67.5	1.5
26B	1948.1	37.1	71.3	1.8
27A	1840.5	38.9	44.4	3.5
28A	1995.4	36.0	58.1	1.7
31A	1879.9	39.8	55.6	2.0
32A	1492.7	37.1	55.0	2.2
33A	1839.8	41.2	69.4	5.2
34A	1894.2	39.6	71.9	0.9
35B	2086.4	29.9	81.9	0.6
37A	1829.3	39.0	71.3	3.0
40A	1591.7	34.5	61.9	0.8
41A	1584.3	37.4	62.5	6.4
45B	1711.5	34.7	61.3	1.3
4A	2017.4	36.6	61.9	2.4
52B	1428.6	35.0	56.3	3.9
5A	1882.8	38.2	46.3	1.3
6A	1828.4	38.5	70.0	1.8
72B	1820.3	29.8	90.6	2.7
75B	1353.3	34.4	72.5	2.4
8A	1810.7	35.0	65.6	1.6
Nametil	1876.8	31.6	85.0	1.0
Mean	1811	36.4	65.8	2.6
LSD (5%)	381.7	2.8	10.5	3.2
CV (%)	18.1	8.2	13.7	11.3

4.3.2 Data for individual locations

4.3.2.1 Analysis of variance

Results on analysis of variance of each location are presented in Table 4.4a,b and c. The results indicated that there were highly significant differences (P≤0.001) among genotypes for most traits studied. Years and year x genotype interactions were not significantly (P≥0.05) different for percentage of 1-2 seeds per pod and plant height for the three locations. Genotypes were significantly different for all traits, except seed yield in Nampula.

Table 4.4a: ANOVA Table for Nampula data

Source of variation	df	Seed yield	Rosette	1-2 seeds	Maturity	100 seed weight	Plant height
Year (Y)	1	178729492.6***	0.1	0.0	0.0	2956.6***	0.0
Rep(Y)	6	17279032.8	1.5	100.5	1183.0	245.2	458.5
Genotype (G)	31	572331.1	5.9**	1124.8***	1861.3***	64.5***	298.89***
G X Y	31	479528.6	5.5**	0.0	0.0	27.6	0.0
Pooled error	186	424317.1	3.0	92.3	510.7	24.6	57.3

*Data significant at P=0.05; ** Data significant at P = 0.01; ***Data significant at P = 0.001

Table 4.4b: ANOVA Table for Mapupulo data

Source of variation	df	Seed yield	Rosette	1-2 seeds	Maturity	100 seed weight	Plant height
Year (Y)	1	36797493.4***	36.7***	3.5	15006.3***	31.6	3.9
Rep(Y)	6	16071836.1	3.0	81.9	878.6	230.3	476.8
Genotype (G)	31	472006.44*	5.2**	1047.6***	890.0***	131.9***	292.1***
G X Y	31	1009574.08*	5.7***	14.0	404.2	32.2	0.2
Pooled error	186	586347.7	2.5	82.2	373.5	22.5	57.1

*Data significant at P=0.05; ** Data significant at P = 0.01; ***Data significant at P = 0.001

Table 4.4c: ANOVA Table for Namapa data

Source of variation	df	Seed yield	Rosette	1-2 seeds	Maturity	100 seed weight	Plant height
Year (Y)	1	119152995.1***	0.1***	0.0	0.0	1971.1***	0.0
Rep(Y)	6	11519355.2	1.0	67.0	788.7	163.5	305.7
Genotype (G)	31	381554.1*	3.9**	749.9***	1240.9***	43.0***	199.3***
G X Y	31	319685.7	3.7**	0.0	0.0	18.4	0.0
Pooled error	186	282878.1	2.0	61.5	340.5	16.4	38.2

*Data significant at P=0.05; ** Data significant at P = 0.01; ***Data significant at P = 0.001

4.3.2.2 Mean yield, yield components and rosette disease incidence

Mean yield and 100 seed weight over the two years across locations are presented in Table 4.5a. The results showed that genotypes were significantly ($P \leq 0.05$) different for all traits, except for seed yield in Nampula. In Namapa, the mean seed yield over the two years was 2037 k gha^{-1} and ranged between 1462.9 and 2496.3 kg ha^{-1}. The highest yielding genotype was 20A (2496.3 kg ha^{-1}), and the lowest yielding genotype was 32A (1462.9 kg ha^{-1}). For Mapupulo, the mean seed yield was 1814 kg ha^{-1} and ranged between 1208.3 and 2349.8 kg ha^{-1}. Genotype 28A had the highest seed yield with 2349.3 kg ha^{-1}, genotype 16A had the lowest mean seed yield with 1208.3 kg ha^{-1}.

In Nampula, the 100 seed weight was 34.9 g and ranged between 29.4 and 40.0 g. Genotypes 40A and 26B had the highest 100 seed weight (40.0 g) and genotype 41A had the lowest (29.4 g). The mean 100 seed weight in Namapa was 38.0 g and ranged between 30.0 and 46.3 g. Genotype 40A had the highest 100 seed weight and genotype 41A had the lowest (30.0 g). For Mapupulo, the average mean 100 seed weight was 36.2 g where the highest 100 seed weight was observed in genotype 40A (47.6 g) and the lowest in genotype 52B (27.0 g).

Mean pod maturity and groundnut rosette incidence are presented in Table 4.5b. In Nampula, pod maturity was 58.2 % and ranged between 33.8 and 90.0 %. Genotype 72B had the highest pod maturity (90.0 %) and genotype 27A had the lowest (33.8 %). The mean pod maturity percentage in Namapa was 65.8 % and ranged between 44.4 and 90.6 %. Genotype 72B had the highest pod maturity (90.6 %) and genotype 27A had the lowest (44.4 %). In Mapupulo, mean pod maturity was 73.3 % and ranged between 48.8 and 92.5 %. Genotype 13A had the highest pod maturity (92.5 % and genotype 5A had the lowest (48.8 %).

In Nampula, the disease incidence was 1.1 % and ranged between 0.0 and 4.1 %. Genotype 72B had the highest disease incidence (4.1 %) and genotypes Nametil and 8A had the lowest (0.0 %). For Namapa, the mean disease incidence was 0.7 % and ranged between 0.0 and 3.6 %. Genotype 72B had the highest disease incidence (3.6 % and genotypes 52B, 21A, 75B, 32A, 16A, 17A, 8A and Nametil had the lowest (0.0 %). The mean disease incidence in Mapupulo was 5.9 % and ranged between 0.4 and 6.8 %.

Genotype 15A had the highest disease incidence (6.5 %) and genotype 75B had the lowest (0.4 %).

Table 4.5a: Mean seed yield and 100 seed weight of advanced lines grown at three locations and two seasons

	Seed yield (kg ha^{-1})			100 seed weight (g)		
Genotype	NPL^{ns}	NMP*	MPL*	NPL*	NMP*	MPL*
10A	1377.5	1676.3	1317.1	38.1	38.8	32.1
13A	1836.0	2279.8	1925.9	29.4	30.0	30.3
15A	1452.4	1887.2	1775.1	33.8	41.3	42.4
16A	1433.8	1868.4	2045.0	40.0	46.3	47.6
17A	1348.1	1876.8	1846.9	35.6	39.4	37.4
19A	1970.3	2185.2	2045.3	35.0	39.4	39.4
1A	1681.1	2393.0	2223.8	36.9	41.3	37.8
20A	1873.6	2496.3	1767.5	35.6	40.0	36.9
21A	1862.8	2246.3	1497.7	38.8	37.5	33.1
23A	2234.6	2370.1	1892.9	35.0	38.1	36.6
24A	1634.5	1893.4	1352.4	31.9	33.1	30.8
25B	1461.9	2091.3	1554.7	30.6	34.4	35.5
26B	1443.0	2181.3	2219.9	36.9	38.1	36.3
27A	1529.2	1939.2	2053.2	38.1	42.5	36.0
28A	1785.5	2072.2	2128.5	32.5	33.1	42.5
31A	1240.2	2049.6	2349.8	36.3	40.6	42.5
32A	1371.5	1462.9	1643.5	33.8	39.4	38.3
33A	1495.0	2019.4	2004.9	37.5	45.0	41.1
34A	1642.0	2251.3	1789.5	40.0	41.3	37.6
35B	1846.0	2312.9	2100.2	30.6	30.6	28.4
37A	1709.6	1972.0	1806.2	36.9	41.3	38.9
40A	1521.5	1731.6	1521.9	31.9	32.5	39.3
41A	1447.1	1727.1	1578.8	36.3	40.0	35.9
45B	1269.7	1870.9	1993.8	34.4	36.3	33.5
4A	1875.2	2379.9	1797.1	35.6	37.5	36.6
52B	1158.8	1918.5	1208.3	35.6	35.6	33.6
5A	1727.0	2094.4	1827.1	35.6	40.6	38.3
6A	1201.1	2184.6	2099.5	35.6	42.5	37.4
72B	1556.7	1809.8	2094.5	30.0	32.5	27.0
75B	1034.2	1718.9	1306.7	34.4	35.0	33.8
8A	1765.0	2118.2	1549.0	35.6	39.4	30.1
Nametil	1791.4	2103.4	1735.6	30.6	33.1	31.0
Mean	1581.0	2037.0	1814.0	34.9	38.0	36.2
LSD	889.0	792.6	548.5	5.5	4.8	4.2
CV	21.3	18.9	15.6	13.2	11.7	8.8

NPL=Nampula; NMP=Namapa; MPL=Mapupulo; ns=Data not significant; *=Data significant at P=0.05

Table 4.5b: Mean pod maturity and groundnut rosette disease incidence of advanced lines grown at three locations and two seasons

	Maturity (%)			Rosette incidence (%)		
Genotype	NPL*	NMP*	MPL*	NPL*	NMP*	MPL*
10A	63.8	71.3	78.8	4.1	3.6	4.8
13A	71.3	81.9	92.5	0.0	0.0	2.3
15A	76.3	73.8	71.3	1.1	0.5	8.3
16A	45.0	56.3	67.5	1.7	1.5	16.4
17A	41.3	50.6	60.0	0.5	0.0	7.0
19A	67.5	66.9	66.3	1.3	0.8	2.7
1A	42.5	58.1	73.8	2.6	2.0	2.1
20A	53.8	63.1	72.5	0.4	0.0	0.8
21A	58.8	68.8	78.8	1.4	0.7	14.0
23A	55.0	68.1	81.3	0.4	0.3	8.3
24A	70.0	67.5	65.0	2.1	1.9	8.9
25B	65.0	67.5	70.0	1.3	0.2	3.1
26B	73.8	71.3	68.8	1.4	0.3	3.7
27A	33.8	44.4	55.0	1.5	1.1	8.0
28A	40.0	58.1	76.3	0.9	0.5	3.8
31A	48.8	55.6	62.5	0.4	0.1	5.3
32A	36.3	55.0	73.8	2.3	1.2	3.2
33A	66.3	69.4	72.5	0.6	1.1	14.0
34A	67.5	71.9	76.3	1.7	0.6	0.6
35B	80.0	81.9	83.8	0.0	0.0	1.9
37A	65.0	71.3	77.5	1.1	1.6	6.3
40A	41.3	61.9	82.5	1.2	0.3	0.9
41A	58.8	62.5	66.3	0.2	0.0	19.1
45B	52.5	61.3	70.0	1.1	0.3	2.5
4A	38.8	61.9	85.0	0.7	0.0	6.5
52B	38.8	56.3	73.8	0.1	0.0	11.5
5A	43.8	46.3	48.8	0.6	0.0	3.2
6A	67.5	70.0	72.5	0.7	0.2	4.6
72B	90.0	90.6	91.3	1.3	1.3	5.4
75B	70.0	72.5	75.0	0.4	0.3	6.5
8A	53.8	65.6	77.5	0.2	0.1	4.4
Nametil	85.0	85.0	85.0	0.9	0.7	1.5
Mean	58.2	65.8	73.5	1.1	0.7	5.9
LSD	22.1	19.2	14.0	1.7	1.7	8.9
CV(%)	21.3	18.6	13.2	15.4	16.1	24.9

NPL=Nampula; NMP=Namapa; MPL=Mapupulo; *=Data significant at P= 0.05

4.3.3 Correlations among agro-morphological traits

The phenotypic correlations among agro-morphological traits are given in Table 4.6. The results showed that most of the traits were significantly correlated. The phenotypic correlation between seed yield and groundnut rosette disease incidence was significant and negative (*r=-0.127, P≤0.01*), while correlation between seed yield and 100 seed weight was significant and positive (*r=0.368, P≤0.01*).

Groundnut rosette disease incidence was significantly and positively correlated to pod maturity (*r=0.115, P≤0.01*). Pod maturity and 100 seed weight were significantly and negatively correlated (*r=-0.087, P≤0.05*).

Plant height was significantly and positively correlated to pod maturity (r=0.072, P≤0.05). It was also negatively correlated (*r=-0.141, P≤0.01*) to 100 seed weight and percentage of 1-2 seeds pod^{-1} (*r=-0.345, P≤0.01*).

Table 4.6: Phenotypic correlation among agro-morphological traits recorded in advanced groundnut lines grown at three locations and two seasons in Mozambique

	Disease incidence	Seed yield	1-2 seeds pod^{-1}	100 seed weight	maturity	Plant height
Disease incidence	1					
Seed yield	-0.127**	1				
1-2 seeds pod^{-1}	-0.006	0.040	1			
100 seed weight	0.001	0.368**	0.064	1		
maturity	0.115**	0.002	0.009	-0.087*	1	
Plant height	-0.022	0.054	-0.345**	-0.141**	0.072*	1

*Significant at P = 0.05; ** Significant at P = 0.01

4.3.4 GGE biplot and stability analysis for yield across locations

The GGE biplot based on seed yield data of advanced lines explained 90.96% (59.15 % by PC1 and 31.82 % by PC2, respectively) of the total variation (Figure 4.1). The three environments fell into two sectors (Namapa+Nampula and Mapupulo) with different winning genotypes. Genotype 31A was the highest yielding in Mapupulo, and genotype 23A was the highest yielding in Nampula and Namapa. Genotypes 20A and 4A were very close in performance to genotype 23A in Nampula and Nampula.

Mean seed yield, regression coefficients (bi), variance deviation from regression (var-dev) and coefficient of determination (R^2) are presented in Table 4.7. Coefficient of regression ranged from 0.208 (32A) to 2.169 (6A). Six genotypes (4A, 35B, 13A, 16A, 15A and 27A) had coefficient of regression around unity. Twelve genotypes had slope more than unity and 14 genotypes had regression coefficient less than unity. Genotype 31A had the highest variance deviation while genotype 41A had the lowest (86.17).

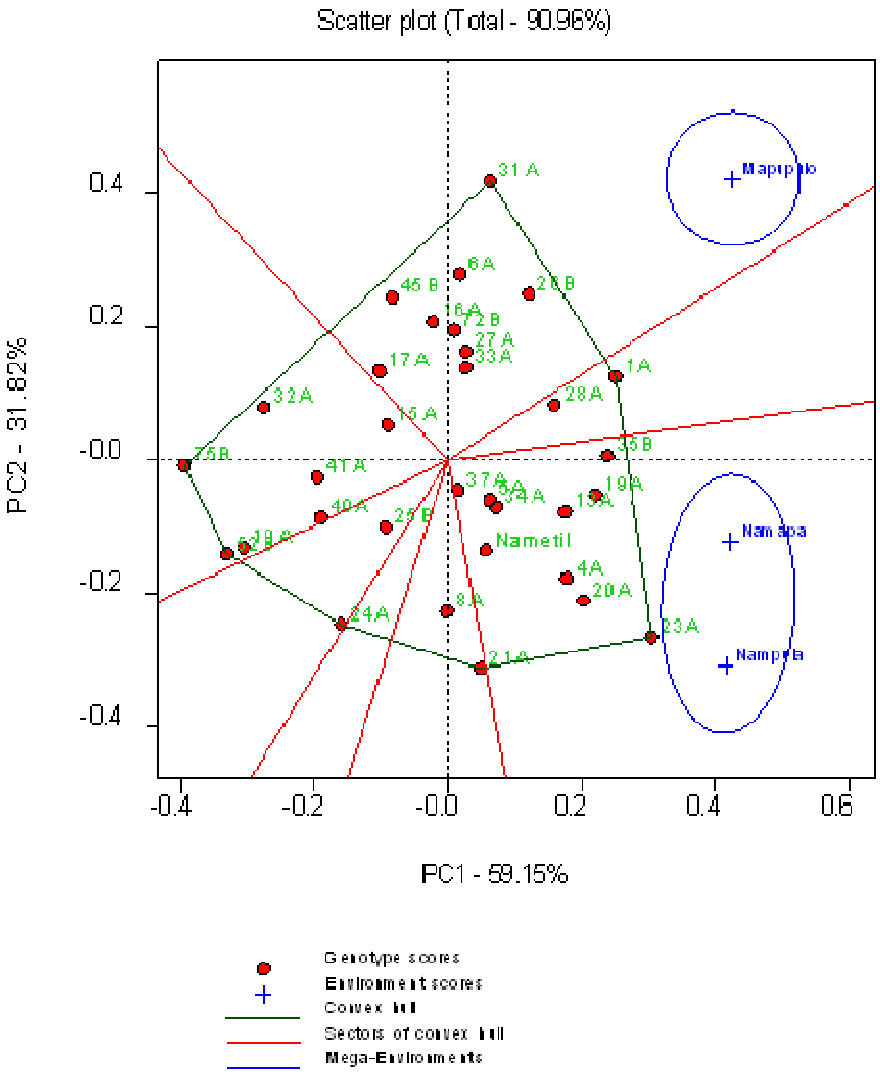

Figure 4.1: GGE biplot based on yield data of 32 advanced lines grown at three locations over two years, environment-centred

Table 4.7: Genotype mean yield, regression coefficient (b_i), variance deviation (var-dev) and coefficient of determination of 32 groundnut advanced lines grown at 3 locations over 2 seasons

Genotype	Mean yield (kg ha^{-1})	b_i	var-dev	R^2
10A	1457	0.648	30263.0	0.591
13A	2014	0.969	12486.0	0.887
15A	1705	0.957	6737.0	0.934
16A	1782	0.966	100934.0	0.490
17A	1691	1.167	34849.0	0.802
19A	2067	0.470	807.5	0.932
1A	2099	1.567	21344.0	0.923
20A	2046	1.352	119989.0	0.613
21A	1869	0.823	209822.0	0.251
23A	2166	0.284	112561.0	0.069
24A	1627	0.554	114460.0	0.218
25B	1703	1.373	34894.0	0.849
26B	1948	1.632	106465.0	0.722
27A	1841	0.909	65931.0	0.566
28A	1995	0.635	25739.0	0.820
31A	1880	1.797	322915.0	0.510
32A	1493	0.208	33834.0	0.117
33A	1840	1.158	39020.0	0.781
34A	1894	1.331	17891.0	0.911
35B	2086	1.024	162.8	0.999
37A	1829	0.574	936.2	0.973
40A	1592	0.457	7625.0	0.740
41A	1584	0.614	86.2	0.998
45B	1711	1.332	115856.0	0.614
4A	2017	1.096	75245.0	0.624
52B	1429	1.655	76457.0	0.788
5A	1883	0.803	5118.0	0.923
6A	1828	2.169	104457.0	0.824
72B	1820	0.568	111217.0	0.232
75B	1353	1.499	3989.0	0.983
8A	1811	0.762	104777.0	0.365
Nametil	1877	0.677	30875.0	0.607
Mean	1811			

4.4 Discussion

The results of analysis of variance across environments and seasons indicated highly significant differences (P≤0.01) among genotypes for all traits studied. Seasons, environments and their interactions were significantly different for most the traits, which suggested that the advanced lines differed significantly in their response to changes in the environment. Some of the genotypes outyielded the check cultivar (Nametil) and others were more resistant to groundnut rosette disease than the check cultivar. These results suggested that the check cultivar can be replaced with some of the evaluated new genotypes which is high yielding and groundnut rosette disease resistant.

The results indicated that groundnut rosette disease incidence was generally low in all the environments. However, environments and genotypes reacted differently on the disease incidence. Mapupulo had higher disease pressure compared to Nampula and Namapa. Most of the genotypes were groundnut rosette disease free in Namapa. The low disease incidence in Namapa might be because of the regular rainfall and well distributed during the growing seasons where by plant establishment, canopy cover and high plant density were achieved few weeks after planting. High plant density promotes the establishment of a microclimate which prevents the aphid from growing wings and limits disease transmission (Dollet et al., 1986).

The results showed that most of the traits were significantly correlated with one another. The phenotypic correlations between seed yield and groundnut rosette disease incidence was significant and negative which indicated that seed yield was influenced negatively by groundnut rosette disease incidence. The positive correlation between seed yield and 100 seed weight indicated that high yielding genotypes also had high 100 seed weight. Mekontchou et al. (2006) reported that seed yield from breeding groundnut lines in Camerron was positively associated with 100 seed weight. This significant and positive correlation, according to the authors, indicated that the increase of 100 seed weight, there is also an increase on yield.

Groundnut rosette disease had significant and positive correlation to pod maturity. This positive correlation indicated that genotypes with resistance to groundnut rosette disease also had early pod maturity.

Mega-environment is defined as a group of locations that consistently share the best performing set of genotypes across years (Yan and Rajcan, 2002). Yan et al. (2007)

suggested that data from multiple years were essential to decide whether or not the target region can be divided into different mega-environments. Based on the definitions, the data on seed yield of the advanced lines were grouped into two mega-environments (Namapa+Nampula and Mapupulo) with different winning genotypes. From the biplot analysis, the results indicated that genotype 31A was the best in Mapupulo, while genotype 23A was the best in Nampula and Namapa. Further results indicated that genotypes 75B and 35B were the most stable across environments.

A genotype is judged more stable over locations which have regression coefficient (bi) equal to or very close to unity and high R^2 (Petersen, 1989). Eberhart and Russell (1966) also indicated that a genotype is stable if its coefficient of regression is equal to or close to unity. The authors further reported that coefficient slopes less than unity shows adaptability in low yielding environments and coefficient slopes over unity reveal adaptability in high yielding environments. In this study, six genotypes (4A, 35B, 13A, 16A, 15A and 27A) had coefficient of regression around unity suggesting that these genotypes could be cultivated in a wide range of environments. Fourteen of the genotypes (e.g. 35B, 17A, 1A, 20A and 6A) had regression coefficient more than unity and some showed above average seed yield (e.g. 35B, 1A, 20A and 26A). These results suggest that these genotypes could be cultivated in good environments. Other genotypes (e.g. 10A, 19A, 23A and 24A) had regression coefficient less than unity which suggest that these genotypes are less stable and are suitable for poor environments. The results in this study were in agreement with those of Mekontchou et al. (2006) who evaluated newly development groundnut lines for yield and yield components in Cameroon.

In the present study and according to the stability models, genotype 35B was stable across environments since it had coefficient of regression around unity (bi=1.024), high coefficient of determination (R^2=0.999), and small variance deviation (var-dev=162.8) and above average yield (13 % above average seed yield). It is, therefore, concluded that genotype 35A had wide adaptability and could be recommended for cultivation in diverse environments of northern Mozambique. Nawaz et al. (2009) et al. (2009) reported similar results in Pakistan whereby genotype ICGV-92040 was stable across environments since it had above average yield performance, small variance deviation, high value of coefficient of determination and coefficient of regression around unity.

4.5 Conclusion

The advanced lines responded differently across environments. The different responses indicated that some of the advanced lines could be suitable for good environments, others in poor environments and others could be suitable in wide range of environments. Based on regression coefficient, six advanced lines were suitable for cultivation in a wide range of environments. Line 35B was the best among them and it could be recommended for cultivation on diverse environments in northern Mozambique. Groundnut rosette disease incidence was generally low in all environments. However, Mapupulo had higher disease incidence compared to Namapa and Nampula. Most of the traits were significantly correlated with seed yield and groundnut rosette disease. The correlation between seed yield and disease incidence was significant and negative indicating that seed yield was influenced negatively by disease incidence.

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V. INHERITANCE OF RESISTANCE TO GROUNDNUT ROSETTE DISEASE IN GROUNDNUT (*ARACHIS HYPOGAEA* L.)

Abstract

Groundnut (Arachis hypogaea L.) rosette disease is one of the important diseases in groundnut. Information on the genetics of groundnut rosette disease in Mozambique is limited and breeders and other scientists working on groundnut depend entirely on outside information. Therefore, a study was conducted to determine inheritance of resistance to groundnut rosette disease. Twenty-one F_2 populations from a seven-parent half diallel cross and their parents were evaluated under field conditions for resistance to groundnut rosette disease using the spreader row technique in a randomized complete block design at Nampula Research Station, Mozambique during the 2010/2011 growing season. The results showed that JL-24 had the highest DI (99.5 %) while ICGV-SM 01711 had the lowest (1.2 %). Both general combining ability (GCA) and specific combining ability (SCA) variances were highly significant (P≤0.001). Genotype JL-24 had the highest positive GCA (42.5) and genotype ICGV-SM 01513 the highest negative (-18.8). The highest positive SCA was observed for cross CG 7 X ICGV-SM 01711 (23.7). The cross between the two susceptible cultivars (JL-24 and CG) had the highest negative SCA (-23.3). The GCA:SCA ratio was 0.97 indicating that additive gene action was more important than non-additive gene action in the expression of resistance to groundnut rosette disease. The segregation pattern from 7 F_2 populations (ICG 12991 X CG 7, ICGV-SM 01513 X CG 7, ICGV-SM 90704 X CG 7, JL-24 X ICGV-SM 01513, JL-24 X ICGV-SM 01731, JL-24 X ICG-SM 01711 and CG 7 X ICGV-SM 01711) showed that groundnut rosette disease was controlled by two recessive genes. Segregation from two populations (ICG 12991 X JL-24 and ICGV-SM 90704 X JL-24) indicated that groundnut rosette was controlled by one recessive gene. Pooled data of resistant X susceptible and susceptible X resistant F_2 populations did not fit 1:3 or 1:15 ratios. The segregation patterns in this study suggested that apart from one or two recessive genes, genetic modifiers might also be involved in the expression of resistance to groundnut rosette disease.

Key words: Groundnut rosette disease, *Arachis hypogaea*, inheritance, combining ability, gene action

5.1 Introduction

Groundnut rosette disease is widely distributed in sub-Saharan Africa region and the offshore islands, including Madagascar (Nigam and Bock, 1990; Naidu et al., 1998). It is the most destructive virus disease of groundnuts in sub-Saharan Africa (Nigam and Bock, 1990; Naidu et al., 1998; Olorunju and Ntare, 2008). Yield losses up to 100 % have been reported under severe disease conditions. The disease is caused by a complex of three agents namely: groundnut rosette assistor virus (GRAV), groundnut rosette virus (GRV) and a satellite RNA (sat RNA) (Murant et al., 1988; Naidu et al., 1998). The disease is transmitted by an aphid vector, *Aphis craccivora* Koch, in a persistent manner. In order for the aphid be to able to transmit the disease successfully, all the three agents must be present together in the host plant (Subrahmanyam et al., 1998).

Several methods for groundnut rosette disease management have been suggested and include insecticide application, cropping practices and breeding for both vector and virus resistance (Naidu et al., 1998; Naidu et al., 1999). Insecticides kill the vectors thereby preventing the spread of rosette disease. Cropping practices involve early planting and uniform plant density. Although cropping practices can reduce the incidence of groundnut rosette disease, farmers do not follow these recommendations for several reasons, including farmer priority, lack of seed and uncertainty of rainfall.

In sub-Saharan Africa, the use of host resistance is the most economically-effective and environmentally-beneficial method of combating diseases and pests (Russell, 1978). The use of cultivars resistant to groundnut rosette disease will allow groundnut growers to save money which would otherwise be used for insecticide purchase and application.

Many studies have evaluated *A. hypogaea* germplasm for resistance to groundnut rosette disease since 1907 when the disease was first described. The existence of significant resistance within *A. hypogaea* germplasm was reported from Burkina Faso in 1952, when an epidemic of groundnut rosette disease destroyed a large collection of germplasm (Nigam and Bock, 1990; Subrahmanyam et al., 1998; Olorunju et al., 2001). The sources identified then, formed the basis for the rosette resistance breeding programmes throughout Africa (Subrahmanyam et al., 1998; Olorunju et al., 2001) leading to the development of several groundnut rosette disease resistant cultivars.

The National Research System of Mozambique in collaboration with ICRISAT-Malawi tested some of the groundnut rosette disease resistant cultivars in different agro-ecological zones of the country. Through these experiments, some resistant cultivars, namely Nametil (ICG 12991) and Mamane (ICGV 90704) were released for cultivation for the farmers in northern Mozambique. However, recent surveys have indicated that farmers continue growing local landraces, and this has been attributed to the fact that the new cultivars lack some farmer-preferred traits. For example, Nametil is small-seed while farmers prefer large-seeded cultivars.

There is conflicting information regarding inheritance of resistance to groundnut rosette disease. Some researchers have reported that resistance is controlled by two independent recessive genes (Berchoux de, 1960; Bock et al., 1990; Nigam and Bock, 1990). Other researchers, such as Olorunju (1990) using progeny from the cross between RMP-12 X M1204.78I reported that resistance was controlled by one dominant gene. There is a need to conduct further studies to elucidate the inheritance pattern in available sources of resistance to groundnut rosette disease

Adamu et al. (2008) studied the general and specific combining abilities for rosette resistance and other traits in groundnuts, using three male (RMP12, ICGV-SM88709 and ICGV-SM 88710) and eight female (ICGV87281, ICGV87018, ICGV86124, ICGV86024, ICGV86028, ICGV86063 and ICGV-SM 87003) cultivars crossed in a factorial mating design in Nigeria. The results from the study indicated that the magnitude of GCA was higher than SCA for all studied traits in both F_1 and F_2 generations indicating that additive genetic effects were more important than non-additive genetic effects, and that ICGV-SM 88710 was the best combiner for haulm yield, early maturity, and rosette resistance.

The results from studies conducted in other parts of the world cannot be applied to Mozambican conditions due to differences in the genotypes used and environmental conditions, and hence, this study was conducted. Objectives of this study were to: (i) determine the general and specific combining ability for resistant to groundnut rosette, and (ii) determine the number of genes controlling resistance.

5.2 Materials and methods

5.2.1 Study area

The study was conducted in 2010/2011 growing season at Nampula Research Station. The station is located about 7 km east of Nampula (15º 09' S, 39º 30' S) town in northern Mozambique and is elevated 432 m above sea level. The soil type is sandy loam and the vegetation is predominantly grassland. The average rainfall is slightly over 1000 mm. The rainy season starts around November/December up to April/May with its peak in January. The maximum temperature in the region is about 39^{o} C and the minimum temperature is 19^{o} C.

5.2.2 Germplasm development and field establishment

Seven groundnut cultivars that were originally obtained from ICRISAT-Malawi and were adapted to Mozambican conditions were used in this study. They included two cultivars that were susceptible to groundnut rosette disease (JL-24 and CG 7) and five resistant cultivars (ICG 12991, ICGV-SM 01513, ICGV-SM 01731, ICGV-SM 90704 and ICGV-SM 01711) (Table 5.1).

The seven cultivars were planted in a crossing block on 15th December, 2008. A second planting was made on 30th of December, 2008 to ensure that enough flowers were available for hybridization. At flowering, cultivars were crossed in a half diallel mating design, using standard artificial hybridization procedures for groundnut (Norden, 1980; Knauft and Ozias-Akins, 1995).

The 21 F_1 populations resulting from the crosses were planted at Nampula Research Station in 2009/2010 growing season and allowed to self-pollinate to generate F_2 populations. The F_2 populations along with the parents were evaluated for resistance to groundnut rosette disease in the 2010/2011 growing season.

The test materials (7 parents and 21 F_2 populations) were planted at Nampula Research Station on 20th January, 2011 in a randomized complete block design with two replications. The replicates were separated by 2 m alleys. An individual genotype was planted in 2 row plots, 4 m long with 0.5 m between rows and 0.2 m within rows.

The test materials were infected using the spreader-row technique whereby each test genotype was flanked with two spreader rows. The experiment was planted in late January in order to subject the test material to high groundnut rosette disease

pressure that generally occurs late in the season. The spreader rows were planted with a groundnut rosette susceptible cultivar (JL-24) 15 days earlier than the test materials.

Table 5.1: Name, market type and rosette disease reaction of the groundnut cultivars used in this study

Genotype	Botanical classification	Reaction to rosette	Remarks
ICG 12991	Spanish bunch	Resistant	Released in Mozambique
JL-24	Spanish bunch	Susceptible	Released in Mozambique
ICGV-SM 01513	Spanish bunch	Resistant	Released in Mozambique
ICGV-SM 01731	Virginia bunch	Resistant	On-farm trials in Mozambique
CG 7	Virginia bunch	Susceptible	Released in Mozambique
ICGV-SM 90704	Virginia bunch	Resistant	Released in Mozambique
ICGV-SM 01711	Virginia bunch	Resistant	On-farm trials in Mozambique

5.2.3 Data collection and analysis

Individual plants from each genotype were monitored for presence or absence of virus symptoms at 60 days after planting. Disease incidence (DI) for each genotype was calculated as the percentage of plants in a plot with rosette symptoms (Waliyar et al., 2007). Data on DI were subjected to $\log_{10}$ transformation before analysis.

Data was analyzed for combining ability using the Griffing's diallel analysis Model 1 (fixed effects) Method 2 (parents included, reciprocals excluded) (Griffing, 1956; Christie and Shattuck, 1992; Dabholkar, 1992). This approach partitions the variance due to diallel progenies into two components (Table 5.2): 1) due to general combining ability (GCA) and 2) due to specific combining ability (SCA). From the mean sum of squares estimates of GCA effects (gi) for each parent and SCA effects (sij) for each cross combination effects were calculated. The statistical model applied was: $y_{ijk} = \mu + g_i + g_j + s_{ij} + \varepsilon_{ijk}$,

where,

y_{ijk} = Disease incidence of the cross between lines i and j in k replications;

μ = overall mean; $g_i + g_j + s_{ij}$ = the genotypic contribution for cross i x j;

g_i = the GCA of parent i;

g_j = the GCA of parent j;

s_{ij} = SCA of the cross between parents i and j;

ε_{ijl} = random error (assumed as normally and independently distributed i.e. $\mu=0$ and $\sigma^2=1$).

The combining ability estimates were calculated based on the methods described by Singh and Chaudhary (1985), and Huff and Wu (1992) as follows:

$$GCA=\frac{\text{Marginal sum of a parent}}{\text{Number of crosses involved}}-\frac{\text{Grand total of all parents}}{\text{Total number of crosses}}$$

Independent GCA effects were calculated for male and female parents using the same formula. GCA was regarded as significantly different from zero using a t-test, $t=\frac{GCA-0}{SE}$ at 27 degrees of freedom.

Predicted value of a cross = GCA of female parent + GCA of male parent + Grand mean of all crosses.

SCA=Observed mean value of a cross-Predicted value of a cross.

SCA was regarded as significantly different from zero using a t-test, $t=\frac{SCA-0}{SE}$ at 27 degree of freedom.

Table 5.2: Analysis of variance and expected mean squares for Model I, Method 2 from Griffing's (1956)

Source	df	SS	MS	Expectation of mean squares
GCA	$p-1$	S_g	M_g	$\sigma^2 + (p+2)\binom{1}{p-1}\sum_i Sgi^2$
SCA	$p\frac{(p-1)}{2}$	S_s	M_s	$\sigma^2+\frac{2}{p(p-1)}\sum_i \sum_j Sij^2$
Error	m	S_e	$M_{e'}$	σ^2

where,

M_g = mean square due to GCA,

M_s = mean squqre due to SCA,

M_e = mean error

p = number of parents

m = error degrees of freedom

Data were analysed using Diallel-SAS05, a SAS statistical program for Griffing's diallel analyisis (Zhang and Kang, 1997). The F ratios were used to test for significance of the GCA and SCA main effects and t-values were used to test for significance of GCA and SCA estimate effects. The GCA/SCA ratio to estimate the relative importance of the genetic effects (additive, dominant or epistatic) was calculated as reported by Baker (1978) as follows: $\text{Genetic ratio} = \frac{2MS_{GCA}}{2MS_{GCA}+MS_{SCA}}$.

The *Chi-square* (χ^2) was used to test the F_2 populations for fit to a 1:3 (resistant:susceptible) or 1:15 (resistant:susceptible) segregation ratio expected from a one-gene and two-gene inheritance using the formula (Gomez and Gomez, 1984), respectively: $\chi^2 = \frac{\Sigma(\text{Observed-Expected})^2}{\text{Expected}}$.

5.3 Results

5.3.1 Combining ability analysis for groundnut rosette disease incidence

Analysis of variance for combining ability (Table 5.3) showed that mean square due to general combining ability (GCA) and specific combining ability (SCA) were significant (P<0.001) for disease incidence. The GCA to SCA ratio was 0.97 indicating significant importance of additive gene action over non-additive effects for resistance to groundnut rosette disease.

Table 5.3: Mean squares from analysis of variance for combining ability for groundnut rosette from a 7x7 diallel cross

Source	df	MS
GCA	6	107.19***
SCA	21	6.34***
Error	27	1.76
GCA/SCA		0.97

* **Data significant at P≤0.001

The mean disease incidence and general combining ability for groundnut rosette disease were significantly ($P \leq 0.05$) and ($P \leq 0.001$) different among the parents (Table 5.4), respectively. The mean disease incidence for the parents ranged between 1.2 and 99.5 %. JL-24 had the highest disease incidence of 99.5 % and ICGV-SM 01711 had the lowest (1.2 %).

The desirable effects for disease incidence should be negative. The susceptible parents (JL-24 and CG 7) had positive GCA while the resistant parents (ICG 12991, ICGV-SM 01513, ICGV-SM 01731, ICGV-SM 90704 and ICGV-SM 01771) had negative values of GCA. The highest positive values were observed from parent JL-24 (3.7), and the lowest negative value was observed from parent ICGV-SM 01513 (-1.9).

Table 5.4: Parental mean and general combining ability (GCA) effects for groundnut rosette disease resistance from a 7x7 diallel cross

Parent	Phenotype	Mean (DI)	GCA
JL-24	S	99.5	3.7**
CG 7	S	87.0	3.4***
ICGV-SM 01513	R	1.4	-1.9***
ICGV-SM 01731	R	2.5	-1.2***
ICG 12991	R	6.9	-0.9***
ICGV-SM 90704	R	2.6	-1.4***
ICGV-SM 01711	R	1.2	-1.7***
Mean		28.7	
LSD (5%)		15.5	

**Data significant at P≤0.001; ***Data significant at P≤0.0001

The F_2 progeny resulting from the cross between the two susceptible parents (JL-24 and CG 7) had 100.0 % disease incidence (Table 5.5). The cross between ICGV-SM 01513 and ICGV-SM 01731 had the lowest disease incidence (2.5 %). All resistant x susceptible and susceptible x resistant crosses had mean disease incidence of over 80.0 %.

All specific combining abilities involving R X S or S X R crosses were significantly ($P<0.05$) different except for crosses JL-24 X ICGV-SM 90704 and JL-24 X ICGV-SM 01731 significant at $P<0.001$, and CG 7 X ICGV-SM 90704 not significant ($P>0.05$). The highest positive SCA effect (2.3) among R X S and S X R crosses was between the cross CG 7 X ICGV-SM 01711 and the lowest (1.1) was between the crosses ICG 12991 X JL-24 and CG 7 X ICGV-SM 90704.

Table 5.5: Mean disease incidence (%) and estimates of specific combining ability (SCA) for groundnut rosette disease of F_2 populations from a 7X7 diallel cross

Cross	Phenotype	Mean (DI)	SCA
Resistant (R) X Susceptible crosses			
ICG 12991 X JL-24	R X S	87.1	1.1
ICG 12991 X CG 7	R X S	88.5	1.5*
ICGV-SM 01513 X CG 7	R X S	74.6	1.7*
ICGV-SM 01731 X CG 7	R X S	86.0	1.7*
Resistant (R) X Resistant crosses			
ICG 12991 X ICGV-SM 01513	R X R	8.0	0.1
ICG 12991 X ICGV-SM 01731	R X R	13.9	0.2
ICG 12991 X ICGV-SM 90704	R X R	18.3	0.8
ICG 12991 X ICGV-SM 01711	R X R	5.2	-1.2
ICGV-SM 01513 X ICGV-SM 01731	R X R	2.5	-1.2
ICGV-SM 01513 X ICGV-SM 90704	R X R	2.6	-1.0
ICGV-SM 01513 X ICGV-SM 01711	R X R	5.5	-0.2
ICGV-SM 01731 X ICGC-SM 90704	R X R	17.3	1.1
ICGV-SM 01731 X ICGV-SM 01711	R X R	9.4	0.5
ICGV-SM 90704 X ICGV-SM 01711	R X R	5.2	-0.7
Susceptible (S) X Resistant (R) crosses			
JL-24 X ICGV-SM 01513	S X R	87.5	2.1*
JL-24 X ICGV-SM 01731	S X R	87.5	1.6**
JL-24 X ICGV-SM 90704	S X R	87.5	1.6**
JL-24 X ICG-SM 01711	S X R	86.8	1.9*
CG 7 X ICGV-SM 90704	S X R	72.0	1.1
CG 7 X ICGV-SM 01711	S X R	87.8	2.3*
Susceptible (S) X Susceptible cross			
JL-24 X CG 7	S X S	100.0	-2.5**
Mean		49.2	
LSD (5%)		12.3	

*Significant at P≤0.05; **significant at P≤0.001

5.3.2 Segregation for groundnut rosette disease incidence

All the resistant parents did not show disease symptoms, except for a few stunted plants (Table 5.6). However, disease symptoms were observed on most the susceptible parents. Susceptible groundnut parent CG 7 showed more disease symptoms than the other susceptible parent JL-24.

All the F_2 populations resulting from resistant (R) x susceptible (S) and S X R crosses showed some level of segregation. Two F_2 populations (ICG 12991 X JL-24 and ICGV-SM 90704 X JL-24) gave a good fit to a 1:3 (R/S) segregation ratio. The susceptible parent involved in the two populations was JL-24. Eight F_2 populations (ICG 12991 X CG 7, ICGV-SM 01513 X CG 7, ICGV-SM 01731 X CG 7, ICGV-SM 90704 X CG 7, JL-24 X ICGV-SM 01513, JL-24 X ICGV-SM 01731, JL-24 X ICG-SM 01711) gave a good fit to a 1:15 (R:S) segregation ratio. The pooled data did not fit 1:3 or 1:15 (R:S) segregation ratios.

All F_2 populations from the R X R crosses (ICG 12991 X ICGV-SM 01513, ICG 12991 X ICGV-SM 01731, ICG 12991 X ICGV-SM 90704, ICG 12991 X ICGV-SM 01711, ICGV-SM 01513 X ICGV-SM 01731, ICGV-SM 01513 X ICGV-SM 01711, ICGV-SM 01731 X ICGV-SM 01711, ICGV-SM 90704 X ICGV-SM 01513, ICGC-SM 90704 X ICGV-SM 01731 and ICGV-SM 90704 X ICGV-SM 01711) showed no disease symptoms except for a few stunted plants. All F_2 progeny resulting from S X S cross (JL-24 X CG 7) showed disease symptoms and were susceptible to groundnut rosette disease.

Table 5.6: Segregation for groundnut rosette disease incidence in crosses among resistant and susceptible cultivars

Genotype	Phenotype	Number of plants			*Chi-square* (χ^2) for ratio (R:S)	
		Total	Susceptible	Resistant	1:3	1:15
Resistant parents						
ICGV-SM 01513	R	70	0	70		
ICGV-SM 01711	R	76	0	76		
ICGV-SM 90704	R	76	4	72		
ICG 12991	R	74	8	66		
ICGV-SM 01731	R	74	4	70		
Susceptible parents						
JL-24	S	74	74	0		
CG 7	S	78	68	10		
Resistant (R) X Resistant (R) crosses						
ICG 12991 X ICGV-SM 01513	R X R	74	6	68		
ICG 12991 X ICGV-SM 01731	R X R	72	10	62		
ICG 12991 X ICGV-SM 90704	R X R	70	12	58		
ICG 12991 X ICGV-SM 01711	R X R	78	4	74		
ICGV-SM 01513 X ICGV-SM 01731	R X R	80	2	78		
ICGV-SM 01513 X ICGV-SM 01711	R X R	70	4	66		
ICGV-SM 01731 X ICGV-SM 01711	R X R	64	6	58		
ICGV-SM 90704 X ICGV-SM 01513	R X R	78	2	76		
ICGC-SM 90704 X ICGV-SM 01731	R X R	72	12	60		
ICGV-SM 90704 X ICGV-SM 01711	R X R	78	2	76		
Resistant X Susceptible or Susceptible X Resistant crosses						
ICG 12991 X JL-24	R X S	70	57	13	1.54 ns	18.14*
ICG 12991 X CG 7	R X S	70	62	8	6.88*	3.20
ICGV-SM 01513 X CG 7	R X S	74	69	5	13.14*	0.03
ICGV-SM 01731 X CG 7	R X S	72	63	9	6.00*	3.74
ICGV-SM 90704 X JL-24	R X S	72	61	11	3.63	10.01*
ICGV-SM 90704 X CG 7	R X S	74	66	8	7.95*	2.63
JL-24 X ICGV-SM 01513	S X R	72	65	7	8.96*	1.48
JL-24 X ICGV-SM 01731	S X R	72	64	8	7.41*	2.90
JL-24 X ICG-SM 01711	S X R	76	68	8	8.49*	2.37
CG 7 X ICGV-SM 01711	S X R	66	60	6	8.91*	0.91
Susceptible X Susceptible cross						
JL-24 X CG 7	S X S	74	74	0	24.67*	4.93*
Pooled (S X R and R X S)		792	709	83	89.06*	24.18*

* Data significant from the expected ratio at a level of significance of P=0.05.

5.4 Discussion

All groundnut rosette disease resistant genotypes had some level of susceptibility, which implies that none of them was immune. These results were similar to those reported by Kapewa et al. (2002) that JL-24 was more susceptible to groundnut rosette disease than other genotypes evaluated. Further, the results were in agreement with Olorunju et al. (1991a) who reported that under severe disease conditions all groundnut genotypes develop severe rosette symptoms. Hildebrand et al. (1991) found similar results and reported that the recessive genes that governed resistance to groundnut rosette disease did not confer immunity. The authors further suggested that resistance in groundnut could be overcome by the effects of high temperatures and the simultaneous inoculation of the virus by large numbers of aphids. ICGV-SM 01711 was the most resistant (1.2 %) and ICG 12991 was the least (6.9 %). Between the susceptible genotypes, JL-24 was more susceptible (99.5%) than CG 7 (87.0 %).

On average, the F_2 populations developed from a cross with JL-24, as the susceptible parent, had higher disease incidence than those involving CG 7, the other susceptible parent. These findings confirmed that JL-24 was more susceptible to the disease compared to CG 7.

When the segregation data was treated as a quantitative trait the results showed significant GCA and SCA effects which indicated that both additive and non-additive gene action were involved in the expression of resistance to groundnut rosette disease. GCA effects for disease resistance were both positive and negative, indicating that the *per se* parent performances should be good indicators of the performance of resulting F_2 progeny. The low and negative effect observed from JL-24 suggests that this parent is the better combiner for groundnut rosette disease when compared to CG 7. Traits with high GCA are highly influenced by environmental conditions. The use of only one environment in this study implies that the results may be biased (Pensuk et al., 2004; Gichuru et al., 2011) and not reliable because the role of G X E in affecting repeatability has not been quantified. However, the disease pressure applied in this study was sufficiently high to effectively differentiate among genotypes for groundnut rosette disease resistance.

The significant SCA estimates in the F_2 populations were an indicative of the presence of non-additive effects (dominance and epistasis). But Hammons (1973) observed that the general combining abilities in most studies with self-pollinated

crops where fixed models have been assumed are normally greater than the specific combining abilities. However, non-additive effects are expected to decrease after several generations due to inbreeding, making the improvement of the trait through selection possible (Redona and Lantican, 1985; Masood and Kronstad, 2000).

A relatively larger GCA/SCA ratio demonstrates the importance of additive genetic effects and the lower ratio indicates predominance of dominance and/or epistatic gene effects (Christie and Shattuck, 1992). In this study, the ratio of GCA to SCA was close to one. This indicated the predominance of additive gene action in the inheritance of resistance to groundnut rosette disease. The additive gene action in groundnut rosette disease resistance can be exploited through conventional selection methods such as mass selection, pedigree selection or family selection (Redona and Lantican, 1985). However, the presence of non-additive gene effects, even at a lower magnitude, suggests that selection for groundnut rosette disease would be more effective at later generations when the non-additive gene effect is reduced following several generations of inbreeding.

The resistance to groundnut rosette disease is controlled by two recessive genes (Nigam and Bock, 1990; Olorunju et al. (1991b).When the segregation data in F_2 populations was treated as qualitative trait, the inheritance of resistance to groundnut rosette disease was not similar for all crosses in this study. The F_2 progeny of crosses ICG 12991 X JL-24 and ICGV-SM 90704 X JL-24 showed that resistance was controlled by a single recessive gene (1 resistant : 3 susceptible).

The F_2 progeny of crosses ICG 12991 X CG 7, ICGV-SM 01513 X CG 7, ICGV-SM 01731 X CG 7, ICGV-SM 90704 X CG 7, JL-24 X ICGV-SM 01513, JL-24 X ICGV-SM 01731 and JL-24 X ICG-SM 01711 showed that resistance to groundnut rosette disease was controlled by two recessive genes. However, the results were not in agreement with Olorunju et al. (1992) who reported that resistance to groundnut rosette resistance was conditioned by a dominant gene (1 susceptible : 3 resistant). The disparity in their results could be due to background in which resistance genes are placed, differences in the genotypes and environments used in these and other studies. Results of the study suggest that apart from the one or two recessive genes, genetic modifiers may be involved in the expression of resistance to groundnut rosette disease.

5.5 Conclusion

In both parents and segregating populations there was no immunity recorded for groundnut rosette disease. Both GCA and SCA were significant indicating that both additive and non-additive gene action were important in the expression of resistance to groundnut rosette disease. GCA:SCA ratio was close to unity suggesting that GCA effects were more important than SCA effects. This indicated the predominance of additive gene action in the inheritance of groundnut rosette disease. Groundnut rosette disease was controlled by two recessive genes. However, some genetic modifiers may also be present and influence disease expression.

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VI. GENERAL OVERVIEW

Groundnut (*Arachis hypogaea* L.) is an important food and cash crop in Mozambique. The crop is grown by resource-poor small scale farmers under rainfed conditions. Low yields are realized by farmers in the country. The low yields have been attributed to a number of constraints, among which diseases feature prominently. Groundnut rosette disease is one of the most important production constraints in Mozambique. The use of host plant resistant is the most economically effective method for controlling groundnut rosette disease in Mozambique. The aim of the study was to improve the level of resistance to groundnut rosette disease in local groundnut landraces for the benefit of Mozambican farmers.

The objectives of the study were: 1) to identify farmers' major groundnut production constraints and their preferences for cultivars; 2) to evaluate local groundnut landraces for variation in agro-morphological traits and resistance to groundnut rosette disease; 3) to evaluate advanced groundnut lines developed by the local breeding programme in Nampula for agronomic performance and resistance to groundnut rosette disease across locations; and 4) to determine the inheritance of resistance to groundnut rosette disease.

The first objective aimed to obtain baseline information regarding major constraints limiting groundnut production in northern Mozambique and groundnut traits preferred by farmers for cultivars. The study was conducted using a participatory rural appraisal methodology. During the study a survey on prevalence of groundnut rosette disease was conducted in 13 districts. Results from the study showed that farmers were aware of the main constraints affecting groundnut production and productivity in their region, and the specific needs they would prefer a new groundnut cultivar. Intercropping was a common practice among the majority of farmers in the region. Groundnut was the third most important crop after cassava and maize.

Groundnut rosette disease was prevalent in all the fields visited and was the most important constraint affecting groundnut production in the region. This observation highlighted the idea that the disease has the potential to cause severe yield losses in all the groundnut growing regions in northern Mozambique. Nevertheless, the study showed that there was variability of the disease incidence across districts implying that environmental factors had an influence on the occurrence of the disease.

Other constraints mentioned by farmers included insect pests, lack of good quality seed, lack of improved cultivars, low soil fertility, lack of labour and lack of infra-structure. From this list of constraints, it was clear that there is a huge demand for improved groundnut cultivars, and that the currently grown cultivars do not always have the preferred traits.

During the focus group discussions, farmers indicated that research should target certain traits such as resistance to diseases, high oil content and large pod and seed sizes. Release of cultivars lacking these traits may lead to low adoption or rejection of the cultivars. The selection criteria used by women differed from that used by men within village and across villages. High yield and oil content were the most important traits followed by pod and seed size, earliness and disease and insect pest resistance.

The second objective of the study was to evaluate local groundnut landraces with respect to groundnut rosette disease and selected morphological traits. Fifty-eight local landraces were collected from northern Mozambique and evaluated under field conditions. The highest yielding genotypes were Pambara-4, Pambara-2, Pambara-6, Ile-1, Imponge-1-Tom and Gile-5. The data indicated that no correlation between yield and rosette disease under high disease pressure. The results showed high phenotypic variation among the landraces. The variation on morphological characteristics indicated diversity exist among the Mozambican landraces and could be useful for breeding programmes. Clustering of the genotypes on the basis of morphological traits gave six clusters. Based on visual rosette disease symptoms, four local landraces (PAN-4, Imponge-4, Pambara-3, Metarica Joao) were identified with resistance to groundnut rosette disease. These landraces will be used in future breeding programmes in Mozambique.

The third objective of the study was to evaluate advanced groundnut lines for agronomic performance and groundnut rosette disease resistance across locations. Thirty-one advanced lines and one check were evaluated at three locations for two consecutive growing seasons. Groundnut rosette disease infestation was generally very low in all the locations and years. The data indicated negative correlation between yield and groundnut rosette disease incidence.

On the basis of yield data, the advanced lines responded differently across environments. The different responses indicated that some of the advanced lines could be suitable for good environments, others in poor environments and others

could be suitable in wide range of environments. Six advanced lines were found to be suitable in a wide range of environments. Line 35B was the most stable across environments, and could be recommended for cultivation on diverse environments in northern Mozambique.

The fourth objective of the study was to determine the inheritance of groundnut rosette disease. Twenty-one F_2 populations from a seven-parent half diallel cross and their parents were evaluated under field conditions using the spreader row technique. The results of the study showed that both additive and non-additive genetic factors were important in the expression of resistance to groundnut rosette disease. GCA (additive gene action) was more important than SCA (non-additive) in determining the inheritance of resistance to disease.

The chi-square test using segregating F_2 populations showed that resistance to groundnut rosette disease may be controlled by one or two recessive genes. However, some genetic modifiers may have influenced disease expression.

Overall, the significant findings made in this study are as follows:

1) The participatory rural appraisal approach was an efficient and effective technique that enabled farmers to provide detailed information about the groundnut cropping system by prioritizing the main constraints limiting its production in the region and by listing preferred traits of groundnut cultivars.

2) Several groundnut local landraces possessed good levels of resistance to groundnut rosette disease, which will be useful to the groundnut breeding programme in Mozambique.

3) One advanced line (35B) was high-yielding and stable across environments, and could be recommended for cultivation in a wide range of environments in northern Mozambique.

4) One or two recessive genes conditioned resistance to groundnut rosette disease. However, some modifiers may have influenced the disease expression

5) Both additive and non-additive gene effects were important for groundnut rosette disease expression, but additive gene action was predominant.

Some of the limitations encountered during the study included:

1. Challenges of crossing: in order to ensure sufficient seed for the entire experiment (F1, F2, backcrosses with replications) requires making more crosses since each cross it gives maximum of two seeds. Therefore, more people are needed for study like this whereby the timeframe for the study is very short.

2. Availability of vector/disease is depended on weather conditions. This may lead to disease escape. However, future studies can be done with help from other institutions for groundnut rosette disease screening (e.g. ICRISAT-Malawi) because they already have infra-structure for disease screening in place.

RESEARCH IMPLICATIONS

The need for improved, disease-resistant groundnut cultivars for Mozambique has been clearly established. Farmers have given their contribution on the subject of the preferred traits for new cultivars and these traits will be important criteria in formulating selection in the segregating populations of the breeding programme. The groundnut rosette disease will be a major breeding focus, while selection for other traits and constraints cannot be ignored. Resistance has been identified from local landraces and this programme will need to be continued in order to develop the improved groundnut cultivars incorporating preferred traits into groundnut rosette disease resistant landraces. In the breeding programme, farmers will be involved in the early selections in order to ensure that the best genotypes are identified and hence, adoption levels of improved cultivars are increased.

Appendix 1: Participatory rural appraisal questionnaire

Groundnut production problems and copping strategies

1. What range of crops do you grow? Which ones do you grow most frequently? Let the farmer specify.
2. What constraints do you face in your crop farming enterprises?– On the three most important crops.
3. For how many years have you grown groundnut?
4. Which cultivars have you grown in the past 2 years?
5. Rank the cultivars and list their good and bad characteristics
6. Rank the groundnut production constraints (Score: 1 = most important; 10 = least important)
7. Have you ever seen groundnut rosette disease on your field? YES/NO.....
8. If yes, what are the strategies of dealing with the disease?
9. Production and consumption figures (last year)
10. Estimate the quantity (kg) of groundnut that you produced
11. Estimate the quantity that you sold
12. Estimate the quantity that you consumed
13. What characteristics do you prefer from a new groundnut cultivar?
14. If developed, can you adopt the new cultivars? Yes/No
15. If yes, give your reasons.
16. If no, give your reasons.
17. What other characteristics do you expect in the new cultivars?

Details of the area

Respondent.....

Province..... District..... Village.....

Soil texture: sand, loam, clay Rainfall: high, medium, and low

Personal details of respondent

Name of household head	Age	Sex	
		Male	Female
	<30 31-40 41-50 51-60 60-70 >70		

Household details

Household members	Number bellow 18 yr	Number 18 yr and above	Number providing farm labour	Number of hired labour
Male				
Female				

CROPPING SYSTEM

What range of crops do you grow? Which ones do you grow most frequently? Let the farmer specify.

Crop	Area planted (hectares; specify)		Comment
	2008	2009	
Cassava			
Groundnuts			
Sorghum			
Maize			
Cowpea			
Cotton			
Bambara nut			

What constraints do you face in your crop farming enterprises? (Tick the constraints against the crop) – On the three most important crops. Let the farmer specify

Constraint/Crop	cassava	Maize	Groundnut	Sorghum	Cowpea	Cotton	Bambara				
Drought											
Poor soil fertility											
Diseases											
Insect Pests											
Seed availability											
Poor cultivars											
Market availability											
Labour availability											
Transport											

For how many years have you grown groundnut? .....

.....

Which cultivars have you grown in the past 2 years?

Cultivar Name	Source of the seed	Years planted to the cultivar	
		2008	2009
1			
2			
3			
4			
5			

Rank the cultivars and list their good and bad characteristics (1=good; 5=bad

Cultivar Name	Rank	Good Characteristics	Bad characteristics
1			
2			
3			
4			
5			

Rank the groundnut production constraints (Score: 1 = most important; 10 = least important)

Constraint	Rank	Comment
Drought		
Poor soil fertility		
Diseases		
Insect Pests		
Seed availability		
Poor cultivars		
Market availability		
Labour availability		
Transport		

Production and consumption figures

	Quantity (kg) produced	Quantity (kg) consumed	Quantity (kg) sold
Grain			

Desired plant characteristics (tick the appropriate choice)

Plant traits	Tick the appropriate response		
Growth habit	Erect	Bunch	Prostrate
Plant size	Short	Medium	Tall
Pod size	small	Medium	Large
Grain size	Small	Medium	Large
Grain colour	Red	Tan	Brown
Grain taste	Good	bad	Don't care
Stem colour	Green	Purple	Mixed
Maturity period	Early	Medium	Late
Grain yield	Low	Medium	High
Drought tolerance	Low	Medium	High
Disease & pest tolerance	Low	Medium	High
Oil content	Low	Medium	High

Appendix 2: Morphological variation of local groundnut landraces

Appendix 2: Morphological variation in selected qualitative traits recorded in 58 groundnut landraces grown at PAN, Nampula, Mozambique

Genotype	Seed colour	Flower colour	Leaflet shape	Growth habit	Pod size	Pod constriction	Pod beak	Stem colour
1A	Light purple	Yellow-orange	Obovate	Decumbent-2	Medium	Moderate	Moderate	Mixed
35B	Light purple	Yellow-orange	Lanceolate	Decumbent-3	Small	Moderate	Slight	Mixed
41A	Purple	Yellow-orange	Obovate	Decumbent-1	Medium	Moderate	Moderate	Green
75B	Light purple	Yellow-orange	Lanceolate	Decumbent-2	Medium	Moderate	Slight	Purple
Cuamba Lurio Eugenio	Light purple	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Deep	Moderate	Green
Erati Mercado	Purple	Yellow-orange	Lanceolate	Erect	Small	Deep	Slight	Green
Erati Omar	Purple	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Very deep	Moderate	Purple
Erati Sede	Light purple	Yellow-orange	Wide-elliptic	Decumbent-1	Medium	Moderate	Moderate	Green
Gile-1	Light purple	Yellow-orange	Obovate	Decumbent-2	Medium	Moderate	Moderate	Green
Gile-2	Purple	Yellow-orange	Lanceolate	Decumbent-2	Medium	Moderate	Slight	Green
Gile-3	Light purple	Yellow-orange	Obovate	Decumbent-2	Medium	Moderate	Moderate	Green
Gile-5	Light purple	Yellow-orange	Obovate	Decumbent-3	Medium	Moderate	Slight	Mixed
Gile_4	Purple	Yellow-orange	Obovate	Decumbent-2	Small	Moderate	Slight	Green
Ile-1	Purple	Yellow-orange	Lanceolate	Decumbent-1	Small	Moderate	Slight	Purple
Ile-2	Light purple	Yellow-orange	Lanceolate	Decumbent-2	Medium	Deep	Slight	Purple
Impong_1_Tom	Light purple	Yellow-orange	Wide-elliptic	Decumbent-3	Medium	Moderate	Slight	Green
Imponge-2A	Light tan	Yellow-orange	Wide-elliptic	Decumbent-3	Medium	Moderate	Moderate	Purple
Imponge-43	Two colours	Yellow-orange	Obovate	Decumbent-1	Medium	Moderate	Moderate	Purple
Imponge_2	Light purple	Yellow-orange	Wide-elliptic	Decumbent-3	Medium	Slight	Moderate	Purple
Imponge_3	Purple	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Moderate	Purple
Imponge_4	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Very deep	Prominent	Green
Imponge_42	Two colours	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Slight	Purple
Imponge_5	Light tan	Yellow-orange	Oblong-elliptic	Decumbent-2	Medium	Moderate	Slight	Green
Lurio Miguel	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-1	Medium	Moderate	Moderate	Green
Metarica Joao	Pale tan	Yellow-orange	Obovate	Decumbent-2	Medium	Slight	Moderate	Green
Metarica Mutara	Dark tan	Yellow-orange	Wide-elliptic	Erect	Small	Moderate	Slight	Green
Molocue-1	Pale tan	Yellow-orange	Obovate	Decumbent-2	Big	Moderate	Slight	Mixed
Molocue-2	Dark tan	Yellow-orange	Obovate	Decumbent-3	Medium	None	Moderate	Purple
Mualia	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Moderate	Green

Appendix 2: Continued

Genotype	Seed colour	Flower colour	Leaflet shape	Growth habit	Pod size	Pod constriction	Pod beak	Stem colour
Mualia-1	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Slight	Green
Mualia-2	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-2	Big	Moderate	Moderate	Purple
Mualia-3	Pale tan	Yellow-orange	Oblong-elliptic	Decumbent-3	Medium	Deep	Moderate	Purple
Nacate	Pale tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Prominent	Green
Nacate-1	Purple	Yellow-orange	Obovate	Decumbent-2	Big	Moderate	Slight	Green
Nacate-2	Dark tan	Yellow-orange	Wide-elliptic	Decumbent-1	Medium	Moderate	Moderate	Green
Nacate_3	Pale tan	Yellow-orange	Obovate	Decumbent-3	Medium	Moderate	Prominent	Mixed
Namuno-1	Dark tan	Yellow-orange	Oblong-elliptic	Decumbent-2	Small	Moderate	Moderate	Green
Ncoela	Pale tan	Yellow-orange	Obovate	Decumbent-2	Medium	Moderate	Moderate	Mixed
Ncoela-1	Dark tan	Yellow-orange	Wide-elliptic	Decumbent-1	Medium	Deep	Slight	Green
Ncoela-2	Purple	Yellow-orange	Oblong-elliptic	Decumbent-2	Big	Moderate	Moderate	Purple
Ncoela-3	Purple	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Moderate	Green
Ncoela-4	Dark tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Moderate	Green
Ncoela-5	Pale tan	Yellow-orange	Oblong-elliptic	Decumbent-1	Medium	Moderate	Slight	Purple
Ncoela-6	Purple	Yellow-orange	Lanceolate	Decumbent-2	Big	Moderate	Slight	Green
Pambara-1	Dark tan	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	Moderate	Slight	Green
Pambara-2	Purple	Yellow-orange	Wide-elliptic	Decumbent-2	Medium	None	Slight	Green
Pambara-3	Purple	Yellow-orange	Oblong-elliptic	Decumbent-3	Medium	Moderate	Slight	Green
Pambara-4	Purple	Yellow-orange	Obovate	Decumbent-2	Medium	Deep	Moderate	Green
Pambara-5	Purple	Yellow-orange	Wide-elliptic	Decumbent-1	Medium	Moderate	Moderate	Purple
Pambara-6	Purple	Yellow-orange	Oblong-elliptic	Decumbent-2	Medium	Moderate	Moderate	Purple
Pambara-7	Purple	Yellow-orange	Lanceolate	Decumbent-2	Medium	Deep	Moderate	Green
PAN-1	Purple	Yellow-orange	Lanceolate	Decumbent-3	Medium	Moderate	Moderate	Green
PAN-2	Pale tan	Yellow-orange	Lanceolate	Decumbent-3	Medium	Deep	Prominent	Green
PAN-3	Dark tan	Yellow-orange	Wide-elliptic	Erect	Small	Moderate	Moderate	Green
PAN-4	Pale tan	Yellow-orange	Wide-elliptic	Erect	Medium	Moderate	Slight	Green
PAN-5	Dark tan	Yellow-orange	Wide-elliptic	Erect	Medium	Moderate	Moderate	Green
JL-24	Pale tan	Yellow-orange	Oblong-elliptic	Erect	Medium	Moderate	Moderate	Mixed
Unhaphatenha	Pale tan	Yellow-orange	Oblong-elliptic	Decumbent-1	Medium	Moderate	Moderate	Green

Appendix 3: Yield and yield components of local groundnut landraces

Appendix 3: Yield and yield components for 58 groundnut genotypes evaluated at Nampula in Mozambique in 2008/2009 and 2009/2010 growing seasons*

Genotype	Yield			100 seed weight			Number of pods			Pod leng		
	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined
Ncoela-5	407.8	1029.5	775.6	40.0	40.0	43.3	122.0	142.5	132.3	2.8	2.4	2.6
Pambara-5	698.2	957.1	475.1	45.0	35.0	43.3	102.0	132.5	117.3	2.6	2.9	2.8
Nacate-2	727.5	918.0	636.7	41.5	40.0	43.3	91.0	126.5	108.8	2.6	2.1	2.3
Imponge_3	422.6	858.6	591.7	42.0	30.0	43.3	91.0	91.0	91.0	2.7	1.8	2.2
Mualia	658.2	832.9	456.0	33.7	35.2	43.3	91.0	93.5	92.3	2.2	2.2	2.2
1A	816.1	801.0	391.7	44.8	29.3	43.3	91.0	91.0	91.0	2.6	2.4	2.5
Gile-1	326.2	788.4	330.6	32.4	23.8	43.3	123.0	119.5	121.3	2.4	2.4	2.4
Pambara-7	404.3	785.0	562.3	47.3	43.3	45.3	134.0	131.0	132.5	2.2	2.1	2.1
JL-24	804.5	773.3	702.6	51.5	58.0	54.8	149.0	113.0	131.0	2.8	2.7	2.8
PAN-5	786.5	761.7	338.0	47.4	50.0	48.7	91.0	134.5	112.8	2.7	2.8	2.7
Gile-5	906.0	735.2	695.3	64.5	58.0	61.3	91.0	91.0	91.0	2.6	2.1	2.3
PAN-3	683.8	726.0	442.0	50.0	47.0	48.5	121.5	156.5	139.0	2.3	2.9	2.6
PAN-4	495.6	714.7	833.9	46.0	40.5	43.3	93.0	97.0	95.0	2.4	2.4	2.4
Metarica Mutara	506.9	698.9	885.2	55.0	48.6	51.8	91.0	131.0	111.0	2.6	2.6	2.6
Ncoela-3	484.9	692.1	443.8	44.5	31.9	43.3	102.0	107.5	104.8	2.8	2.9	2.8
Molocue-1	584.8	681.7	882.7	40.5	33.6	43.3	123.5	123.5	123.5	2.1	2.2	2.2
Lurio Miguel	503.7	681.2	732.6	43.5	42.9	43.3	132.0	99.0	115.5	2.6	2.6	2.6
Metarica Joao	627.3	681.2	459.1	36.0	41.0	43.3	108.0	108.0	108.0	2.2	2.6	2.4
Pambara-6	817.6	676.4	726.0	42.5	41.1	43.3	107.5	140.5	124.0	2.1	2.6	2.3
Imponge_5	500.4	668.6	849.1	38.7	37.4	43.3	170.0	137.0	153.5	2.4	2.1	2.2
Pambara-3	393.1	660.6	530.5	49.0	54.0	51.5	91.0	93.5	92.3	1.9	2.6	2.2
Gile_4	604.3	653.8	410.2	26.9	36.8	43.3	131.0	96.5	113.8	2.4	2.4	2.4

Appendix 3: Continued

Genotype	Yield			100 seed weight			Number of pods			Pod length		
	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined
Mualia-2	585.4	647.0	692.5	35.6	34.4	43.3	95.5	98.0	96.8	2.5	2.6	2.5
Unhaphatenha	464.2	646.5	742.8	41.3	37.6	43.3	91.0	127.0	109.0	2.7	2.9	2.8
Pambara-1	505.6	628.2	383.6	35.0	23.2	43.3	111.0	92.5	101.8	2.8	2.7	2.7
Ncoela	391.5	619.3	640.6	37.5	30.5	43.3	93.5	91.0	92.3	2.9	3.0	3.0
Nacate-1	482.5	606.2	576.9	37.5	28.9	43.3	95.5	113.0	104.3	2.4	2.1	2.2
Mualia-3	628.9	595.1	633.2	52.5	42.4	47.5	92.0	91.0	91.5	2.6	2.6	2.6
41A	692.4	593.4	395.4	42.5	48.6	45.5	91.0	97.5	94.3	3.1	2.5	2.8
Ncoela-2	451.0	581.7	602.0	53.0	49.7	51.4	126.5	100.0	113.3	2.6	2.3	2.4
Imponge_2	871.8	581.1	440.5	39.9	40.3	43.3	91.0	91.0	91.0	2.6	2.9	2.8
Nacate_3	657.0	560.6	642.1	43.8	46.5	45.1	91.0	92.0	91.5	2.6	2.6	2.6
Imponge-2A	363.8	546.1	548.7	40.3	47.6	43.9	97.5	105.0	101.3	2.0	2.3	2.1
PAN-1	548.8	545.9	551.9	41.0	39.3	43.3	99.5	97.0	98.3	2.6	2.6	2.6
Imponge_42	865.3	537.2	669.1	33.9	41.3	43.3	91.0	91.0	91.0	2.2	2.5	2.3
Erati Omar	214.1	510.8	575.5	41.3	45.4	43.3	98.0	117.0	107.5	2.1	3.0	2.5
Molocue-2	433.6	506.2	721.1	33.5	50.3	43.3	97.0	91.0	94.0	2.7	2.6	2.6
Ncoela-4	328.2	504.3	765.5	44.9	49.1	47.0	126.0	91.0	108.5	2.9	2.5	2.7
Ncoela-1	691.5	495.5	498.8	36.4	36.9	43.3	93.5	91.0	92.3	2.7	2.5	2.6
Imponge-43	789.9	477.4	485.2	38.0	31.1	43.3	134.5	91.0	112.8	2.7	2.7	2.7
Imponge_4	726.0	472.7	424.1	55.4	34.2	44.8	140.0	147.5	143.8	1.5	1.9	1.7
35B	505.9	468.4	377.7	39.8	38.4	43.3	101.5	91.0	96.3	2.7	1.8	2.2

Appendix 3: Continued

Genotype	Yield			100 seed weight			Number of pods			Pod length		
	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined	2009	2010	Combined
75B	646.3	456.6	487.3	45.5	47.6	46.5	110.0	91.0	100.5	3.0	2.1	2.5
Namuno-1	839.0	447.1	494.8	37.6	50.8	44.2	124.5	100.0	112.3	2.7	2.8	2.8
Pambara-4	874.4	444.2	429.2	41.6	52.9	47.2	111.5	91.0	101.3	2.3	2.8	2.5
Gile-3	406.5	438.8	505.9	35.3	40.5	43.3	108.5	91.0	99.8	2.6	2.6	2.6
Pambara-2	853.6	435.7	856.1	50.7	49.9	50.3	97.5	97.0	97.3	3.0	3.1	3.0
Erati Mercado	398.4	425.7	402.5	36.8	38.4	43.3	91.0	111.0	101.0	3.1	1.8	2.4
Ile-2	415.0	412.0	952.0	46.2	47.4	46.8	134.0	135.0	134.5	2.9	2.6	2.7
Nacate	475.5	397.3	568.5	37.7	28.2	43.3	91.0	91.0	91.0	2.6	2.6	2.6
Erati Sede	448.3	392.2	801.3	41.8	42.1	43.3	105.0	105.0	105.0	1.7	1.9	1.8
Ile-1	852.5	385.1	415.0	34.8	35.9	43.3	112.0	131.5	121.8	2.3	2.2	2.2
Mualia-1	514.5	366.5	604.7	43.5	44.1	43.8	91.0	91.0	91.0	2.8	2.1	2.5
PAN-2	582.4	357.2	600.8	43.3	38.2	43.3	125.5	144.5	135.0	2.4	2.8	2.6
Impong_1_Tom	808.3	349.8	614.9	30.3	31.5	43.3	99.5	112.5	106.0	2.7	2.5	2.6
Cuamba Lurio Eugenio	476.3	278.9	500.0	34.6	39.0	43.3	131.0	91.0	111.0	2.6	2.6	2.6
Ncoela-6	466.2	270.6	787.4	40.6	39.1	43.3	100.0	91.0	95.5	2.9	2.6	2.7
Gile-2	617.4	263.5	487.5	34.4	38.0	43.3	91.0	91.0	91.0	2.7	2.6	2.6
Mean	682.0	498.0	587.0	41.7	40.6	41.1	107.3	97.4	101.0	2.5	2.5	2.5
LSD(5%)	227.7	223.4	141.0	12.4	10.1	14.1	25.5	24.7	32.9	0.8	0.8	0.6
CV(%)	38.8	38.0	34.4	29.7	24.9	24.6	23.7	22.7	21.9	16.1	15.7	16.0

Appendix 4: Groundnut rosette disease incidence at 60 days after planting, yield and yield components of groundnut landraces grown at Nampula, in 2010/2011 growing season

Genotype	Disease incidence (%)	Seed yield (kg ha^{-1})	100 seed weight (g)	Number of pods plant $^{-1}$	Pod length (cm)
Nacate-1	48.8	844.7	45.4	81.5	2.3
1A	30.2	767.3	40.0	71.0	2.5
PAN-4	6.2	739.8	39.0	95.5	2.5
PAN-2	27.5	688.2	38.2	123.0	2.2
Impong_1_Tom	19.6	661.3	33.6	97.0	2.8
Imponge_2	63.1	656.7	42.9	78.5	2.8
JL-24	32.6	585.2	37.6	78.0	2.5
Metarica Mutara	51.7	585.0	28.9	82.0	2.1
Imponge_42	55.7	570.9	37.4	71.0	2.4
Pambara-6	12.9	565.3	42.1	71.0	2.3
Pambara-2	52.5	559.5	49.9	72.5	3.1
PAN-1	48.9	559.4	44.1	71.0	2.8
Erati Omar	50.0	539.5	23.8	141.5	2.2
PAN-5	42.3	537.9	39.1	72.0	2.7
Gile-2	25.9	535.7	30.5	74.5	1.7
Pambara-4	14.3	522.0	47.4	82.5	3.0
Ncoela	49.6	520.9	30.5	71.0	2.6
PAN-3	61.0	501.5	31.5	110.0	2.3
Mualia	31.3	498.0	49.7	71.0	3.1
Mualia-2	42.5	474.8	46.5	73.5	2.1
Nacate-2	55.0	469.5	50.3	83.5	2.1
Molocue-1	61.4	461.4	30.5	91.5	2.0
Ile-2	25.0	455.9	30.5	71.0	2.8
Mualia-3	36.8	449.4	47.6	91.5	2.3
Unhaphatenha	71.5	441.3	38.0	91.5	2.1
Gile-1	42.5	441.3	30.5	75.5	2.6
Metarica Joao	9.9	432.0	30.5	71.0	2.7
35B	29.8	425.3	32.8	107.0	2.4
Imponge_4	9.2	423.1	41.1	71.0	2.1
Imponge_5	40.7	408.1	54.0	71.0	2.5
Imponge-2A	41.3	406.2	36.8	104.0	2.1
Ncoela-6	33.6	381.9	43.8	112.0	2.9
Namuno-1	80.0	374.0	44.1	71.0	2.2
Nacate_3	62.4	342.0	30.5	76.0	2.6
Ncoela-5	70.9	341.9	50.8	103.5	2.2
Ile-1	40.0	341.3	30.5	71.0	2.4
75B	30.9	338.2	30.0	85.0	2.3
Pambara-1	23.9	337.5	40.5	103.0	2.6
Gile-3	57.3	334.1	30.5	71.0	2.5
Ncoela-4	53.9	333.2	47.6	82.5	2.4

Appendix 4. Continued

Genotype	Disease incidence (%)	Seed yield (kg ha^{-1})	100 seed weight (g)	Number of pods plant $^{-1}$	Pod length (cm)
Imponge-43	11.1	322.4	34.4	74.0	2.6
Gile_4	52.4	315.4	30.5	101.0	2.2
Erati Sede	35.6	312.5	43.3	93.0	2.7
41A	40.4	308.3	35.3	91.0	2.7
Ncoela-2	41.3	304.9	34.2	71.0	2.5
Nacate	29.2	299.8	39.3	71.0	2.5
Mualia-1	65.8	280.6	40.3	114.0	2.2
Pambara-7	29.8	272.7	35.9	113.0	2.0
Imponge_3	33.6	271.3	38.3	77.0	2.9
Cuamba Lurio Eugenio	70.0	270.1	35.2	79.5	2.6
Gile-5	63.7	266.7	30.5	117.0	2.4
Molocue-2	50.7	252.4	30.5	106.0	2.6
Pambara-3	9.2	240.7	38.4	77.5	2.8
Erati Mercado	37.7	214.8	29.3	87.5	2.4
Ncoela-3	45.2	200.8	38.4	114.5	1.8
Pambara-5	15.6	149.1	28.2	105.5	2.1
Ncoela-1	39.8	84.4	31.1	71.0	2.6
Lurio Miguel	64.8	64.3	23.2	111.0	2.8
Mean	41.0	419.0	37.3	87.3	2.4
LSD (5%)	49.1	463.5	19.3	53.6	0.8
CV (5%)	59.8	55.3	25.9	30.6	15.5

Appendix 5: Combined ANOVA for advanced groundnut lines

Source	DF	Mean Squares				
		rosette	1-2seed	maturity	100 seed w	seed yield
YEAR	1	11.07	1.17	5002.08***	716.88***	125907299.1***
ENV	2	2241.52***	3.52	15006.25***	602.9***	13335503.2***
ENV x YEAR	2	12.85	1.17	5002.08***	1228.52***	44809843.4***
Rep(ENV x YEAR)	18	137.4***	81.9	878.58**	194.88***	15479953.5***
Cultivar	31	64.54**	3142.7***	2670.02***	268.67***	1032106.8***
ENV x Cultivar	62	60.3***	14	404.23	45.77***	356516.5
YEAR x Cultivar	31	6.94	4.67	134.74	22.68	871316.5**
ENVx YEAR x Cultivar	62	2.08	4.67	134.74	24.62	308893.1
Error	558	34.11	82.17	373.54	21.92	457365.6
Corrected Total	767					