MORPHO-PHYSIOLOGICAL CHARACTERISATION OF BAMBARA GROUNDNUT (*Vigna subterranea* L.) LANDRACES COLLECTED IN MPUMALANGA PROVINCE

BY

SELWANA MICHAEL MAGONGWA

(11629556)

DISSERTATION

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For the degree of

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SUPERVISOR: Prof JBO Ogola

CO-SUPERVISOR: Mr C Mathews

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ABSTRACT

Bambara groundnut (*Vigna subterranea* [L.] Verdc.) has a large number of landraces throughout Africa partly because of its drought tolerance. The study was aimed at evaluating genotypic variation of landraces collected in Mpumalanga Province.

The study comprised of two experiments, pot experiment (Experiment I) and field trial (Experiment II). Experiment I was conducted in rain shelter at the University of Venda, Thohoyandou (latitude 22°58´S and longitude 30°26 ´E; 596 m above sea level), Limpopo Province. The experimental design was a split-plot, with watering regime being the main factor and landrace being the sub-plot, arranged in a randomised complete block design with three replicates. Experiment II was conducted during summer 2013 to 2015 involving 27 bambara groundnut landraces (Nkomazi-1, Zm-1, Bushbuckridge-1, MPB 51, Sb7-1, Bosfontein-1, Msholozi-1, Zm-4, Ntunda-1, Sandriver-1, Matsulu-1, Nkangala-2, Msholozi-2, Sandriver-3, Mashishing-3, Brianbeck-2, Zm-6, Ntunda-2, Matsulu-3, Nkangala-3, Mashishing-2, Brainbeck-3, Zm-5, Ntunda-4, Sandriver-2, Msholozi-3 and Mashishing-4. The field experiments were laid out in Randomised Complete Block Design (RCBD) with three replications at two sites. The landraces were collected from the following places: Bosfontein (1), Bushbuckridge (1), Mashishing (3), Matsulu (2), Nelspruit-LRU (8), Msholozi (3), Nkangala (2), Nkomazi (1), Ntunda (3) and Sandriver (3). In experiment I, leaf chlorophyll content and stomatal conductance were measured and experiment II the following traits were measured days to 50% emergence (50% DTE), days to 50% flowering (50% DTF), number of leaves per plant, 100 seed weight, dry pod weight, crop biomass, number of seeds per pod and grain yield.Highest chlorophyll content levels were observed in landraces ZM-4 (35.5 mmol cm^{-2} s^{-1}) and MPB 51 (35.3 mmol cm^{-2} s^{-1}) at week 3. The effect of watering regime on stomatal conductance was significant in 3rd week but not in 1st and 2ndweek. The highest stomatal conductance was observed at high watering regime while the lowest was observed at low watering regime. Days to 50 % emergence, days to 50% flowering varied with landraces in Mzinti and at Nelspruit, and number of leaves per plant generally did not differ in landraces. Bambara groundnut landraces significantly influenced ($P \leq 0.001$) 100 seed weight at both locations. The study showed variation among landraces in days to emergence, days to flowering, dry biomass and 100 seed weight.

Good performance of the landraces Sandriver-2 and Matsulu-3 across all ecological regions makes them suitable for further research under stress conditions and future climate change scenarios.

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DEDICATIONS

I dedicate this work to my wife Mrs. R.J Magongwa, my three children and my mother Ms R.R Magongwa.

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DECLARATION

I hereby declare that this Dissertation, prepared for the degree Masters of Science in Agriculture which was submitted by me at the University of Venda, is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. This work has not been submitted for any degree to any other institution.

Student:

Selwana Michael Magongwa 31 August 2016

(11629556)

.....

Supervisor:

Prof JBO Ogola 31 August 2016

.....

Co-Supervisor

Mr C Mathews 31 August 2016

.....

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ABBREVIATIONS

BAMNET	International Bambara Groundnut Network
DAE	Days after emergence
DAP	Days after planting
DTE	Days to emergence
DTF	Days to flowering
HWR	High watering regime
IITA	International Institute of Tropical Agriculture
IPGR	International Plant Genetic Resources Institute
LWR	Low watering regime

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CHAPTER 1

Introduction

1. Background information

The use of indigenous vegetables in South Africa is as old as the history of man. The Khoisananoid people that lived in Southern Africa over the past 120 000 years relied heavily on the gathering of several wild indigenous plants that were mostly herbaceous leafy vegetables for their survival (van Rensburg *et al.*, 2007). A wide range of indigenous vegetables are currently consumed in South Africa (van Rensburg *et al.*, 2007). Indigenous vegetables contribute greatly to the economic and nutritional well-being of rural people by providing income and essential nutrients required for body growth and development and for prevention of diseases associated with nutritional deficiencies (FAO, 2014).

Indigenous crops are crops that have their origin in a country, added are those crops introduced into the country and are now recognized as naturalised or traditional crops (Shippers 2000). Rural families traditionally have made conscious efforts to preserve indigenous crops around their homesteads, in crop fields and communal lands. In recent years, however, exotic crops have taken prominence over indigenous crops in spite of their generally lower nutritive value (van Rensburg *et al.*, 2007). The availability of indigenous vegetables and crops has declined drastically because of excessive cultivation of exotic crops and habitat change, including deforestation. This has been exacerbated by a lack of major research and extension efforts to improve the indigenous crop husbandry. Efforts have been made to achieve food self-sufficiency in South Africa through increasing the production of cereal crops (like maize) and pulses (like groundnuts) in poor communities but such efforts do fail due to constraints such as low soil fertility, drought and insufficient agricultural inputs (Van Rensburg *et al.*, 2007). The indigenous crops have the potential to provide valuable source of nutrition in areas with hot and dry climates (van Rensburg *et al.*, 2007). Over the last two decades or so, the whole world has experienced rapid changes in climate (global warming) and socio-economic transformations. The socio-economic changes affected and caused severe stress mainly to isolated, peripheral and rural resource-poor areas of the world. Moreover, the changes in economic and social cultural structure of the world caused decreased farm revenues and food insecurity.

Also, there is growing ignorance among young people about the existence of these nutritionally rich indigenous food crops. The decline in the use of indigenous vegetables by many rural

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people has resulted in poor diets and increased incidence of nutritional deficiency disorders and diseases in many parts of the world and most African countries in general (FAO, 2002). This neglect of traditional crops is worrisome, because these crops are particularly important to the countries of sub-Saharan Africa, being better adapted to the environment than the introduced commercial crops and vegetables.

For example, smallholder farmers in Mpumalanga Province, South Africa, cultivate the more marginal areas that are characterized by low and erratic rainfall and sandy soils with limited organic matter and low nutrient content (van Rensburg *et al.*, 2007). Crop production in such areas is limited by the physical constraints of poor soils and inadequate water, amongst other factors. Climate change is likely to worsen the problem. Drought tolerant indigenous legumes such as Bambara groundnut may increase productivity and minimize crop failure risks of current cropping systems. This would in turn lead to improved food security and income of small-scale farmers and thus help in alleviating poverty. Bambara groundnut has several advantages including high nutritional value, drought tolerance, and the ability to produce a good yield in soils that are too poor for cultivation of other commonly grown legume species such as common beans and groundnuts. Therefore, bambara groundnuts may play a significant role in improving household food security and nutrition as well as family income, especially of resource-poor smallholder farmers in the Mpumalanga Province (Mathews, 2010).

Bambara groundnut (*Vigna subterranea* L.) is a popular legume amongst the smallholder farmers in Mpumalanga for nutrition and for generating income. However, there are no improved cultivars of bambara groundnuts in Mpumalanga, and possibly the rest of South Africa, hence these smallholder farmers depend on un-improved local landraces. The lack of improved cultivars and agronomic practices lead to low production and the potential loss of germplasm that have some useful traits. Moreover, the smallholder farmers tend to keep the landraces that appeal to them, in terms of either yield or taste, hence there is the potential danger that landraces that are low-yielding and/or have poor taste but with other useful attributes may be lost. Therefore collection, identification and characterization of local landraces from various agro-ecological areas of the Mpumalanga Province is necessary. Morphological and physiological characterization may help in identifying important traits that might be used in future crop improvement programmes. Moreover, identification of such traits may lead to preservation of landraces with low yields and poor taste that would otherwise be lost through farmer-based selection process.

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1.2 Hypotheses

- There is genotypic variation in morphological and physiological traits of bambara groundnut landraces.
- There is genotypic variation in growth and yield of collected bambara landraces
- The genotypic variation in morphological and physiological traits, and growth and yield of the landraces is associated with geographic distribution of the landraces.
- There is genotypic variation in drought resistance amongst the bambara groundnut landraces.

1.3 Objectives

The general objective of this study was the morpho-physiological characterisation of bambara groundnut landraces obtained from different agro-ecological regions of the Mpumalanga province of South Africa. The specific objectives were to assess the:

- Genotypic variation in morphological and physiological traits of landraces collected from Mpumalanga Province.
- Genotypic variation in growth and yield of collected landraces
- Association of variation in measured parameters with geographic origin of the landraces
- Genotypic variation in drought resistance amongst the bambara groundnut landraces

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CHAPTER 2

Literature review

2.1 Origin, botany, and distribution of Bambara groundnuts

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) belongs to the family Papilionaceae (FAO, 1982), and is related to cowpeas. The genus Vigna (Family Leguminosae) is an important legume taxon (Odongo *et al.*, 2015) and comprises of about 90 described species of which seven species are cultivated as economic crops in various regions. Bambara groundnut is the third most important legume in Africa after peanut and cowpea. It is an annual, creeping leguminous plant whose growth habit is spreading or branched type (Linnemann, 1994). The spreading types are cross pollinating while the bunched types are self-pollinating. The morphological structure matches that of groundnuts (*Arachis hypogea)* in that it bears its fruits below the ground. The crop is a prostrate, herbaceous annual legume with a compact taproot system that is well developed with profuse geotropic lateral roots (Goli, 1997). Stem branching starts as early as about one week after germination and it has about 20 short branches on which the leaves and flower buds are borne (Goli, 1997). The leaves are trifoliate with a long, grooved and stiff petiole that is thickened at the base and exists in various colours from light green to dark green (Goli, 1997).

Bambara groundnuts are widely spread in Africa and have various names; each language and dialect has its variation. Bambara groundnuts have their origin from the African continent. Their centre of origin is thought to be Bambara, near Timbuktu in central Mali, West Africa hence their name Bambara Groundnut (Mkandawire, 2007). However, there is no unanimous agreement on the exact centre of origin of the crop (Mkandawire, 2007). It is an indigenous crop in Africa, mainly grown as a subsistence crop and to some degree for income generation (Mohammad Bannajan *et al.*, 2001). The crop has a large number of landraces throughout Africa, where small-scale farmers have preserved its genetic diversity on their farms; it is found in the wild from Central Nigeria eastwards to southern Sudan (Berchie *et al.*, 2012). Bambara groundnuts landraces are diverse in qualitative and quantitative traits (INCO-DC, 2000) and have significant differences in morphological and agronomic traits (Massawe *et al.*, 2005).

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2.2 Bambara groundnuts production

A study by the International Trade Centre estimated annual global production of Bambara groundnut at 330 000 tons of which half is produced in West Africa, (Burkina Faso, Nigeria, Cameroon and Mali) and the Democratic Republic of Congo (FAO-IDC, 2000). However, it is very difficult to establish accurate production figures from most of the African countries because the crop is mostly consumed at fresh stage and most of the trade is within communities and within villages as well as within countries. In South Africa, the major production areas for the crop are Limpopo, Mpumalanga, North West and KwaZulu-Natal Provinces (Swanevelder, 1998).

2.3 Nutritive value of Bambara groundnuts

The seeds are the edible part, which are consumed by humans and can be consumed in different forms, either in the immature green state or in matured form. However, at maturity the seeds become very hard and therefore require boiling before any specific preparation can be carried out. It is common knowledge that legume seeds generally require long cooking time for tenderization and the period varies from one legume to the other (Omoikhoje, 2008). The crop is important due to its high nutritional values (Table 1) and for soil improvement because of its nitrogen fixation properties (FAO, 1982).

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Table 1: Nutritional values of Bambara groundnuts.

Food Value	Value of edible portion
Calories	390kCal per 100g
Protein	17 -24%
Carbohydrates	17-69.3%
Fat	5.3 - 7.8%

Source: FAO, (2000)

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2.4 Climatic requirements

The production is best suited between latitude of 20° and 28° either side of the equator, i.e. the tropical wet and dry and the sub-tropical dry summer climate zones. Optimal mean temperature is between 19°C and 30°C (Swanevelder, 1998). Temperatures below 16°C and above 38°C are not suited for the production of bambara groundnuts. Bambara groundnut can be cultivated up to 1600m above sea level (Hepper, 1963). The bambara groundnut is very drought tolerant. The minimal annual rainfall requirement is about 300 mm and optimal annual rainfall is between 600 mm and 700 mm (Swanevelder, 1998). Too much rainfall at harvest might be detrimental to the crop. Photoperiod plays an important role in controlling the time and the rate of floral initiation and developments of plants (Linneman, 1993). Long photoperiods are reported to cause abscission of flower buds in Bambara and flower initiation is greatly enhanced by short day photoperiods. Findings by Linneman, (1993) confirmed that beginning of flowering, recorded as the number of days from sowing to the first open flower, was delayed by lengthening the photoperiod. It started 7 days later under 16 hours than under 10 hours, photoperiod caused a delay in the beginning of fruit development. Plants grown under 14 hour photoperiods continue leaf production much longer than plants grown in 10 or 12 hours photoperiods (Linneman, 1993).

2.5 Soil and fertilizer requirement

Optimal soils for bambara groundnut production are sandy loam soils to prevent water logging (Swanevelder, 2003). Optimal soil depth is between 50 and 100 cm, with a light soil texture. Soil fertility should be low, with soil pH between 5 and 6.5 but not lower than 4.3 or higher than 7 (Swanevelder, 2003). Fertilizer requirements for bambara groundnut is not clearly stated in literature but the chemicals composition of the plant serves as guide for quantities removed from the soil as indicated Table 2.

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Table 2: Quantities of macro-nutrients removed by bambara groundnut plant from the soil per 1000 kg seed

Element	Quantity removed (kg)
K	26.2
Mg	6.6
C	25.1
P	7.8
N	55.7

Source: Swanevelder, (1998)

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2.6 Bambara groundnut landraces

Bambara groundnut landraces have recognisable morphological futures, such as seed testa, colour, seed eye, texture of the seed and plant appearance (Swanevelder. 2003). Commonly, landraces have names based on place of origin, area where they are grown and colour of testa. Such methods of classification may lead to one landrace having more than a single name as a consequence of seed introduction to and from other places or the historical movement of people and their crops across the African continent without documentation. Massawe *et al*. (2005) defined a landrace as a variety with a high capacity to tolerate biotic and abiotic stress, resulting in high yield stability and an intermediate yield level under low input agricultural systems. Indeed, this is the case with Bambara groundnut landraces where growers either save their own seed for the next season or buy seed from the market; the mixing of seeds result in a completely different population.

The fact that individuals within a population vary in their yield performance, depending on vagaries of each season, means that the overall genetic composition of a landrace changes each year when the farmer grows crops from their own reserves (Massawe *et al.*, 2005). The variation available in bambara groundnut landraces is of great value in stressful environments and low-input farming systems. However, to exploit this genetic variation characterisation of local landraces is necessary (Berchie *et al.*, 2012). Although line development and hybridization are important, this study focused on physio-morphological characterization of landraces collected in the Mpumalanga Province and evaluated the agronomic performance of promising selected superior individual landraces selected.

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2.7. Genotypic variation in drought resistance

Agronomically drought is defined as insufficient availability of moisture in the soil for optimum plant growth and development (Singh, 1998). Drought resistance is a general term that refers to several methods of survival under drought such as water stress avoidance, dehydration avoidance and dehydration tolerance (Bartels and Ingram, 1999). The timing of drought stress differs within locations but may be classified as early season, late season or where crops are grown under residual moisture (Calhoun and Jones, 1994).

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The development of drought is dynamic in its nature and can occur at different periods of the crop cycle, and with different intensities. Consequently, plants have developed various strategies in response to drought; these may vary depending on species, genotypes, the type of drought, and the combination with other stresses, such as high temperature or evaporative demand. Indeed, several studies have reported genotypic variation in drought resistance in bambara groundnuts and other crops. For example, Mabhaudhi and Modi (2013) showed differences in adaptation to rainfed conditions within local Bambara landraces from KwaZulu-Natal, South Africa and concluded that the better adapted landrace selections probably had drought-avoidance mechanisms. Similarly, Nyabundi *et al.*, (1995) reported differences in performance within local bean (*Phaseolus vulgaris*) landraces in Kenya under different watering regimes. Landrace collections from low rainfall zones performed better than those from high rainfall zones under both high and low water regimes, suggesting some innate genetically determined adaptation in these landrace genotypes (Nyabundi *et al.*, 1995). Genotypic differences in drought resistance, associated with differences in relative water content (RWC) and osmotic adjustment have also been reported in pigeon pea in diverse environments (Subbarao *et al.*, 2000; Nandwal *et al.*, 1993).

2.8. Effect of genotype on morphological and physiological traits

Genotypic variation in morphological and physiological characteristics has been reported in a number of crops. Initial studies in Mpumalanga resulted in the identification of two landraces Brainbeck (MPB51) for higher yield and MPB39 for tolerance to *Alectra vogelli* plant parasite (Mathews 2010). The studies however, were limited to yield and tolerance to *Alectra* plant parasite. Although no significant differences within local bambara landrace selections on stomatal conductance and chlorophyll content were reported, the reduction in these traits due to water stress varied with the selections (Mabhaudhi and Modi, 2013). Talebi., *et al.* (2013) reported that there was wide variation in tolerance to drought stress among chickpea genotypes and that drought-tolerant genotypes had higher relative water content, chlorophyll and carotenoid concentrations and larger K+ accumulation compared to Na+. In a field experiment under rainfed conditions, Ogola and Nethanani (2013) found that RWC and stomatal conductance varied with genotypes in pigeon pea. In earlier studies, differences in leaf water potentials, solute potentials and RWC (Runkulatile., *et al.,* 1993) as well as stomatal conductance and rooting capacity (Nyabundi., *et al.*, 1995) were observed within bean landraces in Kenya. It is clear from the foregoing that there exists wide genotypic variability in

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the morphological and physiological traits amongst bambara landraces and other crops. Therefore there is need to characterize landrace collections from different regions and identify landraces with traits that might be beneficial in crop improvement programmes.

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CHAPTER 3

Material and Methods

3.1 Introduction

Seeds of locally grown landraces of Bambara Groundnut (*Vigna subterranean* L. Verdc) were collected from smallholder farmers in Mpumalanga Province. A total of 27 landraces were collected from the following places: Bosfontein (1), Bushbuckridge (1), Mashishing (3), Matsulu (2), Nelspruit-LRU (8), Msholozi (3), Nkangala (2), Nkomazi (1), Ntunda (3) and Sandriver (3). The names and collection sites of the landraces are given in Table 3 and Figure 1, respectively.

3.2 Experimental sites

This study comprised of two experiments, first experiment was a pot experiment, and the second a field trial. The pot experiment was conducted under a rain-shelter at the University of Venda, Thohoyandou (latitude 22º58´S and longitude 30º26 ´E; 596 m above sea level), Limpopo Province. The field trials were carried out in Mpumalanga Province. In Mpumalanga, the study was conducted in Nelspruit (25º45´S and 30º97´E; 660 m above sea level) and Mzinti research station (25°12´S and 31°12´E, 350 m above sea level) for two seasons (2013 / 2014). Field data for 2012 / 2013 season was not used due high rainfalls which lead to crop loss after flowering in Mzinti and pods loss due to pod rot in Nelspruit.

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3.3 Experimental design

3.3.1 Experiment I

This was a pot experiment conducted in a rain shelter. The experimental arrangement was a split-plot, with watering regime, low watering regime(LWR) and high watering regime(HWR) being the main factor and landrace (ZM-4, Ntunda-2, Nkangala-2, Nkomazi-1 and MPB 51) being the sub-plot factor, arranged in a randomised complete block design with three replicates. The five landraces were selected from 2013 season trials. The watering regime treatments were imposed at 14 days after planting (DAP) until at physiological maturity. Five hundred millilitre of water was supplied daily for control plants (HWR) and 500 ml (LWR) of water supplied once every 5 days until maturity stage.

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3.3.2 Experiment II

This was a field trial conducted in Mpumalanga Province. The 27 bambara landraces (Nkomazi-1, Zm-1, Bushbuckridge-1, MPB 51, Sb7-1, Bosfontein-1, Msholozi-1, Zm-4, Ntunda-1, Sandriver-1, Matsulu-1, Nkangala-2, Msholozi-2, Sandriver-3, Mashishing-3, Brainbeck-2, Zm-6, Ntunda-2, Matsulu-3, Nkangala-3, Mashishing-2, Brainbeck-3, Zm-5, Ntunda-4, Sandriver-2, Msholozi-3 and Mashishing-4) were arranged in a Randomised Complete Block Design (RCBD) and replicated three times. Each experimental plot consisted of 4 rows 0.5 m apart. The seeds were drilled along the rows and seedlings thinned at 14 days after emergence (DAE) to give the target plant population of 10 plants per m².

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Table 3: List of the studied landraces along with their place of collection

No	Origin	Name
1	NKOMAZI	NKOMAZI-1
2	LOWVELD RESERCH UNIT (LRU)	ZM-1
3	BUSHBUCKRIDGE	BUSHBUCKRIDGE-1
4	NKANGALA	MPB 51
5	MZINTI	SB7-1
6	BOSFONTEIN	BOSFONTEIN-1
7	MSHOLOZI	MSHOLOZI-1
8	LOWVELD RESERCH UNIT (LRU)	ZM-4
9	NTUNDA	NTUNDA-1
10	SANDRIVER	SANDRIVER-1
11	MATSULU	MATSULU-1
12	NKANGALA	NKANGALA-2
13	MSHOLOZI	MSHOLOZI-2
14	SANDRIVER	SANDRIVER-3
15	MASHISHING	MASHISHING-3
16	LOWVELD RESERCH UNIT (LRU)	BRAINBECK-2
17	LOWVELD RESERCH UNIT (LRU)	ZM-6
18	NTUNDA	NTUNDA-2
19	MATSULU	MATSULU-3
20	NKANGALA	NKANGALA-3
21	MASHISHING	MASHISHING-2
22	LOWVELD RESERCH UNIT (LRU)	BRAINBECK-3
23	LOWVELD RESERCH UNIT (LRU)	ZM-5
24	NTUNDA	NTUNDA-4
25	SANDRIVER	SANDRIVER-2
26	MSHOLOZI	MSHOLOZI-3
27	MASHISHING	MASHISHING-4

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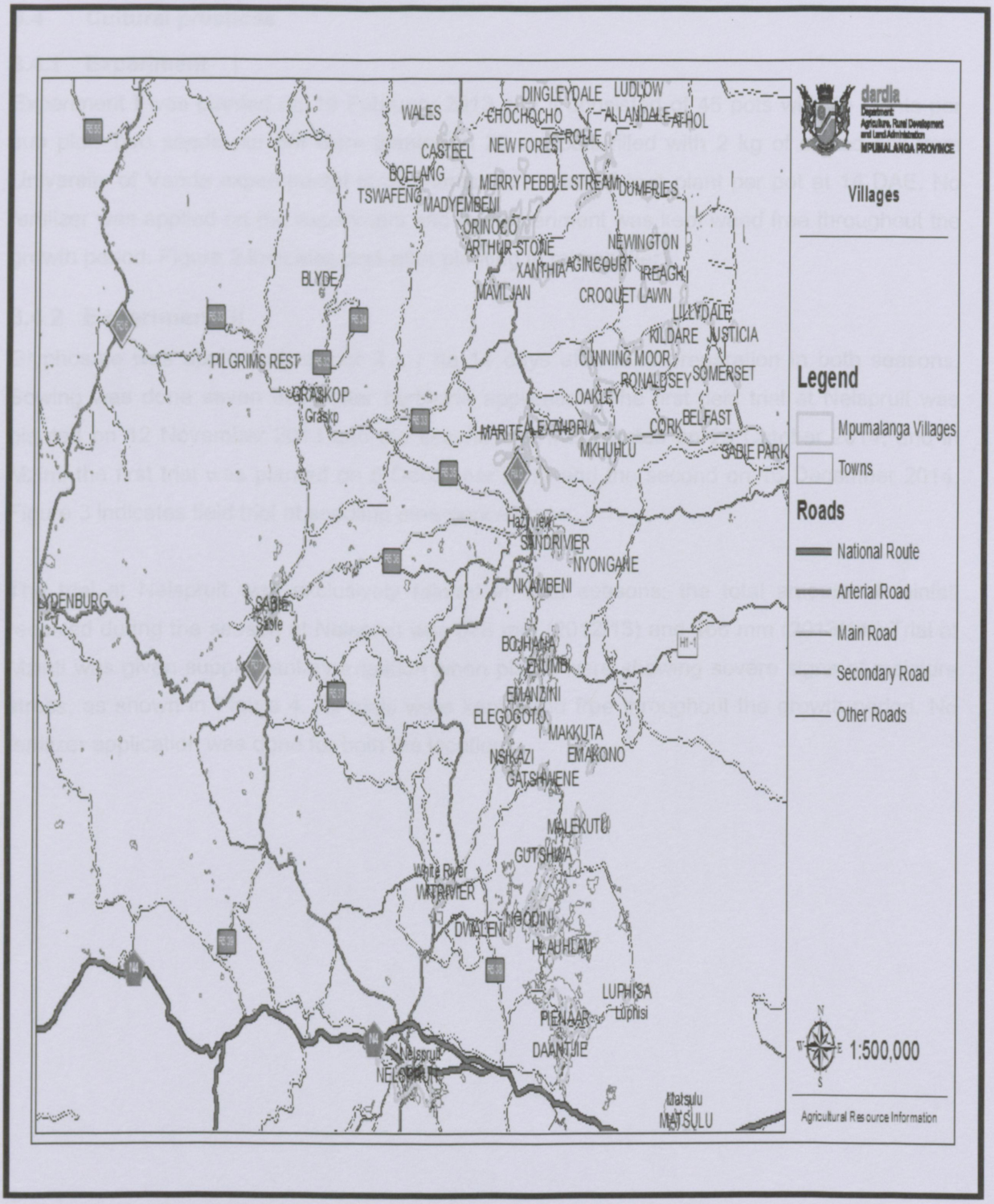


Figure 1: Map of Mpumalanga villages with landraces collection sites

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3.4 Cultural practices

3.4.1 Experiment I

Experiment I was planted on 19 February 2013 and it consisted of 45 pots with 15 plants per sub plot. Two seeds per pot were planted in 20 cm pots filled with 2 kg of sieved soil from University of Venda experimental farm. Plants were thinned to 1 plant per pot at 14 DAE. No fertilizer was applied on the experiment and the experiment was kept weed free throughout the growth period. Figure 2 indicates pots after planting in rain shelter.

3.4.2 Experiment II

Glyphosate was applied at rate of 3 L / ha 14 days after land preparation in both seasons. Sowing was done seven days after herbicide application. The first field trial at Nelspruit was planted on 12 November 2013 and the second trial was planted on 29 October 2014, and in Mzinti the first trial was planted on 5 December 2013 and the second on 16 December 2014. Figure 3 indicates field trial at seedling emergence stage.

The trial at Nelspruit was exclusively rainfed in both seasons; the total amount of rainfall received during the season at Nelspruit was 578 mm (2012/13) and 466 mm (2013/14.) Trial at Mzinti was given supplementary irrigation when plants were showing severe signs of moisture stress, as shown in Figure 4. All trials were kept weed free throughout the growth period. No fertilizer application was done for both the locations.

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Figure 2: Pots at University of Venda under rain shelter

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Figure 3: Field sprayed with pre emergence herbicides at seedling emergence stage at Nelspruit

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Figure 4: Field trial under sprinkler irrigation at University of Venda experimental farm

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3.5 Measurements

3.5.1 Experiment I

In experiment I, leaf chlorophyll content and stomatal conductance were measured. Chlorophyll content was measured weekly between 30 and 60 DAP using chlorophyll content meter (CCM-200 Plus Opti-Sciences, Tyngsboro Massachusets). The readings were taken from bambara groundnut plant marked mid leaf, between 11h00 and 13h00 on each occasion. Stomatal conductance was measured using Leaf Porometer (Decogon Devices Manufacturers model vision 6) weekly between 30 and 60 DAP. Stomatal conductance readings were taken on the upper and lower surface of the mid-leaf of the marked bambara groundnut plant on each occasion between 11h00 and 13h00.

3.5.2 Experiment II

Measurements were according to Descriptors of bambara groundnut (IPGRI/IITA/BAMNET, 2000). The following quantitative traits were measured at different stages of the crop: days to 50% emergence (50% DTE), days to 50% flowering (50% DTF), number of leaves, 100 seeds weight, number of seed per pod and grain yield. Days to 50% emergence were recorded by counting from day of planting until 50% of the plants had emerged in a plot. Seedlings were considered to have emerged when they had two to three fully expanded leaves that had broken free from the soil. Days to 50% flowering were counted from day of planting until half of the plants in a plot had flowered (50% DTF). Numbers of leaves were counted at 31 and 38 DAP (vegetative stage) and 61 and 68 DAP (reproductive stage). Days to maturity was defined in terms of physiological maturity (when at least 50% of leaves in at least half of the plants had senesced in a plot) as depicted in Figure 5. 100 Seed Weight with moisture content of 12% was measured after shelling. Numbers of seeds per pod from five randomly selected matured plants were counted during shelling. Plant height, petiole length (cm) and mid-leaf petiole length (mm) were measured at 61 and 68 day after planting from five randomly selected plants in each plot. The above ground biomass of five randomly selected plants was weighed in (g) after oven draying for 12 hours.

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Figure 5: Bambara groundnut at physiological maturity stage at Nespruit

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3.6 Data analysis

Data obtained were subjected to analysis of variance (ANOVA) using GenStat version 17 and Minitab version 17. Separation of means was performed using standard error of means (SEM) and least significant difference (LSD) at p≤ 0.05. Minitab was used because the GenStat licence expired before all data analysis was completed.

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CHAPTER 4

Results

4.1 Crop phenology

4.1.1 Day to 50% emergence

There were variations in 50 % DTE emergence among the landraces at Mzinti and Nelspruit (Table 4). The differences in emergence days observed was 8 – 14 DAP at Mzinti and 10-13 DAP at Nelspruit. The earliest landraces to emerge at Mzinti were Ntunda-4 (8 DAP) followed by Bushbuckridge-1, Ntunda-1, Sb7-1, Msholozi-2, Zm-5 and Msholozi-3 (9 DAP), Mashishing-3 and Zm1 emerged at 14 DAP. In contrast at Nelspruit the earliest were Nkomazi-1, Zm-1, MPB 51, Sb7-1, Bosfontein-1, Sandriver-1, Nkangala-2, Sandriver-3, Matsulu-3, Brainbeck-3 and Msholozi-3 (10 DAP) and emergence of 14 DAP was observed on Msholozi-3.

4.1.2 Days to 50% flowering

Days to 50% flowering differed amongst the landraces at Nelspruit and Mzinti (Table 4). On days to 50% flowering at Mzinti, Nkomazi-1 flowered first at 40 DAP, Sandriver-3 flowered second at 41 DAP, Msholozi-1 flowered last at 47 DAP. In Nelspruit early flowering was observed on Sandriver-1, Nkangala-3, Msholozi-1 and Brainbeck-2 (43 DAP) and Brainbeck-3 flowered at last (47 DAP).

4.2 Crop growth

4.2.1 Number of leaves

No significant differences were observed on number of leaves 30 days after planting in both seasons at both sites. Though, number of leaves per plant generally did not differ within landraces, Matsulu-1 produced more leaves at Mzinti whereas at Nelspruit, the greater number of leaves was accumulated by Bosfontein-1 landrace (Table 4). At Mzinti the number of laves ranged from 23 to 30 and Nelspruit leaves numbers ranged from 25 to 30. The number of leaves varied with location e.g.Zm-1 in Mzinti scored the lowest number of leaves (23) and in Nelspruit Zm-1 scored the highest number of leaves (30).

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Table 4: Phenology and growth components from two locations for season 2014/15

	Locations					
	Mzinti			Nelspruit		
	PARAMETERS					
Entries	50% Emergence	50% flowering	Number of leaves	50% Emergence	50% Flowering	Number of leaves
Nkomazi-1	11^{d}	40^{j}	29	10^{f}	45	29
Zm-1	14^{a}	44^{e}	23	10^{f}	46	30
Bushbuckridge-1	9^{f}	44^{e}	25	11^{g}	45	28
MPB 51	13^{b}	43^{f}	26	10^{e}	46	27
Sb7-1	9^{f}	46^{c}	27	10^{e}	45	29
Bosfontein-1	10^{e}	44^{e}	28	10^{e}	44	31
Msholozi-1	12^{c}	47^{a}	30	12^{c}	43	28
Zm-4	13^{b}	44^{e}	25	13^{b}	44	27
Ntunda-1	9^{f}	46^{c}	26	11^{d}	45	29
Sandriver-1	11^{d}	42^{h}	29	10^{f}	43	29
Matsulu-1	10^{e}	46^{c}	31	13^{b}	44	29
Nkangala-2	11^{d}	44^{e}	24	10^{e}	45	29
Msholozi-2	9^{f}	45^{d}	26	12^{d}	45	27
Sandriver-3	13^{b}	41^{i}	24	10^{e}	45	28
Mashishing-3	14^{a}	45^{d}	27	13^{b}	45	29
Brainbeck-2	11^{d}	45^{d}	27	13^{b}	43	25
Zm-6	13^{b}	45^{d}	24	11^{d}	44	26
Ntunda-2	10^{e}	46^{c}	21	12^{c}	44	26
Matsulu-3	11^{d}	44^{e}	25	10^{f}	45	29
Nkangala-3	12^{c}	43^{f}	29	11^{d}	43	27
Mashishing-2	10^{e}	46^{c}	28	13^{b}	45	28
Brainbeck-3	12^{c}	46^{c}	26	10^{e}	47	27
Zm-5	9^{f}	44^{e}	27	13^{b}	45	27
Ntunda-4	8^{h}	44^{e}	29	11^{d}	44	26
Sandriver-2	12^{c}	44^{e}	26	12^{c}	45	26
Msholozi-3	9^{f}	46^{c}	26	10^{e}	44	28
Mashishing-4	13^{b}	44^{e}	30	14^{a}	45	26
SE	0.56	0.47	2.02	0.37	0.85	1.55
F-test	***	***	Ns	***	Ns	Ns
R-squared(%)	80.62	85.15	39.25	86.65	34.52	31.61

*ns-Not significant, *-significant at p≤ 0.05, **-significant at p ≤0.01 and ***- significant at p ≤ 0.001* .Means on the same column having the same letter are not significantly different

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4.3 Crop physiology

4.3.1 Stomatal conductance

There were no significant differences in the stomatal conductance within the bambara landraces. However landraces had no consistency in upper and lower leaf surface stomatal conductance, Ntunda-2 had the highest at (30 DAP) and at (40 DAP) was the second lowest after MPB 51.The effect of watering regimes on stomatal conductance was significant at 50 DAP but not at 30 DAP and 40 DAP. The highest stomatal conductance was observed at high watering regime while the lowest was observed at low watering regimes (Table 5). Stomatal conductance of landraces indicates that landraces differed in response to water levels at different growth stages. This is in conformity with the findings of Mabhaudhi and Modi (2013) which states that among the responses of Bambara groundnut (*Vigna subterranea* L. Verdc.) to limited water availability were through stomatal closure.

4.3.2 Chlorophyll content

There were significant responses of chlorophyll content to watering regimes at 60 DAP and 70 DAP, but not at 30 DAP, 40 and 50 DAP (Table 6). Where significance was observed, water regime II increased leaf chlorophyll content as compared to water regime I. Highest chlorophyll content levels were observed in landraces Zm-4 (35.5 mmol cm^{-2} s^{-1}) and MPB 51 (35.3 mmol cm^{-2} s^{-1}) at 40 DAP. All the landraces had their highest chlorophyll content at different periods. For example, Nkomazi-1 had highest chlorophyll content at 50 DAP, Nkangala-2 at 30 DAP, Ntunda at 30 DAP, Zm-4 at 40 DAP. Brainbeck had highest chlorophyll levels at 40 DAP and 50 DAP. Lowest chlorophyll levels were observed on MPB 51 at 60 DAP and Zm-4 at 60 DAP. All landraces had their lowest chlorophyll content levels at 70 DAP when the crop reach maturity.

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Table 5: Mean stomatal conductance of five Bambara landraces measured from the upper and lower leaf surfaces at vegetative and reproductive stages (mmol H_2O m^{-2} s^{-1})

	SC1a	SC1b	SC2a	SC2b	SC 3a	SC 3b
ENTRIES	**30 DAP**		**40 DAP**		**50 DAP**	
ZM- 4	26.2	17.4	21.6	22.9	19.4	21.3
NTUNDA-2	29.4	24.3	12.4	11.2	16.4	23.2
NKANGALA-2	27.9	16.8	16.2	30.1	20.7	27.6
NKOMAZI-1	19.3	12.8	16.2	29.3	19.1	14.5
MPB 51	26.9	12.1	12.2	20.6	15.0	12.0
LSD (0.05)	31.02	16.69	18.51	27.83	20.88	20.84
WATER REGIME						
Low water regime	30.1	16.7	14.4	17.3	9.2^{b}	12.5^{b}
High water regime	21.7	16.7	17.3	28.3	27.1^{a}	27.0^{a}
LSD (0.05)	31.02	16.69	18.51	27.83	20.88	20.84
F-test probability						
VARIETY (V)	ns	ns	ns	ns	ns	ns
WATER REGIME (W)	ns	ns	ns	ns	*	*
V*W	ns	ns	ns	ns	ns	ns
CV (%)	18.4	9.1	16.9	32.4	17.8	3.9

ns-Not significant, *-significant at p≤ 0.05

Means on the same column having the same letter are not significantly different

DAP = Days after planting
SC = Stomatal Conductance
SCa = Upper leaf surface
SCb = Lower leaf surface

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Table 6: Effect of watering regime and landrace on chlorophyll content (mmol cm^{-2} s^{-1})

Entries	CHL 1 (30 DAP)	CHL 2 (40 DAP)	CHL 3 (50 DAP)	CHL 4 (60 DAP)	CHL 5 (70 DAP)
Zm-4	26.1	35.5[a]	26.4	20.5	11.9
Ntunda-2	25.7	17.4[c]	22.5	17.1	14.9
Nkangala-2	27.4	24.3[b]	25	20.5	12.5
Nkomazi-1	25	23[b]	29.1	19.7	16.4
MPB 51	27.1	35.3[a]	33.5	23.9	16.1
LSD (0.05)	14.18	8.91	8.93	16	11.04
WATER REGIMES					
Low	26.6	27.6	27.5	13.3[b]	9.3[b]
High	25.9	26.6	27.1	27.4[a]	19.4[a]
LSD (0.05)	8.97	5.63	5.65	10.12	6.98
F-test probability					
VARIETY (V)	ns	***	ns	ns	ns
WATER REGIME (W)	ns	ns	ns	*	*
V*W	ns	ns	ns	ns	ns
CV (%)	5.9	11.6	9.4	19.8	9.9

ns-Not significant, **-significant at p≤ 0.05, and ***- significant* at p ≤ 0.001
Low water regime (Watered once in five days) High water regime (Watered daily)
Means on the same column having the same letter are not significantly different

DAP- Days after planting
CHL= Chlorophyll Content

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4.4 Yield components

4.4.1 Number of pods

The number of pods per plant varied significantly within the landraces in Mzinti ($p \leq 0.001$) and at Nelspruit ($p \leq 0.01$) in 2014/15 season (Table 7). At Mzinti, the range was from 7 to 13 pods per plant. The highest number of pod per plant was obtained on Zm-4 at 13 and Nkomazi-1 at 12 pods per plant. The landrace that scored the least number of pods per plant of 7 was Brainbeck-3. At Nelspruit, the range was 6 to 14 pods per plant, the landrace that scored the uppermost number of pods per plant was Msholozi-2 at 14 pods per plant and the smallest number was observed on Zm-4 with 6 pods per plant.

4.4.2 100 seed weight

The 100 seed weight varied significantly ($p \leq 0.001$). At Mzinti, the range was from 50 g to 86 g (Table 7). Landrace Sandriver-2 produced heavier kernels of 86 g, Mashishing-2 and Nkangala-3 had the least average weight of 50 g. However, at Nelspruit the highest mean 100 seed weight (86 g) was obtained by Brainbeck-3 which was significantly different from Zm-4 which produced the lowest seed weight (40 g). The highest chlorophyll content levels were observed in landraces Zm-4 but that was not translated to seed weight.

4.4.3 Dry biomass

The results from this study revealed significant difference amongst landraces e.g. crop biomass varied within landraces at both Mzinti and Nelspruit, respectively (Table 8). At Mzinti the average range was from of 110 g to 298.33 g and at Nelspruit the range was from 75 to 291.67 g The highest average dry biomass was recorded by landraces Ntunda-4 (59.66 g per plant), Zm-5 (57.66 g per plant) and Matsulu-1 (41.66 g per plant) at Mzinti and at Nelspruit Matsulu-3 (58.33g per plant), Sandriver-3 (55.34 g per plant) and Ntunda-2 (48.66 g per plant) accumulated more dry biomass (Table 8).

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4.4.4 Dry pod weight

Significant difference ($p \leq 0.05$) in dry pod weight was only observed at Mzinti and not at Nelspruit (Table 8). At Mzinti, the average range was from 88.33 g to 168.33 g. At Mzinti the landraces Sandriver-1 and Sandriver-2 had the highest dry pod weight of 33.66 g per plant and the lowest dry pod weight was observed in Ntunda-4 and Zm-5 at the of 17.66 g. At Nelspruit although there was no significant difference, average range was from 25 g to123.33 g, the highest dry pod weight was observed on Brainbeck-2 at 24.66 g and the lowest on Sb7-1 at 5 g per plant.

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Table 7: Number of pods and seed weight for two trial sites in 2014/15 season

	Locations			
	Mzinti		Nelspruit	
	PARAMETERS			
Entries	Number of Pods/ plant	100-seed weight (g)	Number of Pods/plant	100-seed weight (g)
Nkomazi-1	64^{a}	78^{k}	32^{r}	83^{b}
Zm-1	57^{e}	80^{f}	46^{f}	79^{f}
Bushbuckridge-1	58^{d}	80^{f}	36^{p}	81^{d}
MPB 51	60^{c}	80^{f}	60^{b}	80^{e}
Sb7-1	54^{h}	78^{k}	40^{m}	78^{h}
Bosfontein-1	52^{j}	79^{j}	44^{i}	74^{k}
Msholozi-1	41^{o}	71^{n}	29^{t}	67^{l}
Zm-4	65^{a}	76^{l}	29^{t}	40^{p}
Ntunda-1	55^{g}	81^{e}	38^{n}	78^{h}
Sandriver-1	52^{j}	81^{e}	42^{k}	82^{c}
Matsulu-1	53^{i}	51^{p}	48^{d}	51^{m}
Nkangala-2	56^{f}	75^{m}	45^{h}	78^{h}
Msholozi-2	49^{k}	80^{f}	68^{a}	80^{e}
Sandriver-3	44^{m}	52^{o}	46^{f}	51^{m}
Mashishing-3	52^{j}	82^{d}	33^{q}	74^{k}
Brianbeck-2	39^{p}	79^{j}	45^{h}	79^{f}
Zm-6	46^{l}	78^{k}	41^{k}	77^{i}
Ntunda-2	53^{i}	84^{b}	41^{l}	49^{n}
Matsulu-3	43^{n}	81^{e}	37^{o}	79^{f}
Nkangala-3	40^{o}	50^{q}	44^{i}	48^{o}
Mashishing-2	46^{l}	50^{q}	31^{s}	80^{e}
Brainbeck-3	35^{s}	83^{c}	43^{j}	86^{a}
Zm-5	36^{r}	82^{d}	47^{e}	81^{d}
Ntunda-4	38^{q}	79^{j}	36^{p}	80^{e}
Sandriver-2	53^{i}	86^{a}	32^{r}	76^{j}
Msholozi-3	39^{p}	79^{j}	40^{m}	77^{i}
Mashishing-4	52^{j}	80^{f}	52^{c}	78^{h}
SE	5.21	0.47	6.14	0.96
F-test probability				
Genotype	***	***	**	***
R-squared (%)	56.18	99.62	51.27	98.83

*ns-Not significant, *-significant at p≤ 0.05, **-significant at p ≤0.01 and ***- significant at p ≤ 0.001*

Means on the same column having the same letter are not significantly different

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Table 8: Dry biomass and dry pod weight per plant for two localities in 2014/ 15 season

	Locations			
	Mzinti		Nelspruit	
	PARAMETERS			
Entries	Above ground Biomass (g)	Dry Pod weight (g)	Dry Biomass (g)	Dry Pod weight (g)
Nkomazi-1	158.33^{d}	108.33^{s}	146.67^{q}	88.33
Zm-1	133.33^{l}	95^{o}	240^{d}	41.67
Bushbuckridge-1	183.33^{e}	90^{p}	106^{t}	46.67
MPB 51	108.33^{j}	95^{z}	198.33^{j}	65
Sb7-1	110^{r}	103.33^{l}	182.5^{m}	25
Bosfontein-1	181.67^{f}	110^{i}	196.67^{j}	65
Msholozi-1	136.67^{j}	95^{o}	190^{l}	60
Zm-4	163.33^{b}	125^{o}	157.67^{p}	75
Ntunda-1	101.67^{v}	108.33^{j}	170^{n}	116.67
Sandriver-1	168.33^{a}	115^{q}	226.67^{f}	63.33
Matsulu-1	208.33^{c}	160^{c}	228.33^{f}	26.67
Nkangala-2	135^{f}	126.67^{n}	211.67^{i}	47
Msholozi-2	106.67^{k}	105^{u}	140^{r}	56.67
Sandriver-3	136.36^{k}	103.33^{l}	276.67^{b}	68.33
Mashishing-3	111.67^{i}	98.33^{y}	220^{h}	85
Brian beck-2	113.33^{q}	96.67^{n}	195^{k}	123.33
Zm-6	148.33^{e}	106.67^{t}	179.33^{m}	45
Ntunda-2	205^{c}	165^{b}	243.33^{c}	40
Matsulu-3	163.33^{h}	115^{h}	291.67^{a}	98.33
Nkangala-3	138.33^{i}	111.67^{i}	168.33^{o}	36.67
Mashishing-2	146.67^{e}	100^{w}	123.33^{s}	38.33
Brian beck-3	123.33^{p}	111.67^{i}	171.67^{n}	76.67
Zm-5	228.33^{b}	88.33^{q}	75^{u}	53.33
Ntunda-4	298.33^{a}	88.33^{q}	190^{k}	31.67
Sandriver-2	168.33^{a}	130^{m}	140^{r}	35
Msholozi-3	188.33^{d}	98.33^{m}	240^{d}	58.33
Mashishing-4	171.67^{g}	158.33^{d}	232^{e}	96.67
SE	22	20.27	36.98	21.92
F-test probability				
Genotype	***	*	*	Ns
R-squared (%)	70.23	48.80	47.58	41.18

*ns-Not significant, *-significant at p≤ 0.05, **-significant at p ≤0.01 and ***- significant at p ≤ 0.001*

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CHAPTER 5

Discussion

5.1 Crop phenology

5.1.1 Days to 50% emergence

The earliest landraces to emerge at Mzinti was Ntunda-4 at 8 DAP and landraces that emerged late was Mashishing-3 and Zm1 at 14 DAP. And at Nelspruit the earliest were Nkomazi-1, Zm-1, MPB 51, Sb7-1, Bosfontein-1, Sandriver-1, Nkangala-2, Sandriver-3, Matsulu-3, Brainbeck-3 and Msholozi-3 at 10 DAP and late one was Msholozi-3 at 14 DAP. The difference in emergence days may indicate intra-landrace variability and different responses to environment. Similar observations in seedling emergence time were reported by Touré *et al*. (2012). The variation in crop emergence of bambara groundnut has also been observed by Mabhaudhi and Modi (2013) who reported that germination in bambara groundnut is often erratic and landraces often lack the same vigour as in hybrids or other improved selections.

5.1.2 Days to 50% flowering

Days to 50% flowering at Mzinti was significantly different and ranged between 40 and 47 days for all landraces. Days to 50% flowering were longer for landrace Msholozi-1 which was 47 days to 50% flowering as compared to other landraces. These variations may provide a basis for identification and selection of early maturing landraces. The variations observed in number of days to 50% flowering of the crop in different locations could be attributed to the differences in temperatures and availability of water. The number of days to flowering could be an indicator for biomass accumulation and partitioning (Mabhaudhi and Modi 2013). Early flowering may occur as a result of shortened vegetative growth due to moisture stress, high temperature and other environmental stresses. The landrace Nkomazi-1 which was the earliest to flower at 40 DAP, also accumulated the lowest average biomass of 108.33 g.

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5.2 Crop growth

5.2.1 Number of leaves

The number of leaves per plant did not differ amongst the landraces at 30 days after sowing both at Nelspruit and Mzinti. That could be perceived as an adaptive feature by plants to water stress because plants were rainfed. Mabhaudhi and Modi (2013) reported that moisture stress may lead to reduced number of leaves and plant growth under field conditions. Reduced growth duration is associated with reduced leaf number and could be one of the traits that serve as an adaptation strategy suitable for crop production in dry environments. Plants, by nature, are designed to reduce water use by reducing growth and number of leaves when confronted with water stress (Mabhaudhi and Modi 2013).

5.3 Crop physiology

5.3.1 Stomatal conductance

Though non-significant stomatal conductance varied with landraces, it was not significant. Previous studies have shown that groundnut maintained a high stomatal conductance at lower leaf potential as an adaptive response to drought attributed to turgor maintenance as well as osmotic adjustment (Jaleel *et al*, 2008). That could possibly be the case on landrace Nkangala-2. Moreover, MPB 51 had the least reading compared to other landraces in both the upper and the lower leaf stomatal conductance. MPB 51 may be using stomatal closure as a way of reducing the level of water usage under stress. This could be as a result of the landrace using physiological attributes such as aquaporins to ensure turgor maintenance and leaf temperature reduction in the presence of low levels of water in the soil.

The effect of watering regime on stomatal conductance was only significant at 50 DAP, the reason could be that the chlorophyll matter was already damaged. The effect of watering regime on stomatal conductance could be due to the effect of water stress on stomatal conductance. Increased leaf temperatures lead to the opening of stomata and therefore leading to an increased stomatal conductance which will lead to increased transpiration (Ogola and Nethanani 2013). Changes in stomatal opening are a primary, rapidly occurring effect of drought and heat stress in legumes. Legumes respond to water stress by closing stomata or causing irregular conductance and to high temperature stress by increasing stomatal conductance. Stomata are responsible for the flow of CO_2 fixed and water lost by plants. Closure of stomata

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reduces transpirational losses, thus minimizing water losses through transpiration. Stomatal closure is a plant's initial response to declining soil water content.

5.3.2 Chlorophyll content

Water requirement of a crop is dependent on the botanical characteristics of the crop, its stage of growth and the prevailing weather conditions. At two weeks after planting, the chlorophyll content was found not statistically significantly different. However, at 40 DAP there was a high significant difference in chlorophyll content between varieties. Zm-4 had the highest chlorophyll content of 35.5 mmol cm^{-2} s^{-1}, followed by MPB 51 with 35.3 mmol cm^{-2} s^{-1} Nkangala-1 24.3 mmol cm^{-2} s^{-1}, and the lowest were Nkomazi-1 (23 mmol cm^{-2} s^{-1}) and Ntunda -2 (17.4 mmol cm^{-2} s^{-1}). Reduced water decreased the chlorophyll content measurements at 70 DAP which ranged from 11.9 mmol cm^{-2} s^{-1} to 16.4 mmol cm^{-2} s^{-1}, although such decrease was observed only after an advanced period of stress. The findings are in agreement with findings that reduced water also decreases the photosynthetic electron transport and is indicated by chlorophyll fluorescence decrease observed only after an advanced period of stress (Sales *et al*., 2015). The implication might be negative to crop productivity if chlorophyll content is lowered at reproductive stage of the plant.

5.4 Yield components

All the landraces showed significant difference in most of the parameters such as 100 seed weight and crop biomass. However the differences in crop biomass were not reflected in 100 seed weight as expected. For example landrace Zm-5, had the highest crop biomass but failed to confer the advantage into seed weight, possibly due to poor harvest index. Similarly, the landrace Sandriver-2 had the lowest dry biomass but recorded the highest seed weight. The study results had higher seed weight compared to study by Madukwe *et al*., 2011, who reported seed weight ranging from 34.5 to 46.6 g. The reason for the variation could possibly be explained by differences in the environment under which the crops were grown.

Pod weight did not show any significant differences between landraces, indicating that the parameter was controlled mostly by environment and not the genotype. It suggested that all the varieties were affected by biotic or abiotic factors and failed to express their genetic potential, thus recording similar pod weight. The effect of water stress in bambara groundnuts and how it affects pod weight was also reported by Mabhaudhi and Modi (2013).

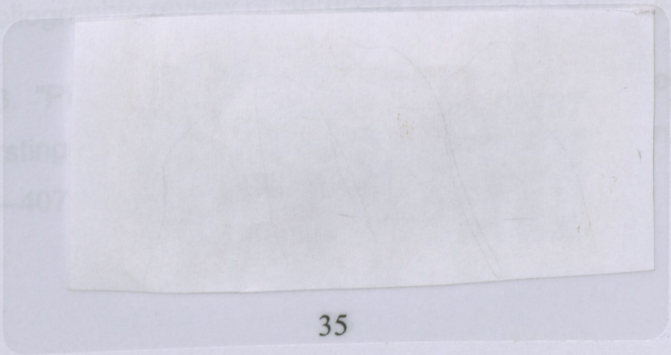
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CONCLUSION

The landraces showed variation in some of the yield components such as 100 seed weight, and crop biomass. Pod weight did not show any significant difference, indicating that the parameter was controlled mostly by environmental factors such as water stress and not the genotype. The landraces performed well in different ecological regions but showed variation in their response to different environment. The landrace Sandriver-2 and Matsulu-3 performed well in Nelspruit and Mzinti. However other landraces were area specific in terms of their performance. The performance of landraces may be linked to their area of origin, implying adaptation to those places. The study showed genetic variation among landraces and notable differences were shown in days to emergence, days to flowering, crop biomass and 100 seed weight. Good performance of the landraces Sandriver-2 and Matsulu-3 across all ecological regions makes them suitable for further evaluation under stress conditions and future climate change scenarios.

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