ASSESSMENT OF FARMER PREFERENCES, CONSTRAINTS AND AGRO-MORPHOLOGICAL VARIATION AMONG BAMBARA GROUNDNUT (*Vigna subterranea* (L.) Verdc.) ACCESSIONS AS A BASIS FOR SEED YIELD SELECTION INDEX

MASTER OF SCIENCE IN AGRICULTURE

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Abstract

Bambara groundnut (*Vigna subterranea* (L) Verdc) is an orphan, underutilised and less exploited crop in Africa and beyond, Yet, it is an essential traditional crop for the majority of local farmers. The first step in preparing such local germplasm for possible pre-breeding is to undertake a needs assessment study to find out what farmers have on their farms and what they would rather have as an improvement. After that, a pre-breeding program with appropriate breeding goals and objectives can be formulated. Currently, in Namibia, a pre-breeding or breeding program is yet to be put in place. Thus, objective one of this study was to investigate, using a survey instrument, constraints encountered by Bambara groundnut farmers and the farmers' preferred morpho-types that can be used in the breeding program. The ethnobotanical study was first done across five regions, targeting some key constituencies. Data were collected on varieties, descriptors, uses, preferences, crop improvement status, seed source, and production challenges. Chi-square test showed significant differences among farmers' preferences ($P \leq 0.05$) and crop improvement status ($P \leq 0.05$). The results also showed that farmers faced challenges, including susceptibility to insects and the use of low yielding, unimproved cultivar. Results further indicated that many farmers had different Bambara groundnut preferences, such as large seed size and high yield cultivar. The second objective focused on the evaluation of local and exotic Bambara groundnut germplasm. Twenty-five Bambara groundnut germplasm accessions were characterised and evaluated for diversity, using qualitative and quantitative traits. The experimental design was square lattice design replicated three times. For qualitative descriptors, data collected included seed eye colour pattern, seed coat colour, seed pattern, pod shape, pod colour, and pod texture. The Shanon Weiner Index showed high diversity, with an average value of 0.92. Also, a dendrogram indicated five clusters of similarity. Quantitative data were analysed using multiple analysis of variance, Pearson correlation moment, Principal Component Analysis (PCA), and dendrogram. Analysis of variance (ANOVA) indicated significant differences ($P \leq 0.05$) among accessions for the number of pods with two or more seeds, seed length, seed width, fresh pod weight per plant, dry pod weight per plant, 100 seed weight, shelling percentage, and harvest index. Other variables that were highly significant ($P \leq 0.01$) included the number of pods per plant, pod yield, seed yield, plant height, terminal leaflet width, terminal leaflet length, number of branches, fresh biomass, and dry biomass. Dendrogram sub-criterion indicated three clusters suggesting that few accessions were dissimilar, which was confirmed with Principal Component Analysis, showing that germplasm accessions with common traits were grouped into the same quadrant. For meaningful progress, crop breeding hardly focuses on a single trait at a time. Since crop yield is a polygenic traits, some breeders nowadays use a selection index technique for yield improvement. In this study, a selection index was constructed using yield traits as seed yield, biological yield, dry pod weight per plant, and fresh pod weight per hectare. The index based on three traits, namely seed yield, dry pod weight per plant, and fresh pod weight that had a GA of 41.23% and selection efficiency of 376%. This selection method for seed yield appears to be more effective and efficient compared to the conventional method, the straight selection method.

Keywords: Bambara groundnut, Crop improvement, Genetic diversity, Selection index, Namibia.

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Abbreviations and Acronyms

ANOVA - Analysis of Variance

CRS - Chitedze Research Station

DFA - Discrimination Function Analysis

PCA - Principal Component Analysis

DAPEES - Directorate of Agricultural Production, Engineering and Extension Services

DF - Degree of freedom

FAO - Food and Agriculture Organisation

MAWF - Ministry of Agriculture, Water, and Forestry

NBRI - Namibia Botanical Research Station

OMRS - Omahenene Research Station

PC - Principal Component

PRA - Participatory Rural Appraisal

UNAM - University of Namibia

SPSS - Statistical Package for the Social Sciences

SSA - Sub-Saharan Africa (SSA).

AM-FPs - Agro-morphological –Farmers Preferred

PGR - Plant Genetic Resources

GA- Genetic Advance

RE- Relative Efficiency

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Dedication

This thesis is dedicated to my husband Benhard Tshuutheni Nuuyoma, sons Jimmy Asser Nghidipohamba, Johannes Elago, Joel Tshipandeni, and only daughter Emilia Ndeutenge. To my parents for their love and dedication during the study.

Declaration

I, Johanna Shekupe Valombola, declare hereby that this study is a true reflection of my own research, and that this work or part thereof has not been submitted for a degree in any other institution of higher education. No part of this thesis/dissertation may be reproduced, stored in any retrieval system, or transmitted in any form or by means (e.g., electronic, mechanical, photocopying, recording, or otherwise) without the prior permission of the author, or The University of Namibia in that behalf.

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Student's name: Johanna Shekupe VALOMBOLA Signature: Date: 14/03/2020

CHAPTER 1

GENERAL INTRODUCTION

1.1 Orientation of the study

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an orphan, underutilised and less exploited crop in Africa and beyond. It is an edible grain legume crop indigenous to sub-Saharan Africa, which plays socio-economic roles in semi-arid regions of the sub-continent (Massawe, Mwale, Azam-Ali, & Roberts, 2005; Juliet, Vincenzo, Cathrine, & Anita, 2017). Although it is also grown in Asia, this crop originated from West Africa (Hillocks, Bennett, & Mponda, 2012). It is drought tolerant and commonly grown in semi-arid regions such as Namibia. The crop has been neglected by donors and researchers all over the world. Hence, this study is important for Namibia and Africa at large. In Africa, Bambara groundnut is ranked as the third most important legume after cowpea and groundnut (Ntundu, Inga, Christiansen, & Andersen, 2004). The major world producers are mainly West African countries such as Burkina Faso, Cameroon, Mali, and Niger (FAO, 2015).

In sub-Saharan Africa, agricultural production is limited by water scarcity, lack of improved crop varieties, and loss of genetic diversity (Massawe et al., 2002), increasing dependence on a few crops for food. Bambara groundnut needs crop improvement for genetic conservation and full utilisation. Currently, Bambara groundnut research is quite limited as compared to cereals (pearl millet, sorghum, and maize), pulses (peanuts and cowpeas), among others (Ouedraogo et al., 2008).

Namibia is a semi-arid country in southwestern Africa, where the Bambara groundnut is grown by 82% of subsistence farming households (Fleissner, 2006). The crop is mainly grown in northern regions of Omusati, Oshana, Oshikoto, Ohangwena, Kavango West, and Kavango East, where it is ranked as the second most crucial legume after cowpea. Although its grain yield level on the research station measured 400 to 600 kg/ha (Fleissner, 2006), the on-farm yield level is currently unknown and expected to be much lower.

In Namibia, like in most other African countries, the Bambara groundnut improvement program is currently non-existent; genotypes exist merely as landraces, which are informally classified and named according to areas of production and market. As a result, a single accession may be produced under different names or vice versa, resulting in some farmers cultivating materials of inferior genetic qualities with consequent persistently low yield. There is, therefore, a need to scientifically determine the genetic diversity of the local landraces to help improve production (Massawe et al., 2005) and maximise the income of subsistence women farmers. The first step in preparing such local germplasm for possible pre-breeding is to undertake a needs assessment study to find out what farmers have on their farm and what they would rather have as an improvement. After that, a pre-breeding program plan with the appropriate breeding goal and objectives can be formulated. Currently, in Namibia, either a pre-breeding or breeding is yet to be put in place.

Bambara groundnut is predominantly self-pollinating, thus expected to exist as nonidentical inbred-lines. However, in the past, the lack of co-dominant markers prevented the assessment of heterozygosity. Being marginalized, this crop is threatened by genetic erosion (Chivenge, Mabhaudhi, Modi, & Mafongoya, 2015). Genetic diversity within lines and populations is fundamental for breeding and germplasm conservation (Zhang, Jia, Meng, Ti, & Wang, 2015; Aliyu et al., 2016). Plant breeders need materials with minimum polymorphism to develop new genotypes (Ndiang et al., 2014). Therefore, collection, characterisation, evaluation, and storage of Bambara groundnut germplasm are major steps toward establishing a crop improvement program that would supply suitable parent materials.

1.2 Problem Statement

Bambara groundnut is a neglected and under-utilized crop possessing traits and properties that are of socio-economic importance; however, it is exploited and remained an orphan crop. There is currently a lack of scientific data concerning morphological and agronomic characteristics of Bambara groundnuts in Namibia. Previously, the crop has received little attention from research and development agencies, remaining associated with traditional knowledge through which seeds are selected from the previous harvest. This practice leads to genetic erosion and gradual loss of genetic diversity, reducing plant tolerance to biotic and abiotic stress, and weakening important agronomic traits such as yield. Although subsistence farmers produce Bambara groundnut at a reasonable quantity, their preferences, source of seeds, production status, and challenges are unknown by crop breeders. This information can be incorporated in the breeding program, as farmers from different areas or countries have different interests. This study determined farmers’ preferences regarding seeds and varieties of Bambara groundnut and its production status. The study also characterised and evaluated genotypic variation among different Bambara groundnut accessions for agro-morphological characters. Finally, The selection index for seed yield was created to help initiate a local crop improvement programme and popularise commercialisation of the crop.

1.3 Objectives of the study

1.3.1 General objective

Investigate the improvement needs and variation in farmers’ preferred Bambara groundnut (*Vigna subterranea* (L.) Verdc.) accessions for developing seed yield selection (SYS) index

1.3.2 Specific objectives

1. Assess Bambara groundnut grower needs related to variety improvement, preferences, production, seed source, utilisation, and constraints in terms of variables behind farmer preferred cultivars currently produced in Northern Namibia,
2. Determine diversity among local and imported Bambara groundnut cultivar based on agro- morphological characters, and
3. Develop a selection index for Bambara groundnut seed yield.

1.4 Hypotheses of the study

$H_{01:}$ The farmer responses on the currently cultivated (preferred) cultivars suggest no need for further improvement.

$H_{02:}$ The Bambara groundnut accessions used in the study are not phenotypically diverse.

$H_{03:}$ Selection indices do not make a significant contribution to Bambara groundnut seed yield.

1.5 Significance of the study

The needs assessment was the onset of the study to determine what the farmers prefer about Bambara groundnut as an underutilised crop. Bambara groundnut is one of the legume crops that is widely consumed by many household members in Namibia and Africa as a whole. However, there are limited studies conducted on the crop. Therefore, this is one of the few studies to characterise Bambara groundnut accessions in Namibia and evaluate their agronomic parameters. Data generated will be useful for plant breeders, contributing to high on-farm yield level and improved livelihoods of subsistence farmers.

1.6 Limitation of the study

Resources for this research were limited as there was no funding for the study. The experimental site equipment was limited and expensive, and the cost of the survey was very high and only limited Bambara groundnut germplasm accessions were assessed for genetic diversity.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bambara groundnut (*Vigna subterranean* (L.) Verdc.) is an annual, creeping leguminous plant, grown mainly for its edible seeds. It is the third most eaten legume after groundnut and cowpea in Africa (Omoikhoje, 2008). The crop originated from West Africa and has been cultivated throughout the drier tropical area of Africa. In Southern Africa, Zimbabwe is the centre of production. It can also be found in tropical parts of America, Asia, and Australia, but the present degree of cultivation outside Africa is negligible (Omoikhoje, 2008).

2.2 Bambara groundnut taxonomy and botanical description

The crop species *Vigna subterranea* (L.) Verdc. belongs to the genus *Vigna*, subgenus *Vigna*, Family *Fabaceae or Leguminosae*, subfamily *Faboideae*, tribe *Phaseoleae,* and subtribe *Phaseoline* (Baudoin and Mergeai, 2001; Bamshaiya et al., 2011). Bambara groundnut is herbaceous, intermediate, annual, the self-pollinating crop with creeping stems at ground level additionally, is a legume crop that grows to a height of 0.30–0.35 m with compound leaves of three leaflets. Flowering starts from 30 to 35 days after sowing depends on the variety and continues till the end of plant life. The sepal enlarges, and the fruit develops above or just below the soil surface, and the unripe pod is yellowish-green, while the mature pods vary in colour. The small pods are about 1–5 cm long, round or slightly oval-shaped and wrinkled with mostly one or sometimes two or more seeds. The seeds are round or oval up to 1,5 cm in diameter, smooth and very hard when dried with different colours range from are cream, brown, red, mottled, with or without hilum colouration. The leaves are trifoliate with ± 5 cm long and are attached to the stem by the petiole. The petioles are about 15 cm long, stiff and grooved, and are green or purple. The terminal leaflets of Bambara groundnut are larger than the lateral leaflets, with an average length of 6 cm and an average width of 3 cm (Goli, 1995; Tweneboah, 2000; DAFF, 2016).

2.3 Bambara groundnut origin and distribution

The centre of origin for Bambara groundnut *(Vigna subterranea* (L.) Verdc.*)* is West Africa–North-Eastern Nigeria, Northern Cameroon Africa, Central African Republic, and Chad. It is found in wild Central Nigeria eastward to Southern Sudan but has become widely distributed throughout the semi-arid zone of sub-Saharan Africa (SSA). Bambara groundnut, as a pulse in West Africa, was recorded in the 14th century (Hillock, 2012).

Bambara groundnut is adapted to hot, dry, marginal soils, from sea level to an altitude of 2 000 m. It grows in harsh conditions better than most crops such as sorghum, maize, and peanuts. Optimal conditions for growth are 30–35 °C day temperature for germination, average day temperatures ranging from 20 to 28°C under full sun, average annual rainfall of 600–750 mm, It requires good phosphorus and potassium soil content and light sandy loams with a pH of 5.0–6.5. *Vigna subterranea* can grow in more humid conditions (annual rainfall > 2000 mm), and in every type of soil provided it is well-drained and not too calcareous. It is tolerant to drought, to pests and diseases, particularly in hot conditions. In many traditional cropping systems, it is intercropped with other root and tuber crops (Brink, Ramolemana, & Sibuga, 2006).

2.4 Importance of Bambara groundnut

In sub-Saharan Africa, agricultural production is limited by water scarcity, lack of improved crop varieties, and loss of genetic diversity (Massawe et al., 2002), increasing dependence on a few crops for food. Bambara groundnut is an essential crop for semi-arid sub-Saharan small-scale farmers that have no access to irrigation, fertilisers, and extension services (Mabhaudhi et al., 2013). The Bambara groundnut became more critical in many parts of Africa, because of the expansion of its production, but in recent years, the interest has renewed for cultivation in the arid savannah zone. It is highly nutritious, containing 65% carbohydrate, 18% protein content, and 6.5% fat, making it a valuable food for poor people who cannot afford expensive animal protein (Tadele, 2009, Zerihun, 2009; Ndiang et al., 2014). In the subsistence settings, Bambara groundnut is mainly consumed as fresh grain, but it is also processed into flour. In Senegal, Bambara groundnuts are also used for the medicinal purpose (Hepper, 1963), while in Namibia, it is commonly sold by subsistence women farmers and hence regarded as a women cash crop. Despite its numerous benefits, the Bambara groundnut has been ignored by research and conservation entities (Mabhaudhi, Modi, & Beletse, 2013) and hence remains marginalised and underutilized. Bambara groundnut has many agronomic, morphological, medicinal, and nutritional properties, making it a suitable crop for plant breeding (Akpalu, Sarkdie-Addo, & Akpalu, 2012; Atoyebi, Oyatomi, Osilesi, Adebawo, & Abberton, 2017). It is resistant to high temperatures and drought and can fix nitrogen, and hence a valuable source of nutrition in dry areas with infertile soils.

2.5 Biotic and abiotic stress on Bambara groundnut

Bambara groundnut fruits are buried in the soil, which protects them from insect damage, unlike other legumes such as cowpea, common bean, and soybean, whose fruits are above ground and hence exposed to pests (Massawe et al., 2015). The primary diseases of Bambara groundnut are: i) Fusarium wilt, that attacks the young seedlings in wet weather, mainly under waterlogged conditions; ii) Cercospora leaf spot, on crops under irrigation; iii) in dry weather, pods are attacked by termites with severe attack resulting in the loss of an entire crop; iv) Root-knot nematode (*Meloidogyne javanica*) also attack the roots of the plant in sandy soils (Kankam & Adomako, 2014); and v) in storage, shelled Bambara groundnut seeds were susceptible to attack by bruchids (*Callosobruchus maculatus*). As reported by Hillock et al. (2012), most landraces were attacked by these bruchids, but the black-seeded landrace was affected less severely. The unshelled seeds were more resistant to bruchid attacks than shelled seeds (Hillock et al., 2012). According to FAO 2007, crop yield loss was about 75% annually due to abiotic stress. The abiotic stress such as drought which is a recurrent climatic phenomenon across the world affects Bambara produced.

2.6 Needs Assessment about farmers' preferred Bambara groundnut traits

To take advantage of launching a program based on Agro-morphological-farmer-preferences (AM-FP), a Needs Assessment is an important step that must come before the formulation of breeding goals. Needs assessment goes by several names, namely: Participatory Rural Appraisal, Rapid Rural Appraisal, Force field Analysis, SWOT depending on the type of survey or instrument desired in line with given objectives for the expected findings (Fleissner, 2006; Mukakalisa, Kandawa-Schulz, & Mapaure, 2006; Happy, Hussein, Lainga, Patrick, & Mponda, 2018). The expected findings will be useful for defining a production system that will be relevant to farmers' needs in terms of preferences and improvement of Bambara groundnut. A production system, in turn, will contribute a breeding plan toward a breeding objective (Abu & Buah, 2011).

Needs assessment survey is a crucial means to learn from rural farming communities about their perceptions and local needs (Chamber, 1994; Happy et al., 2018). In Namibia, research efforts on Bambara groundnut improvement are currently limited. For instance, local farmers use landraces of unknown genetic quality that may need further improvement. However, in many cases, the farmer-preferred cultivars tend to be persistently poor yielders (Happy et al., 2018). It is also associated with poor seed germination (Brink, Ramolemana, & Sibuga, 2006). Bambara groundnut without proper fertiliser such as potassium may lead to reduced crop establishment, particularly in the arid regions (Lineman and Azam-Ali 1993; Goli, 1995). In Swaziland, the yield reported was 649-1582 kg/ha, with annual rainfall between 633–728 mm/year (Fleissner, 2006). In Botswana, the yield reported was 68.5–159.9 kg/ha, under annual rainfall of 389–433 mm (Molosiwa, 2012). With suitable conditions, however, *Vigna subterranea* has a yield of the potential of 3ton/ha both in the field and controlled environments (Collinson et al., 1996, 1999, 2000; Mohammed., 2014). Correlation coefficient analysis that measures the degree and direction of the relationship among two or more traits has shown to be of great value for selecting yield, thus playing an influence on yield selection (Nath et al., 2014).

Seed colour may play an essential part in consumer and producer's preference (Pungulani, Kadyampakeni, Nsapato, & Kachapila, 2012; Abu & Buah, 2011). In Africa, for instance, consumers tend to prefer white and cream Bambara groundnuts with large size (Berchie et al., 2010), while in South East Asia, black and red landraces are preferred. In some African countries, the majority of farmers, >60% grow white landraces while about 10-15% cultivate black, cream, and red landraces. Dark-coloured Bambara groundnut seeds black and red are not preferred due to higher tannin content (Akpalu et al., 2013). The tannin content in Bambara ground is perhaps why Bruchids attack black-seeded Bambara groundnut types to a lesser extent.

On the above, research focus on AM-FPs will begin to have functional relevance to a farmer by which further progress is enabled the conventional phenotyping and/or genotyping by sequencing steps. In the preceding that a plant breeder can meaningfully collect information on phenotypes (e.g. agro-morphological), family relationship, and genetic (molecular-wise). After this, the data can be used by a breeder to determine accession selections using selection indexes such as Smith-Hazel and the subsequent choice of the appropriate breeding methods for the achievement of a genetic gain toward a new variety (Smith, 1936).

Plant Genetic Resources (PGR) are the essential components of agro-biodiversity. Plant breeding is based on capturing the genetic diversity (variation) component for breeding. The PGR includes a) primitive forms of cultivated plant species and landraces, b) modern cultivars, c) old cultivars, d) breeding lines and genetic stocks, e) weedy types, and related wild species (IPGRI 1993). Genetic diversity is also created in the farmers' fields through on-farm selection for an agro-morphological farmer or consumer-preferred varieties, for instance, in which farmers are directly participating in varietal selection; hence indirect do phenotypic selection as part of their needs**.** (Fleissner, 2006; Pungulani et al., 2012).

Hence, Bambara groundnut germplasm can be studied using agro-morphological traits (Valombola, Akundabweni, Awala, & Hove, 2019), and molecular markers to identify unique germplasm for breeding (Ouedraogo et al., 2008; Mukakalisa et al., 2006). Some studies have indicated that 15–20 agronomic characteristics are fundamental to assess the genetic diversity among Bambara groundnut (Ouedraogo, et al., 2008; Ndiang, et al., 2014). The genetic worthiness of Bambara groundnut accessions can be studied by growing the crop in preliminary field trials because germplasm characterisation is the primary phase in long-term crop improvement programs (Shengro, et al., 2013; Zhang et al., 2015).

2.7 Assessment of Bambara groundnut genetic diversity

The agro-morphological characterisation is a necessary value addition step in phenotyping for observable genetic variability and identification of desirable crop traits (Shegro, Jansen van Rensburg, & Adebola, 2013; Zhang et al., 2015). Morphological characteristics of Bambara groundnut accessions provide essential information for the breeding program. The rule of thumb in understanding the phenotypic nature is based on the AM-FP varieties can be based on the 70:20:10 indicator ratio, which suggests that a seventy is a purely environmental contribution to a phenotype, 20 is genotype by environment interaction. At the same time, 10 is a likely gene additive variance. For a '70', the agronomic and morphological characters are influenced by environmental factors such as temperature, altitude, soil condition, and genotypic factors (Massawe, 2005; Masindeni, 2006; Ouedraogo et al., 2008; Shegro et al., 2013).

The study on agro-morphological done in Cameroon by Ndiang et al. (2014), reported variability in twelve Bambara groundnut accessions characteristics. The results obtained by Ndiang et al. (2014) were to the exception of days to flowering and maturity among accessions. According to Ouedraogo et al., 2008 when agro-morphological characterisation and evaluation of Bambara groundnuts were carried out in Burkina Faso, they showed high agronomic and morphological variability in the number of pods per plant, the weight of 100 seed weight, shell percentage and seed weight per plant between accessions. However, they were collected from the semi-arid zone of the country, suggesting a possible genetic variability. Another study done in Tanzania assessed genetic diversity (variation) based on agro-morphological characters and results showed high diversity for agronomic and morphological traits. Such findings are crucial in germplasm utilisation in the crop improvement program (Ntundu et al., 2006). The study on agro-morphological and agronomic variation in South Africa on eighteen Bambara groundnut traits also revealed variation among accessions that suggested good phenotypic characters a practical value addition in the identification of parental materials for future breeding programs (Unigwe et al., 2016). Agro-morphological variation study can be supported by molecular markers to confirm results and to reduce the time needed to identify variation (Massawe, Dickinson, Roberts, & Azam-Ali, 2002).

The molecular markers are used to label and track genetic variation in plant DNA samples (Mojtaba & Mehdi, 2015) at any developmental as are not influenced by the environment (Bernardo, 2008). The molecular markers commonly used in plant genetic studies are Randomly Amplified Polymorphic DNA (RAPD) (Amadou, Bebeli, & Kalsikes, 2001; Mukakalisa et al., 2006), Amplified Fragment Length Polymorphism (AFLP) (Massawe et al., 2002; Ntundu, Inga, Christiansen, & Andersen, 2004) and Simple Sequence Repeats (SSRs) (Somta, Chankaew, Rungnoi, & Srinives, 2011; Odongo et al., 2015). RAPDs have been used to detect polymorphism among and within Bambara groundnut lines (Amadou et al., 2001). AFLP is capable of detecting various polymorphism in different genomic regions simultaneously; it is also sensitive, highly reproducible and can amplify between 50–100 fragments at once (Caballero, Quesada, & Rolan-Alvarez, 2008). In a study conducted by Massawe et al. (2002), AFLP analysis revealed extensive genetic diversity among 12 African Bambara groundnut landraces from diverse origins. SSRs are the markers of choice used to study the genetic diversity of crops, including Bambara groundnut (Langercrantz, Ellengren, & Anderson, 1993). They have advantages of being more accurate (Odongo et al., 2015), multi-allelic, co-dominant, simple and are distributed throughout the genome and hence easy to use in self-pollinating crops (Somta et al., 2011; Molosiwa et al., 2013). However, these tools should not be perceived as an alternative to traditional crop improvement methods, but as complements to conventional breeding techniques.

In Namibia, Bambara groundnut pre-breeding work was started by Fleissner (2006) in which 146 accessions collected from Namibian farmers and other countries. The evaluation of genetic diversity using the agro-morphological markers was carried out, and results indicated that accessions are highly diverse. The yield for these accessions was also evaluated whereby KFBN, SB16-5A, and GP41 showed high yield. The survey was also carried out in Nambia, focusing on the farmers' preferences of Bambara groundnuts. Mukakalisa, Kandawa-Schulz, & Mapaure (2006) carried out a survey on Bambara groundnut acceptability, processing, and utilisation in Namibia. They also assessed genetic diversity using molecular marker Randon Amplified DNAs (RAPD) and microsatellite on six Bambara groundnut accessions. The results of the molecular analysis showed low genetic diversity when using RAPD and a high diversity when using microsatellite among six accessions. Mukakalisa et al., (2006) further measure diversity using Shanon Weiner Index, where the low diversity was evaluated. Since the departure of researchers, there have been no efforts to sustain research activities on Bambara groundnut in Namibia. However, this crop remains one of the critical sources of livelihoods among smallholder farmers, especially for women.

2.8 Measures of genetic diversity that could be relevant in Bambara groundnut pre-breeding

The determination of distinctness and uniqueness of phenotype, genetic constitution, and parent selection for hybridisation in crop breeding program (Geleta et al., 2006), therefore, is important in plant breeding. There are many indices; however, the most commonly used measures are Shannon Wiener's Index H' and Simpson index (D_s). Shannon Wiener Index when evaluating unknown germplasm in a breeding program that may include AM-FPs. The latter index combines both evenness and richness in a single measure. Simpson measures are commonly much superior to the other measures. Shannon Wiener Index measures genetic variation in a population when genetically controlled qualitative characters are considered. The latter Index value increases as diversity increases. The formula used is as follow:

Shannon index (H') =. $$-\sum_{i-1}^{s}(pilnpi)$$ ……………..………………Equation 1

Where: P_i is the proportion of accessions (n/N) of individual of one particular character found (n) divided by the number of individual found (N), ln is the natural logarithm, Summation of the calculation and s is the number of characters

2.9 Construction of selection index for yield

Reference to the selection index has already been mentioned concerning agro-morphological-farmer-preferences in the preceding sections. It is essential when more than two traits need to be considered in a breeding program, which is often the best way to go. It can be applied to yield characters, among others. Yield is a complex polygenic character and depends upon the action and interaction of several factors (Ferdous, Shamsuddin, Hasna, & Bhuiyan, 2010). The process of yield improvement can be enriched if instantaneous selection for most of the economic yield traits contributing to grain yield is considered. Thus, in plant breeding, the relationship between yield and yield-related traits is crucial for the need of a selection index in a subsequent crop yield improvement (Babariya, Dobariya, Sapovadiya, & Vavdiya, 2014). In Bambara groundnut, a very constricted research work has been done on the construction of selection indices. For this purpose, the use of appropriate multiple selection criteria based on the selection indices would be more desirable (Karikara & Tabone, 1997). Selection index is the most widely used method for selection which can be used more than one trait. The superiority of index increases with the increasing number of traits under selection but decreases with increasing differences in relative importance (Akter, Biswasb, Azad, Hasanuzzama, & Marifuzzaman, 2010). The superiority of the selection index is maximal when the traits considered are equally important. According to Ferdous, Shamsuddin, Hasna, & Bhuiyan (2010) demonstrated that the correlation studies provide useful and reliable information on the extent, nature direction of the relationship of yield traits. The application of discriminant function developed by Fisher (1936) and first applied by Smith (1936) helps to identify the vital combination of yield components useful for selection by formulating suitable selection indices (Siddhi & Mehtaand LataRaval, 2016).

Construction of selection indices and their analysis gives appropriate phenotypic values of two or more traits for simultaneous selection. The standard formula for calculating selection index is: 1 = b1 X1 + b2 X2 +……bn X n

Where, b1, b2, …, bn are index weights and X1, X2,….Xn is phenotypic information sources.

Selection indices were found to be more efficient than straight selection based on yield only.

The practical or economic value of a plant is affected by several traits. Since the majority of the economic traits are polygenically inherited, and their expression is subjected to varying degrees of fluctuations due to environmental factors. Eventually, direct selection may not be useful for such characters. Therefore, from the literature reviewed, Needs assessment needs to be undertaken to throw light on the generation of meaningful or relevant data on which are the farmers' needs and how they are being fulfilled in the 'as is" situation and which more can be met by breeding. It also suggests that Bambara groundnut pre-breeding need to be carried out and sustainably continue, so that variation among and between landraces or accessions to be identified. Yield is indicated by research as critical descriptors that need breeding attention so that it can be improved.

CHAPTER 3

PRELIMINARY SURVEY STUDY 1: FARMERS' NEEDS ASSESSMENT ON PREFERENCES, SEED SOURCE, CROP IMPROVEMENT, UTILISATION, PRODUCTION AND CONSTRAINTS OF BAMBARA GROUNDNUT IN NORTHERN NAMIBIA

3.1 Introduction

Bambara groundnut (*Vigna subterranea* [L.] Verdc.) has a large number of accessions throughout Africa and beyond, where smallholder farmers have preserved their genetic diversity on their farms (Massawe, Mwale, Azam-Ali, & Roberts, 2005). In production terms, Bambara groundnut has relative advantages over other legumes as it performs well under drought conditions, poor soils, high temperature and fixes nitrogen in the soil, hence making it a suitable crop for the low-input production systems. However, despite these benefits, farmers still grow unimproved landraces that are low yielding.

Researchers and plant breeders in Namibia have no information on the types of Bambara groundnut cultivar farmers grow on their farms and the challenges they encounter in their farming activities. This information is essential so that the farmer preferred traits could be included in breeding programs. The inclusion of farmers in the survey is essential in that they could feel that they are part of the study, and they would easily accept any improved varieties from the program. Such information could be obtained from farmers by conducting a needs assessment survey. Therefore, the objective of this study was to determine the farmer's preferences, seed source, seed selection criteria, production, farming practices, and production challenges of Bambara groundnut.

3.2 Materials and Methods

3.2.1 Site description

The Needs Assessment survey was conducted in five regions in northern Namibia, namely, Omusati, Oshana, Oshikoto, Ohangwena, and Kavango West. In each region, one constituency was selected depending on where the Bambara groundnut is commonly grown and the accessibility of the area. The study areas description and location are shown in Table 1 and Figure 1.

Table 1: Environmental characteristics and population of the study area

Region	Constituency	Latitude	Longitude	Rainfall (mm)	Temperature (ºC)	Altitude	Constituency population	Number of households/con.
Omusati	Anamulenge	17°23′29"S	15°07′42"E	439	22.5	1109	13 410	2 500
Oshana	Okatana	17°44′25″S	15°42′31″E	477	22.5	1102	15 562	2 600
Oshikoto	Omuntele	18º14′00″S	16°14′00"E	505	22.7	1098	21 884	3 300
Ohangwena	Ondobe	17°23′25"S	16°06′34"E	570	22.8	1120	22 491	3 614
Kavango West	Kapako	17°49′17"S	19°34′00"E	579	22.8	1073	25 653	4 200

Source: (htts://en.climapte-data.org/africa/namibia-89/, 2019; NSA, 2011).
con: Constituency

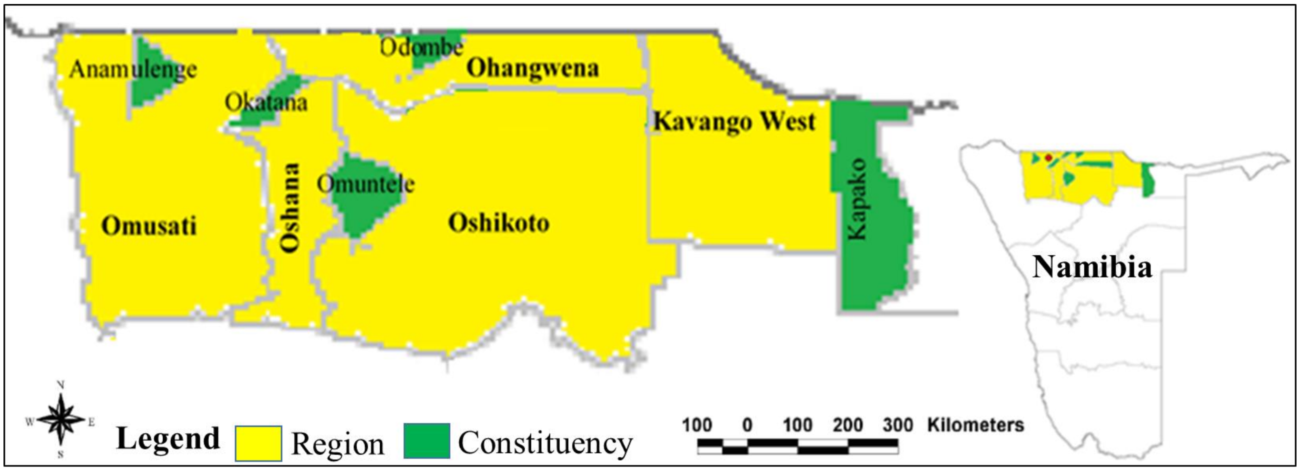

Figure 1: Namibia map showing the regions and constituencies used in the needs assessment survey.

3.2.2 Materials and sampling techniques

Individual farmer survey: The questionnaire was developed using structured questions, closed open-ended questions (Appendix 1). The population sample was selected using a four-stage sampling method (MSS), a probability sampling method. Five northern regions and five constituencies were selected purposively, whereby two villages were randomly selected from each constituency, and ten farmers were interviewed from each village, giving a total of twenty households per constituency per region. The sample size was determined by the formula of Cochran:

$$n_0 = \frac{Z^2 pq}{e^2}$$

Where n_0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails (1 - α equals the desired confidence level, e.g., 95%) and Z is found in statistical tables which contain the area under the normal curve, p is the estimated proportion of an attribute that is present in the population, q is 1-p, and e^2 is the desired level of precision (Cochran, 1977).

The samples were further reduced to a small sample size due to the number of households in the study area, using the formula that is used when the population is <50 000, as shown below:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

Where n_0 is the sample size, and N is the population size.

The samples were reduced to a hundred due to the high cost and limited time.

3.2.3 Data collection and analysis

The data was collected from each farmer on the following variables: socio-demographic, trait preference, variety preference, improvement of Bambara groundnut, seed source, agronomic practices, utilisation, extension services, marketing, and challenges. The survey data were subjected to cross-tabulation. Chi-square (χ^2) and frequencies analysis were performed on discrete data using SPSS 21st edition statistical program. Tables and graphs were used to summarise the results of the study.

3.3 Results

3.3.1 Social demographic of Bambara groundnut farmers

The house-to-house demographic findings were as follows: 91% of females as compared to 9% of males were interviewed. Thirty-one per cent (31%) of those interviewed were between the age of 46 and 60 years, 30% were above 60 years, 27% were between 31 and 45 years, while 12% were between the age of 15 and 30 years. There was a significant chi-square difference (χ^2 = 23.628; *P* = 0.023) in the age groups among the constituencies. The study found that 56% `of the dwellers had attended secondary school hence could read and write. Primary school leavers were 28% as compared to 12% who had not attended school. The chi-square test indicated a highly significant difference (χ^2 = 42.935; P = 0.001) on educational level. Forty-eight percent were married, 41% were single, while 11% were widows. Further, 41% of the respondents indicated that households were headed by men (Table 2).

Table 2: Sociodemographic data of selected Bambara groundnut farmers

		Region and Constituency								
Variable	**Category**	Omusati Anamulenge	Oshana Okatana	Oshikoto Omuntele	Ohangwena Odombe	Kavango West Kapako	Percent (%)	df	Chi-Square (χ^2)	*P*-value
Gender	Male	1	0	4	3	1	9	4	6.593	0.159
	Female	19	20	16	17	19	91			
Age	15-30	5	1	0	2	19	12	12	23.628	0.023
	31-45	6	5	4	2	9	27			
	46-60	6	10	7	6	5	31			
	≥61	6	4	9	10	1	30			
Marital Status	Single	8	9	7	8	3	41	8	8.018	0.432
	Married	11	6	12	10	11	48			
	Widowed	1	5	1	2	2	11			
Education level	None	2	1	2	0	10	15	12	35.798	0.000
	Primary	7	3	6	10	2	28			
	Secondary	11	16	11	10	8	56			
	Tertiary	0	0	1	0	0	1			
Household size(Children)	≤10	18	20	20	19	17	94	8	8.362	0.399
(Number of children/family)	11-20	2	0	0	1	2	5			
	≥21	0	0	0	0	1	1			
Adult	≤10	15	18	18	19	20	90	8	9.528	0.300
(Number of adult/family)	11-20	4	2	1	1	0	8			
	≥21	1	0	1	0	0	2			
Owner of the house	Man	11	9	13	13	13	59	8	6.051	0.641
	Woman	9	11	7	7	7	41			

3.3.2 Yield of Bambara groundnut and farmers' agronomic practices

It was reported that farm size allocated to Bambara groundnut cultivation was less than a hectare. In most cases, Bambara groundnut was planted as a sole crop. However, in Anamulenge, Okatana, Ondobe, and Omuntele while in Kapako constituency, Bambara groundnut was reported to be intercropped with maize and other crops (Table 6). For mixed cultivation, the following crops were generally grown on a larger part of the farm: pearl millet or *mahangu* (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), maize (*Zea mays*), melons (*Citrullus spp)*, groundnut (*Arachis hypogaea)* and pumpkin (*Cucurbita)*.

The other incentive aspect of maintaining the Bambara groundnut in the cropping systems is already known by farmers, that it fixes nitrogen in the soil; hence, many farmers (76%) do not fertilise Bambara groundnut. Some farmers (24% response), however, might fertilise the crop with NPK fertilizer, goat manure or cattle manure. Despite, fertiliser use, the yield obtained by most farmers in the study area was quite low (> 51 kilograms per planted area). The farmers understandably felt that there was a need to have improved cultivar for better yields. On drought-tolerance of Bambara groundnut, 43% of farmers agreed that it could survive during the drought period although the yield is always affected. The chi-square tests revealed highly significant differences (P = 0.000) among Bambara groundnut field size, cropping systems, yield per unit area, types of fertiliser used, and drought tolerance. However, there was no significant difference (χ^2 = 26.929; P = 0.359) observed in fertiliser application.

Table 3: Summary of chi-square tests on farmers' agronomic practices and yield of Bambara groundnut

		Region and Constituency								
		Omusati	Oshana	Oshikoto	Ohangwena	Kavango West		Chi-Square Tests		
		Anamulenge	Okatana	Omuntele	Ondobe	Kapako	Total	χ^2	df	*P*-value
Total field size	<1ha	1	2	0	2	9	14	22.757	6	0.001
	>1ha	19	18	20	18	11	86			
Major crops	Mahangu,sorghum,cowpea,bambaranut and others(maize,*Citrullus spp*,groundnut *etc)*	17	18	18	10	0	69	127.053	48	0.000
	Mahangu,Sorghum,Cowpea and Bambaranut	3	1	14	0	0	9			
	Mahangu and Sorghum	0	1	1	0	0	1			
	Mahangu,Sorghum and Bambaranut	0	0	0	0	0	1			
	Mahangu,Cowpea and Bambaranut	0	0	0	0	4	4			
	Mahangu and Bambaranut	0	0	0	0	9	9			
	Mahangu,Cowpea, Bambaranut and others	0	0	0	0	5	5			
	Bambaranut and others	0	0	0	0	1	1			
	Mahangu, Bambaranut and others	0	0	0	0	1	1			
Bambaranut Cropping system	Sole crop	19	20	10	10	0	79	94.274	6	0.000
	Intercropped	1	0	0	0	20	21			

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BGN Fertilizer application	Application	8	3	4	0	1	24	16.118	6	0.013
	No application	12	17	6	10	19	76			
Type of fertilizer	Cattle manure	1	2	1	0	1	5	26.929[a]	25	0.359
	Goat Manure	2	0	0	0	1	2			
	Inorganic fertilizer	1	0	0	1	0	7			
	Compost	1	0	0	0	0	1			
	Cattle manure+Goat manure	2	1	1	0	0	4			
	Cattle manure + Inorganic fertilizer	0	0	1	0	0	2			
Yield per household	<10	8	2	1	1	0	14	58.266	30	0.001
	10-20	1	3	2	3	0	15			
	21-30	2	1	1	0	4	13			
	31-40	5	5	0	3	4	21			
	41-50	2	4	0	2	3	13			
	>55kg	2	5	6	1	9	24			
Drought survival	Yes	13	5	7	6	1	43	25.541	6	0.00
	No	7	15	3	4	19	57			

3.3.3 Household utilisation and consumption preference

Bambara groundnut was found to have multi-purpose uses (Table 4). It is used for consumption and selling. For edibility, it is cooked while fresh or dry. Chi-square test detected no significant differences (χ^2 = 7.64; P = 0.469) among constituencies on utilisation. Consumption of cooked fresh pods takes place when the pods are harvested before maturity and are eaten as a vegetable. Chi-square test showed highly significant difference (χ^2 = 39.297; P = 0.000) among constituencies in terms of consumption. In Anamulenge, Bambara groundnut is mainly consumed as a freshly cooked pod. The roasted seed was common in Kapako constituencies in the Kavango West Region. The use of leaves as fodder for goats was common in all the four constituencies, except in Kapako Constituency. Significant differences (χ^2 = 18.004; P = 0.006) were detected by chi-square on use Bambara groundnut leaves among constituencies. The nutritional value of the Bambara groundnut is also known by farmers as reflected by their responses, indicating that the crop contains carbohydrate, protein, fat, and other trace minerals.

From the above it is apparent that the introduction of any new use is likely to strengthen the value addition in Bambara groundnut, for example, canning, grinding into flour, and making Bambara groundnut butter and any other form of agro-processing. The commercial snack of Bambara groundnut, just as the case for peanut can also be exploited in its crop improvement.

Table 4: Utilization of Bambara groundnut in different constituencies in the study area

		Omusati	Oshana	Oshikoto	Ohangwena	Kavango West		Chi-square Test		
		Anamulenge	Okatana	Omuntele	Ondobe	Kapako	Total	Df	χ^2	*P*-value
Uses of bambara groundnut	Consumption only	7	11	7	7	8	40			
	Consumption+selling	12	9	13	11	12	57	8	7.64	0.469
	Consumption+selling + other	1	0	0	2	0	3			
Form of consuming	Fresh pod	4	1	13	12	0	30			
	Fresh pod + Dry seed	16	19	7	8	19	69	8	39.058	0.00
	Freash pod+dry+roasted	0	0	0	0	1	1			
Farmers biomass usage	Yes	10	8	8	8	0	34	4	13.547	0.009
	No	10	12	12	12	20	66			
Usage of Bambara nut leaves	Feeding goats	10	6	9	8	0	33			
	Feeding goats and cattle	0	1	0	0	0	1	6	7.159	0.306
	Compost	0	1	0	0	0	1			
Use Bambara Groundnut by-products	Yes	15	12	12	15	0	54	4	31.159	0.00
	No	5	8	8	5	20	46			

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Uses of by-products	Empty pods for feeding goats	6	11	8	7	0	32			
	Empty pods for feeding pigs	5	0	3	3	0	11			
	Empty pods for feeding goats and pods	3	0	0	3	0	6			
	Compost	1	1	0	1	0	3	15	18.374	0.244
	Empty pods for feeding pigs and chickens	0	1	0	1	0	2			
	Mixed with cowpeas for feeding goats and pigs	0	0	1	0	0	1			
Nutritional Value	Protein	3	3	1	1	2	10			
	Carbohydrate	11	7	9	10	18	55			
	Other	0	3	0	1	0	4			
	Protein, carbohydrate and fat	2	0	2	1	0	5			
	Carbohydrate and Other	1	1	3	2	0	7	32	42.242	0.106
	Protein and other	0	2	1	3	0	6			
	Protein, carbohydrate and other	0	1	0	0	0	1			
	Protein Fat	1	0	0	0	0	1			

3.3.4 Marketing of Bambara groundnut

The study showed that 63% of the respondents reported having sold Bambara groundnut to generate income for household needs. Also, all respondents (100%) agreed that selling was an important function of growing Bambara groundnut, implying that a high yield would invariably contribute to a high surplus for sale. It was found that farmers sold their produce informally at local open markets, local shebeens, villages, pension places, and wherever there were gatherings. Significant differences (χ^2 = 90.727; P = 0.000) were detected by chi-square for marketing venues among constituencies. The selling of fresh Bambara groundnut was done during the growing season. The farmers reported that consumers preferred large-seeded nuts.

Further, it was reported that not all seeds are eaten or sold, as some are preserved for future planting (crop seed). In the event of poor harvest, there is usually an informal seed exchange among different constituency farmers. As a priority of cultivar development, setting up a seed multiplication program is imperative.

Table 5: The percentage of farmers' response to the marketing of Bambara groundnut among constituencies

	Response	Frequency	Percentage (%)
Marketing of bambara groundnut	Yes	63	63.0
	No	37	37.0
Selling fresh or dry	Fresh Bambara nut	40	66.7
	Dry Bambara nut	3	5.0
	Fresh and Dry Bambara nut	17	28.3
Market place	Local shebeen	19	31.7
	Local Open Market	19	31.7
	Local open market and Pension place	4	6.7
	Village	7	11.7
	Windhoek market	4	6.7
	Village and roadside	1	1.7
	Windhoek market and Village	1	1.7
	Pension place	2	3.3
	Village and open market	3	5.0
Income generation	Yes	83	100.0
Selection of Bambara nut for selling	None	2	3.3
	Nutrition	1	1.6
	Seed size	35	57.4
	Seed size and quantity	1	1.6
	Mature seeds	13	21.3
	Seed size and cookability	1	1.6
	Seed size and seed type	1	1.6
	Clean pods	2	3.3
	Clean pods and seed size	1	1.6
	Freshness and seed size	2	3.3
	Seed size and mature seeds	2	3.3

3.3.5 Farmers' preferred cultivar, traits, and improvement of Bambara groundnut

(a) Cultivar preferred

Cultivar preferences appeared to be constituency-specific and were significantly different ($P \leq 0.000$). Results showed that farmers had specific preferred cultivars which they cultivate and are named according to colours and performance. **S**ignificant differences ($\chi^2 =$ 138.86; P = 0.000) among different varieties grown across the five constituencies were detected (Table 6). The cultivars grown in north-central constituencies were described. In this regard, Okaongoti (Tan) was 42% popular, followed by Olunya (cream) (25%) and Okambishi (black) (23%). In one north-eastern constituency, cultivated seed types were described by colour. In this regard, 49% of the respondents shows that the cream seed was popular, followed by both black and red (21%). The response suggested that the most colour preferred is tan (42%) for north-central Namibia and cream for north-eastern Namibia (49%). Other less preferred colours included black and red (representing about 22%).

In any study dealing with the diversity aspect, especially where unimproved cultivars are involved, it is essential for a breeder to rely on taxonomic rather than ethnobotanical nomenclature to distinguish among the cultivars. Findings in this study indicated that four main seed colours were present among the germplasm encountered, namely, cream, tan, black and red. Most seeds in the open market are commonly a mixture of these colours in varying proportions. When the mixture is separated in individual colours, red appears in a small proportion. There is breeding merit in colour variation which can constitute a breeding objective (for example nutritional significance, pest-attack, the colour of food preparation among others).

Table 6: Bambara groundnut cultivars preferred and grown by farmers

		Cultivar												
Cons.	Class	Olunya	Engowa	Egogani	Okambishi	Okaogonti	Onkwaya	Tan	Red	Maroon	Black	Cream	No idea	Total
Anamulenge	Count	0	0	0	1	12	0	0	1	0	0	3	3	20
	Expected Count	2.2	0.4	0.4	2.2	2.2	0.2	0.4	2	0.4	2	4.6	2.8	20
Okatana	Count	8	2	2	2	0	1	0	1	0	1	1	2	20
	Expected Count	2.2	0.4	0.4	2.1	2.1	0.2	0.4	1.9	0.4	1.9	4.4	2.7	20
Omuntele	Count	4	0	0	6	4	0	0	3	0	2	1	0	20
	Expected Count	2.2	0.4	0.4	2.2	2.2	0.2	0.4	2	0.4	2	4.6	2.8	20
Ondobe	Count	0	0	0	2	4	0	0	0	0	4	10	0	20
	Expected Count	2.2	0.4	0.4	2.2	2.2	0.2	0.4	2	0.4	2	4.6	2.8	20
Kapako	Count	0	0	0	0	0	0	2	5	2	3	8	0	20
	Expected Count	2.2	0.4	0.4	2.2	2.2	0.2	0.4	2	0.4	2	4.6	2.8	20
Df														44
Chi-square														138.86
P-value														0.000

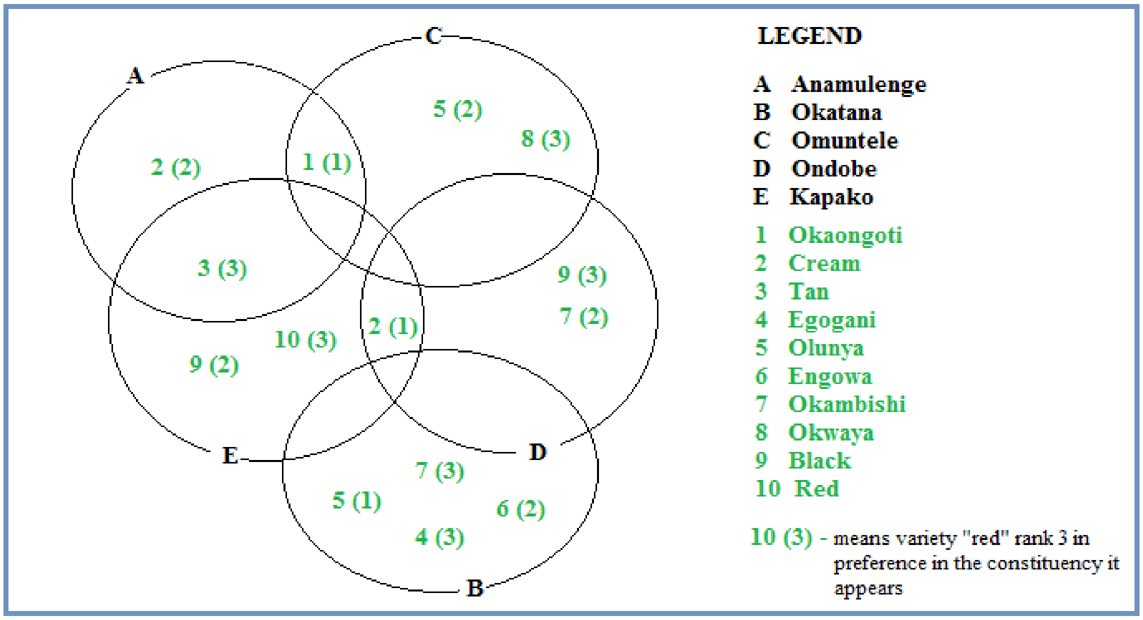

Figure 2: Venn diagram summarises cultivars preference per constituency

Table 5: Summary of chi-square tests on farmers' descriptors preferences of Bambara groundnut from the study area

	Constituency					
Trait	Anamulenge	Okatana	Omuntele	Ondobe	Kapako	Total(%)
Seed colour	1	1	2	2	0	6
Seed size	12	9	7	13	16	57
Maturity	2	2	1	1	1	7
Pods with 2 or more seeds	0	0	1	0	0	1
Seed size + maturity	0	0	3	0	0	3
Seed colour + seed size	4	5	2	0	2	13
Seed colour + seed size+ maturity	0	0	2	0	0	2
Maturity + pods with 2 or more seeds	0	0	0	1	1	2
Seed colour + seed size + maturity + pods 2 or more seeds	1	0	1	0	0	2
Seed colour + taste	0	2	1	1	0	4

Seed colour seed size + taste	0	1	0	0	0	1
Seed colour + taste	0	0	0	2	0	2
Total number of farmers	20	20	20	20	20	100
Chi-square						58.852
df						44
P-value						0.066

(b) Agro-morphological preferences

Farmers gave multiple responses on preferred traits which showed that Bambara groundnut possesses traits that may need attention in breeding. Farmers in the study area preferred particular Bambara groundnut cultivars based on seed size, seed coat colour, maturity, taste, and pods with two or more seeds. The preferred traits showed no significant differences (χ^2 = 58.852, P = 0.066) among constituencies (Table 7). Seed size depicted the highest percentage (57%) of preferences though large-sized seeds were more preferred. Early maturity was preferred by 7% of the farmers. Maturity is important in terms of not only giving an early yield but, also in evading drought, that is a common feature in Namibia. Smaller seed size content ranged from 1–6%, indicating that the descriptor was less important to their farmers. Farmers expressed other preferences for big leaves, drought-tolerance, thick pod, yellow pod, seed shape, bushy type, high yield variety, medium leaves, and nitrogen fixation.

(c) Improvement of farmers preferred cultivars

Improvement of Bambara groundnut is one of the main objectives in breeding this crop. Bambara groundnut farmers in all five constituencies indicated that the use of unimproved cultivars (92%) was a main constraint. They agreed that improved cultivar are needed. The chi-square test detected a significant difference ($\chi^2 = 34.783$; $P \leq 0.000$) among farmers' responses toward the adoption of improved varieties; particularly yield (45%). A combination of yield, seed size, and insect tolerance was, to some degree, notable (16%) (Table 8). The chi-square test for descriptors showed that there was a highly significant difference ($\chi^2 = 79.334$; $P \leq 0.000$) among constituencies.

Table 6: Chi-square test of identified farmers' preferred traits for Bambara groundnut improvement

			Y	SS	IR	DT	YSSO	YSS	YSSIR	YO	IRO	YIRO	SSIR	Total	χ^2value	df	*p*-value
Omusati	Anamulenge	Count	14	2	0	0	1	2	1	0	0	0	0	20			
		Expected Count	9.0	1.7	.4	.9	.2	2.8	3.2	.4	.9	.2	.2	20.0			
Oshana	Okatana	Count	12	1	0	1	0	4	1	1	0	0	0	20			
		Expected Count	9.0	1.7	.4	.9	.2	2.8	3.2	.4	.9	.2	.2	20.0			
Oshikoto	Omuntele	Count	5	2	1	0	0	5	6	0	0	0	1	20			
		Expected Count	9.0	1.7	.4	.9	.2	2.8	3.2	.4	.9	.2	.2	20.0	79.334[a]	40	0.000
Ohangwena	Odombe	Count	9	2	1	0	0	2	6	0	0	0	0	20			
		Expected Count	9.0	1.7	.4	.9	.2	2.8	3.2	.4	.9	.2	.2	20.0			
Kavango West	Kapako	Count	2	1	0	3	0	0	1	1	4	1	0	13			
		Expected Count	5.9	1.1	.3	.6	.1	1.8	2.1	.3	.6	.1	.1	13.0			

Legend: **Y**-Yield, **SS**-Seed size, **IR**-Insect resistance, **DT**-Drought tolerant, **YSSO**-Yield, seed size and others, **YSS**-Yield and seed size, **YSSIR**-Yield seed size and insect resistance, **YO**-Yield and other, **IRO**-Insect resistance and others, **YIRO**-Yield, insect resistance and others, **SSIR**-Seed size and insect resistance

3.3.6 Farmers memory recall of Bambara groundnut cultivation and seed source

Farming experience of Bambara groundnut farmers

Responses for this parameter were age-group based. For example, the age group of thirty years could only remember their familiarity with Bambara groundnut cultivation within their time, or unless learnt from elsewhere informally or at school. The same applies to the responses that came from other age groups. Response according to the age group, gender and level of education as detected by the chi-square test varied significantly (χ^2 = 77.395; P = 0.000). Fifty-nine per cent of the respondents estimated that Bambara groundnut had been cultivated for over 41 years. This response might have come from the mid-year late and senior citizens age category (Table 2).

Bambara groundnut seed source

Seed source was found to be of no significance ($P \leq 0.067$) to growers (Table 9), possibly due to the informal nature of seed exchange among farmers coupled with recycling of the planting seed by each farmer. Results showed that many farmers (61%) obtained their seeds from the previous harvest. Twenty-five per cent of farmers' sourced seeds both from the open market and/or the previous harvest.

Table 7: Summary of chi-square tests on farmers' seed source and farming experience on Bambara groundnut

		Region and constituency								
		Omusati	Oshana	Oshikoto	Ohangwena	Kavango West				
	Category	**Anamulenge**	**Okatana**	**Omuntele**	**Ondobe**	**Kapako**	**Total**	**df**	χ^2	**P-value**
Farming duration	<10	0	2	5	3	1	11	16	77.395	<.000
	11-20	0	0	4	2	15	21			
	21-30	0	0	1	4	3	8			
	31-40	0	0	0	0	1	1			
	>41	20	18	10	11	0	59			
Source of seeds	Own seed	13	16	5	10	12	61	24	29.433	0.204
	Open market	0	1	0	3	1	5			
	Neighbour	0	1	3	1	0	5			
	Own seed + Open Market	6	1	5	6	7	25			
	Open market+ Neighbour	1	0	1	0	0	2			
	Own seed +Neighbour	0	1	0	0	0	1			
	Own seed+ Open market +Neighbor	0	0	1	0	0	1			

Farmers' criteria for Bambara groundnut crop seed selection

Results showed that farmers' selected seed for the following season based on seed and cultivar traits such as seed colour, seed size, taste, early maturity and to some extent on pods with two or more seeds among others. Chi-square test indicated that there was a highly significant ($\chi^2 = 57.271$; $P \leq 0.000$) difference in seed selection criteria among the constituencies. Seed size was considered to be the most important criterion, followed by seed colour and size; seed colour, taste, seed size and taste and then by other axillary criteria (Figure 2).

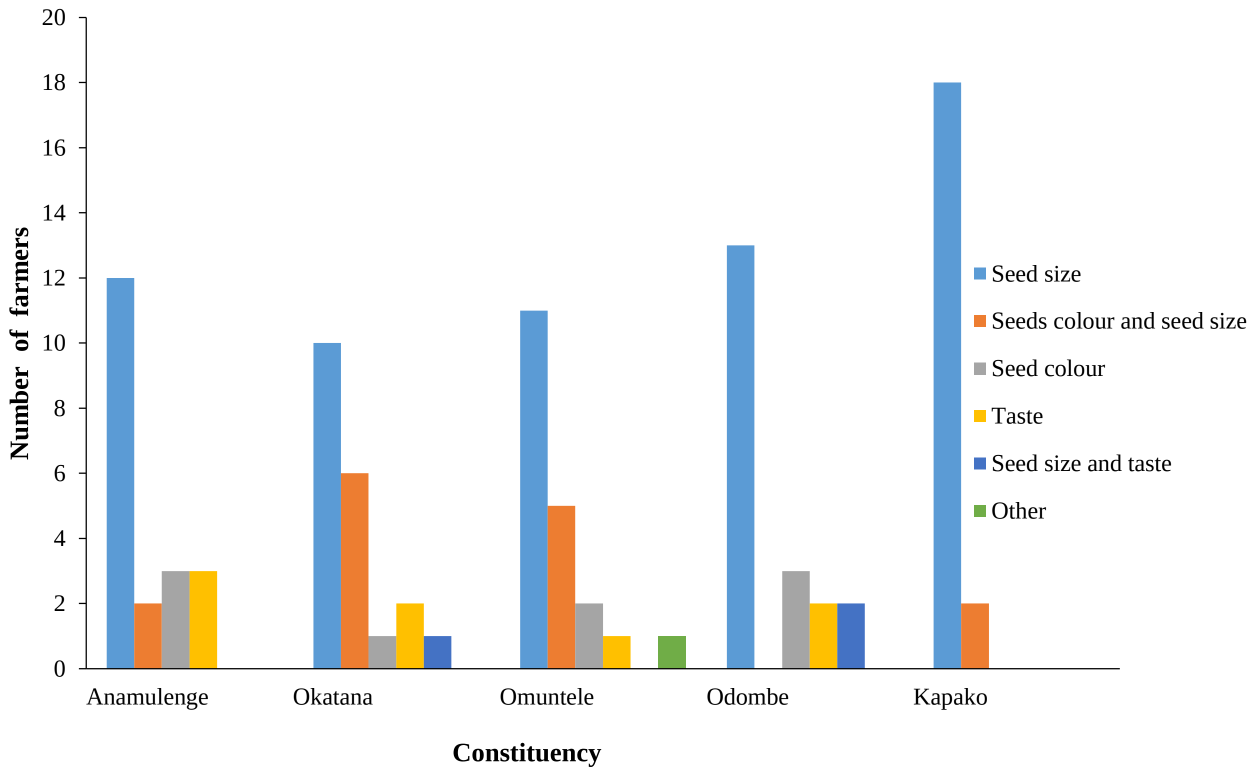

Figure 3: Number of farmers selected seed by traits in constituencies

Seed colour preference

Seed colour was another attribute that farmers considered in all the constituencies. Forty-five farmers chose seed colour as one of their selection criteria, where cream colour was the most selected colour (36%), followed by red colour (33%). The least selected colour was purple, liked by one farmer representing 2%. The black colour was preferred by 18% of the farmers, who said that black seeds had better drought tolerance. Tan colour was selected by 11% of farmers.

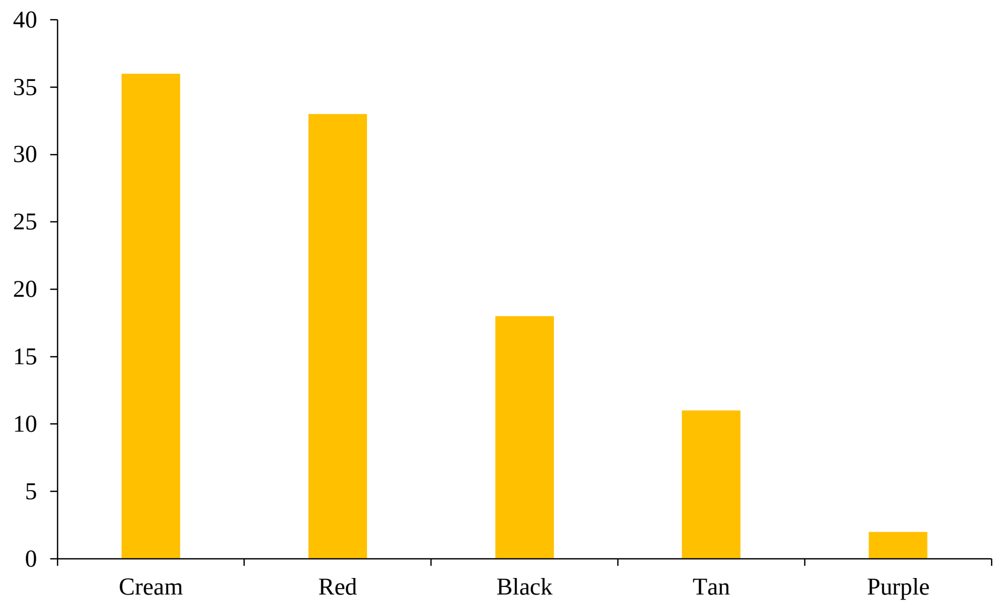

Figure 4: Preferred seed colour by farmers in the study area.

3.3.7 Accessibility of extension services on Bambara groundnut production

Chi-square tests on extension service of Bambara groundnut farmers indicated that there was no variation (χ^2 = 8.421; P = 0.209) among constituencies. This should be obvious since constituencies are not delimited in the ecological sense; however, accessibility through extension services might suggest that there were no new messages of either research or emerging development in Bambara groundnut plant breeding. According to Figure 4, generally, the importance of training was demonstrated (92% respondents). Seventy-five per cent of the respondents pointed out that they needed training. Unfortunately, 95% said they did not receive any training on Bambara groundnut.

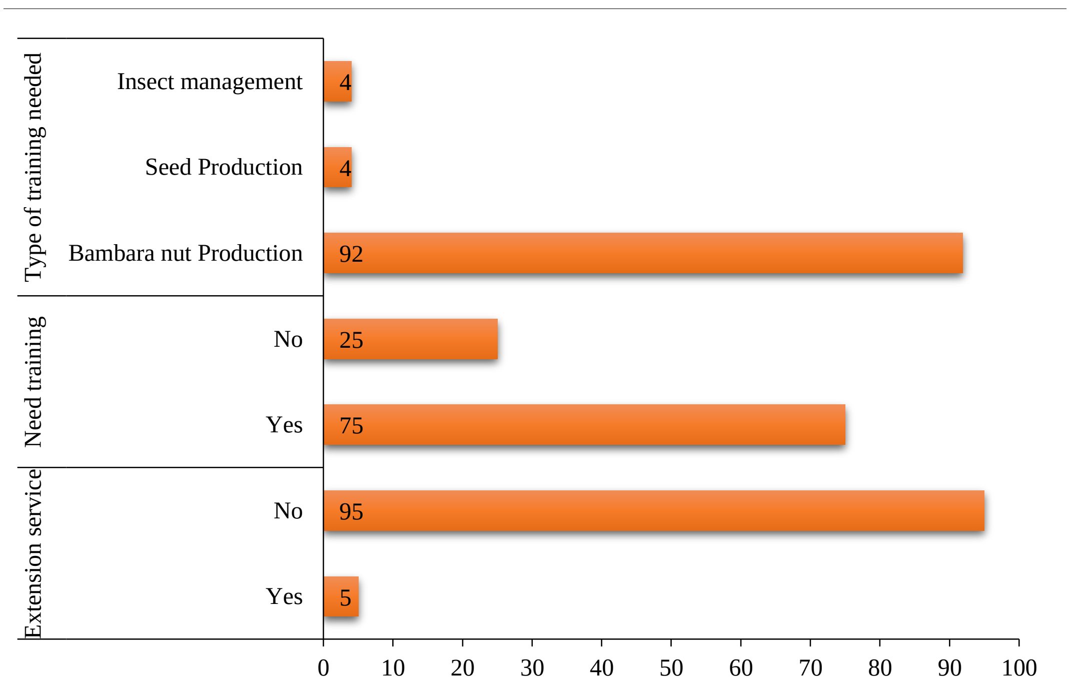

Figure 5: Views on the availability of extension services by Bambara groundnut farmers.

3.3.8 Production constraints associated with Bambara groundnut

Production constraints ranked according to the farmers' responses are as presented in Figure 4. Farmers production constraints on Bambara groundnut production varied significantly (χ^2 = 142.616; P = 0.036) across constituencies. Results indicated that the main challenges were insects, especially aphids and termites, low yield, use of unimproved varieties and others, for example, flooded Bambara groundnut field, squirrel, and rodents (Figure 7).

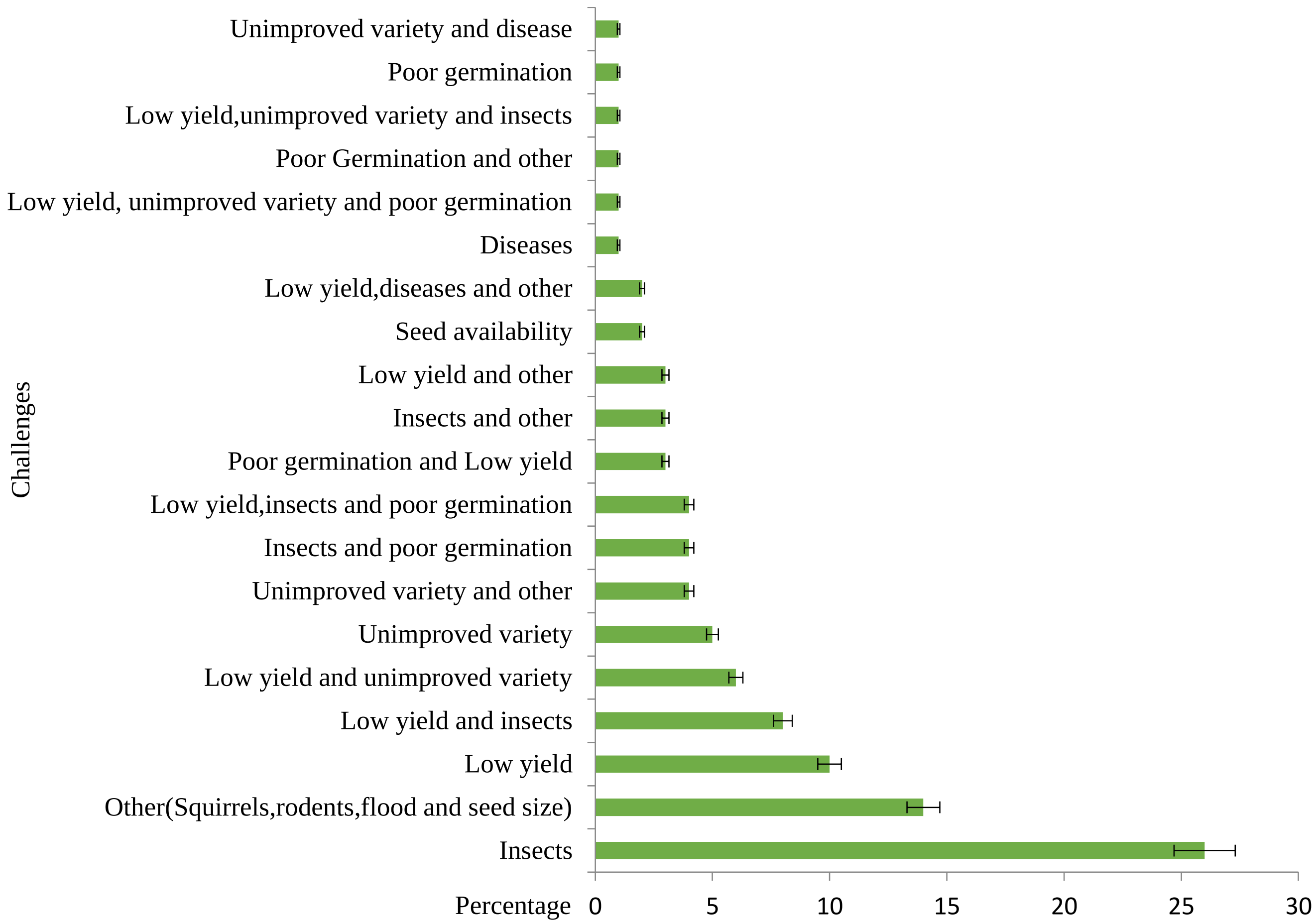

Figure 6: Production constraints experienced by Bambara groundnut farmers in the study area.

3.4 Discussion

Bambara groundnut is one of the neglected and underutilised crops grown by poor smallholder farmers in Africa. The study focused on Bambara groundnut farmers' preferences and diversity of accessions used by the farmers in selected constituencies in northern Namibian regions. According to the sociodemographic details, many farmers interviewed were females (91%), possibly because the Bambara groundnut is believed to be a women crop. This finding is in agreement with those of Massawe et al. (2005), Berchie et al. (2010), and Ibrahim et al. (2018). Most of the respondents were adults between the age of 46–60 years. This was attributed to the fact that most of the young people migrated to urban areas to search for jobs, while older people remained in rural areas undertaking farming. The memory recall for the history of the crop is therefore likely to be of a long term nature compared to responses to the younger group category. The total number of households in the five constituencies comprised 94% of children, who could be fed with Bambara groundnut because it is rich in protein, carbohydrate, and fat. Hence it can be a substitute for meat (Mubaiwa, Fogliano, Chidewe, & Annita, 2018). Many of the farmers in the study area were literate; as a result, they knew the importance and benefits of using improved seeds. The sociodemographic findings seem to suggest the following: a) There is a full understanding of the needs assessment feedback that was being provided; b) The importance of the crop as a supplemental food; c) The value of the crop residue to livestock and a source of soil organic matter.

Farmers in the study area had similar preferences for Bambara groundnuts, whereby big-sized nuts were favoured. The preferences for growing big-size nuts could be in response to consumer demands. This result was in agreement with the results obtained by Fleissner (2006). Bambara groundnut is regarded as a drought-tolerant crop compared to other legume crops. Hence farmers also preferred drought-tolerant cultivars. Also, farmers preferred Bambara groundnut cultivars with big leaves because of their higher fodder yield. High yielding Bambara groundnut varieties are some of the most preferred traits, and big-sized seeds could be one of the traits that correlate with high yield due to their mass. Hence, farmers need to have a high-yielding crop to produce a surplus for household consumption and income generation. The results of the study showed that farmers had specific preferred varieties and were named according to colour and performances. Bambara groundnut accessions originated from Namibia are given local names such as Engowa, Okambishi, Egogani, Okaongoti, Olunya, and Onkwaya (Fleissner, 2006).

Since Bambara groundnut farmers had their preferred traits, and not all cultivars have quality traits that farmers need, crop improvement is required to fill this gap. In fact, 92% of farmers from the five constituencies agreed that they need improved varieties, except farmers (8%) from Kapako constituency who did not agree on varietal improvement for the reason that Bambara groundnut is not their main crop. Every farmer needs to have high yielding varieties for every crop, that is why gain yield scored the highest percentage (45.16%). However, many farmers indicated that Bambara groundnut is low yielding giving less than 55 kg/ha. Yield is a polygenic trait and can be influenced by environmental factors (Oyiga & Uguru, 2011), including climate change, thereby affecting yield (Challinor, Wheeler, Graforth, Craufurd, & Kassam, 2007). Most farmers in the study area had been growing Bambara groundnut for more than 41 years, using unimproved varieties sourced from informal market, neighbour and relatives, which might lead to genetic erosion. This result is in line with the results presented by Ibrahim et al. (2018) since the crop is self-pollinated. However, Karikari et al. (1997) and Ouedraogo et al. (2008) stated that farmers from Burkina Faso also obtain seeds from the previous harvest, but some genotypes are not fixed, causing segregation in progeny. They further stated that seeds sown were mixed and environmental conditions of each year could favour one or some accessions to the detriment of others, hence only adapted accessions will produce more progenies. So, the composition of seed will change from year to year according to previous environmental conditions (Atoyebi, Oyatomi, Osilesi, Adebawo, & Abberton, 2017).

The seed colour was another preference, and one of the bases used to select seeds for planting. There were significant differences across constituencies, with the preferred colours being tan, black, cream, red and purple. Farmers indicated that the cream Bambara groundnut was preferred, because of its sweet taste, less cooking time, marketability, preference for home consumption, produce seed with homogeneous attributes. This is in agreement with results obtained by Buah, Abu, & Leduah (2011). The black/dark colour was also preferred because black-seeded varieties were known to be drought tolerant (Feldman, Wai, Massawe, & Mayes, 2019; Mayes et al., 2019). These findings are similar to those of Mukakalisa, Kandawa-Schulz, & Mapaure (2006). The order for preference is cream, red and black, and this finding is similar to that reported by (Bamshaiye, Agegbola, & Bamishaiye, 2011).

The study further highlighted the need for crop improvement program on Bambara groundnut. Farmers use the crop for household consumption because it is rich in nutrients such as protein, carbohydrate, fat, and minerals. Hence Bambara groundnut can substitute meat which is expensive and usually unaffordable by poor farmers. The Bambara groundnut is consumed as fresh pods, dry seeds and leaves are used as fodder for livestock. These results concur with those of Mubaiwa, Fogliano, Chidewe, & Annita (2018) and Okpuzor, Ogbunugafor, Okafor, & Sofidiya (2010).

In northern parts of the country, farmers cultivated Bambara groundnut as a sole crop in small plots (<hectare), although some farmers may have big fields (>hectare) (Massawe, Mwale, Azam-Ali, & Roberts, 2005). In the Kavango West Region, Bambara groundnut is intercropped with cereal crops such as maize and *mahangu*. Generally, sole cropping in the interest of creating a new variety usually provides a sound basis for developing breeding objectives for a) any new cultivar expansion; b) a pronounced expression of both abiotic and biotic constraints that are cultivar specific. As already stated, a realistic assessment of the low yields, insects, unimproved varieties, and seed availability can be better addressed under sole cropping. Sole cropping also suggests a promise to commercialise Bambara groundnut production as a sole crop in mentioned constituencies.

It is known that legumes fix nitrogen in the soil and improve soil fertility, and thus farmers do not apply any fertilizer in the Bambara groundnut field. These findings are in agreement with those of Anchirinah & Bennet-Lartey (2002), who reported that farmers in Ghana did not apply fertilizer to Bambara groundnut crops. The farmers in Namibia also indicated that they do not get assistance from the extension service to help them improve Bambara groundnut production, nor did they get improved seeds. This could be attributed to the fact that Bambara groundnut is an orphan crop, and therefore researchers and other agencies do not regard it as an important legume crop (Buah, Abu, & Leduah, 2011).

Farmers' production constraints on Bambara groundnut production varied significantly across the constituencies studied. The main challenges were insects, especially aphids and termites, causing low yield as pests usually destroyed pods and leaves. Similar results were reported by Ibrahim et al. (2018) in Western Niger. Other causes of low yield reported by farmers included floods, squirrel and rodents—and these were in agreement with those of Mkandawire (2007). Nonetheless, Bambara groundnut in the study area was grown by 63% with the aim of selling to generate income for household needs and all farmers (100%) agreed that selling Bambara groundnut does generate income (Berchie et al., 2010).

3.5 Conclusion

In five constituencies of northern Namibia, more women than men were involved in Bambara groundnut farming. The farmer's most preferred-traits were seed size, seed coat colour, early maturity and drought-tolerant. Farmers preferred varieties included Olunya, Okaongoti, Engowa, Okambishi, and Egogani, whose names may have been derived from their seed colours and production levels. Farmers have been growing Bambara groundnut for a long period of time and have acquired indigenous knowledge on production. Most farmers sourced Bambara groundnut seeds from the previous harvest or informal markets. The Bambara groundnut is used as food while the crop's vegetative materials are used as livestock fodder. Smallholder farmers sell surplus Bambara groundnut to generate income, but consumers also have their preferred traits such as large seed size and cream colour.

CHAPTER 4

EXPERIMENT 2: CHARACTERISATION AND EVALUATION OF BAMBARA GROUNDNUT GERMPLASM ACCESSIONS

4.1 Introduction

Vigna subterranea (L.) Verdc.) is a leguminous plant from the *Papilionaceae* family (Hammer et al. 2001; Amarteifio, 2003), containing carbohydrate, fat, and protein (Minka & Bruneteau, 2000; Amarteifio et al., 2006), which can supplement the staple food crop of Namibian and other African crops (Ndiang et al., 2012). Despite its nutritional and environmental relevance and its ability to grow under harsh climatic conditions (Adu-Dapaah & Sangwan, 2004; Kone´et al., 2007), Bambara groundnut's world annual production is estimated at 160,378 tons, with 111,562 tons (nearly 70%) produced in West Africa (FAOSTAT, 2017). The available cultivars are low yielding (ca 650 kg/ha) because of improper farming methods, lack of improved cultivar and pests attack (Anchirinah et al., 2001; Ntundu et al., 2006). Some research suggested that improved Bambara groundnut accessions yield of 3 000 to 4 500 kg/ha can be reached under favourable field conditions (Sibuga et al., 1994; Azam-Ali et al., 2001). The evaluation of different germplasm accessions is necessary for the selection of germplasm and pre-breeding strategies (Hall et al., 2003; Hedge & Mishra, 2009; Ndiang et al., 2014). This study was designed to generate baseline data on crop agro-morphology diversity information for the pre-breeding of the crop.

Materials and Methods

The study site

The field experiment was carried out at University of Namibia-Ogongo Campus in Omusati Region located approximately at a latitude of 17°40′37.6″S, longitude 15°17′43.0″E and altitude of 1109 m above sea level during the 2017/2018 cropping season. The site is characterised by low annual precipitation with an average of 300–400 mm, and the mean temperature ranging from 23–39 °C. The soil type is sand loamy. The experimental site is shown in Figure 6.

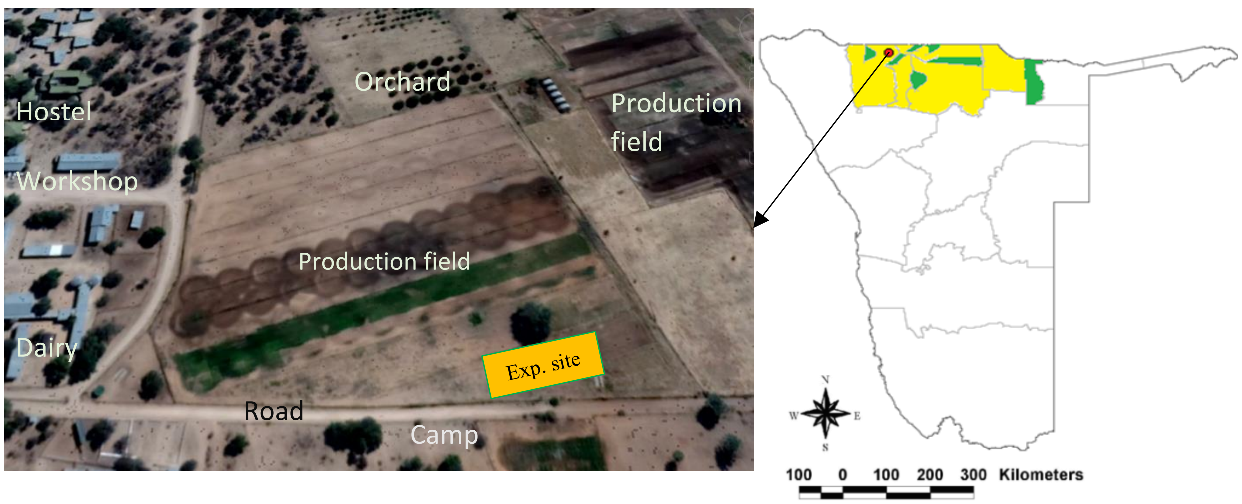

Figure 7: Map showing the location of the experimental site (yellow) in Ogongo Campus.

4.1.1 Plant materials and multiplication of germplasm accessions seeds

A total of 25 Bambara groundnut germplasm accessions, 10 from Namibia Botanical Research Institute (NBRI), 10 from Omahenene Research Station, Namibia; two from Kitwe, Zambia; and three from Chitedze Research Station, Malawi were used in this study (Table 10). The germplasm accessions were multiplied in field plots at the Crop Science Experimental Field, Ogongo Campus, during 2016/2017. The design of the experiment was a square lattice with 25 accessions in three replications and 15 blocks totalling 75 experimental units. The size of individual plots was 8.1 m^2 (3.6 m long × 2.25 m wide) with the intra-row spacing of 45 cm and inter-row spacing of 75 cm, giving three rows per plot. Each row comprised 10 hills, giving a total population of 30 plants per plot. Estimated plants in the experiment were 2 250. The experimental area was 1,018 m^2 (68 m long × 15 m wide).

Table 8: Bambara groundnut germplasm accessions used in the study

Serial No.	Accession ID	Country of origin	Source
1	NAM 3900	Namibia	OMRS
2	AHM 968	Namibia	OMRS
3	NAM 1754/3	Namibia	NBRI
4	NAM BLACK	Namibia	OMRS
5	LR6	Namibia	OMRS
6	NAM 3804	Namibia	NBRI
7	NAM 1195/2	Namibia	NBRI
8	MW 791	Malawi	CRS
9	ZAM 02	Zambia	Kitwe
10	NAMFA	Namibia	Farmers
11	NAM 1762/2	Namibia	NBRI
12	UNISWA RED	Swaziland	OMRS
13	NAM 1866	Namibia	NBRI
14	NAM 1758/3	Namibia	NBRI
15	NYAKC	Swaziland	OMRS
16	MW 2875	Malawi	CRS
17	ZAM 01	Zambia	Kitwe
18	NAM RED	Namibia	OMRS
19	NAM 1084/3	Namibia	NBRI
20	DIPC	Botswana	OMRS
21	KFBN	Namibia	OMRS
22	NAM 1156/3	Namibia	NBRI
23	NAM 959/4	Namibia	NBRI
24	LR4	Namibia	OMRs

25	MW 266	Malawi	CRS

Legend: OMRS-Omahenene Research Station, NBRI-Namibia Botanical Research Station, CRS-Chitedze Research Station.

4.1.2 Experiment design

After seed multiplication, accessions were characterised and evaluated in the field for agronomic and morphological differences during the 2017/2018 season. The experimental area was 1,018 m^2 (68 m long × 15 m wide). The design of the experiment was a square lattice design with 25 accessions in 3 replications (and 15 blocks), totalling 75 experimental units. The size of individual plots was 8.1 m^2 (3.6 m long × 2.25 m wide) with the spacing of 45 cm intra-row and 75 cm inter-row, giving three rows per plot with ten hills totalling a population of 30 plants per plot. The estimated total plant population for the experiment was 2 250 plants.

4.1.3 Land preparation and trial management

The experimental land was ploughed, disked and demarcated before planting. Planting was done manually by sowing two seeds at a depth of 2 to 4 cm at each planting station. Crops were thinned at 21 days after emergence to leave one plant per station. No fertiliser was applied to the experiment, mimicking the practice being used by Bambara groundnut subsistence farmers. Weed control was done manually by hand-hoeing to keep a weed-free experiment. The earthing of Bambara groundnut plants was done at the flowering stage in order to bury the pegs and newly formed pods.

4.2.5 Data collection

Qualitative and quantitative variations were recorded according to Bambara groundnut descriptors (IPGRI, 2000), as indicated in Tables 11 and 12.

Table 9: Qualitative descriptors of Bambara groundnut accessions

	Descriptors	Code	Recording description/method
1	Seed shape	SS	1) Round, 2) Oval, 99 Other
2	Seed testa colour	STC	1)Cream, 2) Grey, 3)Light red, 4)Dark red, 5)Light brownish red, 6)Dark brown, 7)Dark purple, 8) Black, 99)Other
3	Seed eye pattern colour	SEPC	1) Cream testa butterfly-like eye,4) Cream testa triangular eye, 10) Light brow testa with a butterfly-like eye, 99 Other
4	Seed hilum colour	SHC	1)White,99) Other
5	Growth habit	GH	1) Bunch type,2) Semibunch type,3) Spreading type
6	Terminal leaflet shape	TLS	1)Round, 2)Oval, 3)Lanceolate, 4)Elliptic, 99) Other
7	Stem hairiness	SH	0)Absent, 3)Sparse, 7)Dense
8	Pod texture	PT	1)Smooth 2)Little grooves,3)Much grooved
9	Pod colour	PC	1)Yellowish-brown, 2) Brown, 3)Reddish-brown, 4)Purple, 5)Black, 99Other
10	Pod shape	PS	1) Without a point, 2)Round on the other side,3) With nook on the other side,4) Two points on each side

Table10: Quantitative variation used in the study

	Characters	Code	Recording description/method
1	Days to emergence	DEM	Recorded when 50% of the plants have begun to the emergence
2	Days to 50% flowering	D50F	Recorded when 50% of the plants have begun to flower
3	Plant height	PH	Recorded 10 weeks after planting, Measured from the ground level to the tip of the highest point
4	Terminal leaflet weight	TLW	Recorded 5 plants ten weeks after planting, 3 leaves per plant
5	Terminal leaflet length	TLL	Recorded 5 plants ten weeks after planting, 3 leaves per plant
6	Number of leaves	NL	Recorded 5 plants two weeks after first flowering
7	Number of branches per plant	NBP	Recorded at harvest, the average number of five health plants
8	Number of pods per plant	NPP	Average of 5 plants, counted pods after harvest
9	Number of pods with 2 or more seeds	N2P	Average of 5 plants, counted pods after harvest
11	Seed width	SW	Recorded within two months after harvest
12	Fresh Pod weight	FPW	Recorded immediately after harvest
13	Dry pod weight	DPW	Recorded within two months after harvest
14	100 pod weight	PW	Recorded within two months after harvest
15	100 Seed weight	SD	Recorded within two months after harvest
16	Seed length	SL	Measured with a micrometer after threshing
17	Seed width	SW	Measured with a micrometer after threshing
18	Fresh Biomass	FB	Recorded immediately after harvest
19	Dry Biomass	DB	Recorded within one month after harvest
20	Shelling percentage	SP	Recorded two months after harvest, the average percentage of 10 pods, on the weight of mature seeds
21	Harvest index	HI	Calculated from Pod/ Seed weight of Biomass
22	Pod yield per hectare	YPP	Weight of dried pod
23	Seed yield per hectare	SPP	Weight of dried seed

Source: (IPGR, 2000)

4.2.6 Data analysis

The diversity of qualitative characters was calculated using the Shannon Wiener Index ($H' = \sum p_i \ln p_i$) and hierarchical cluster analysis that formed different clusters. Quantitative data of Bambara groundnut was analysed using analysis of variance (ANOVA) with GenStat 19th edition software program. Coefficients of variation (CV) were also determined as an indicator of agro-morphological variability. The Pearson correlation coefficient was calculated to determine the relationships between the studied agro-morphological variables. Multivariate analysis of agro-morphological data by Principal Component Analysis (PCA) was used to discriminate genetic diversity among the Bambara groundnut accessions. This analysis has been widely used as a data reduction method to analyse multiple data on agro-morphological characteristics, and it has proven to be a valuable tool to understand relationships between characters. Genetic similarity between pairs was calculated using the agglomeration method—the unweighted pair-group method with the arithmetic averages (UPGMA) (Gonné, Félix-Alain, & Bargui, 2013).

4.3 Results

4.3.1 Phenotypic characterisation of Bambara groundnut germplasm accessions through crop morphology

4.3.1.1 Phenotypic characterisation of Bambara groundnut germplasm

The nine qualitative traits recorded on the 25 Bambara groundnut germplasm accessions showed variation for different traits studied. It was observed that the seeds of 60% of the germplasm accessions studied in the field were oval-shaped, while 40% of the seeds were round. Seed testa colour/pattern percentage was 20% for the tan colour, 12% for red cream, dark tan, and purple were 8% each; and minimum percentage of 4% colour for speckled brown, cream, brown, and black (Figure 7). Regarding seed eye pattern colour, 64% of the accessions had no eye colour, 16% had amber colour and 4% for brownish, brown, grey, black, and purple colour (Figure 7). Growth habit showed that 44% of the germplasm accessions were bunch, 24% are semi-bunch, and 32% were slightly spread. Terminal leaflet shape indicated that many of them were oval, representing 64%, 24 elliptic, and 12% are lanceolate (Figure 8). Stem hairiness was sparse (56%), absent (40%), and (4%) dense among germplasm. For the pod shapes, 70% were ending points, round on the other side, while 28% were ending point, with nook on the other side. Pod colours were brown (40%), reddish-brown (4%), yellow (24%), yellowish-brown (24%) and yellowish (8%). The pod textures were little groove (36%), much grooved (32%), and smooth (32%) (Table 13).

Table 13: Percentage of qualitative data frequency distribution

Characteristic	Description	Percentage (%)
Seed Shape	Oval	60
	Round	40
Seed Testa Colour	Black	4
	Brown	4
	Brown dark dotted	4
	Cream	12
	Cream purple	4
	Cream with purple patterns	4
	Dark cream	4
	Dark tan	4
	Dark tan with brown dots	4
	Light tan	8
	Purple	8
	Red	12
	Tan	20
	Tan with brown dots	8
Seed Eye Pattern Colour	None	64
	Brownish	4
	Brown	4
	Grey	4
	Black	4
	Purple	4
	Amber	16
Seed Hilum Colour	White	100
Growth Habit	Bunch	44
	Semi-bunch	24
	Spread	32
Leaflet Shape	Elliptic	24
	Oval	64
	Lanceolate	12
Stem Hairiness	Sparse	56
	Absent	40
	Dense	4
Pod Shape	Ending points, round on the other side	70
	Ending point, with nook on the other side	28
Pod Colour	Reddish-brown	4
	Yellow	24
	Brown	24
	Yellowish	8
Pod Texture	Little groove	36
	Much grooved	32
	Smooth	32

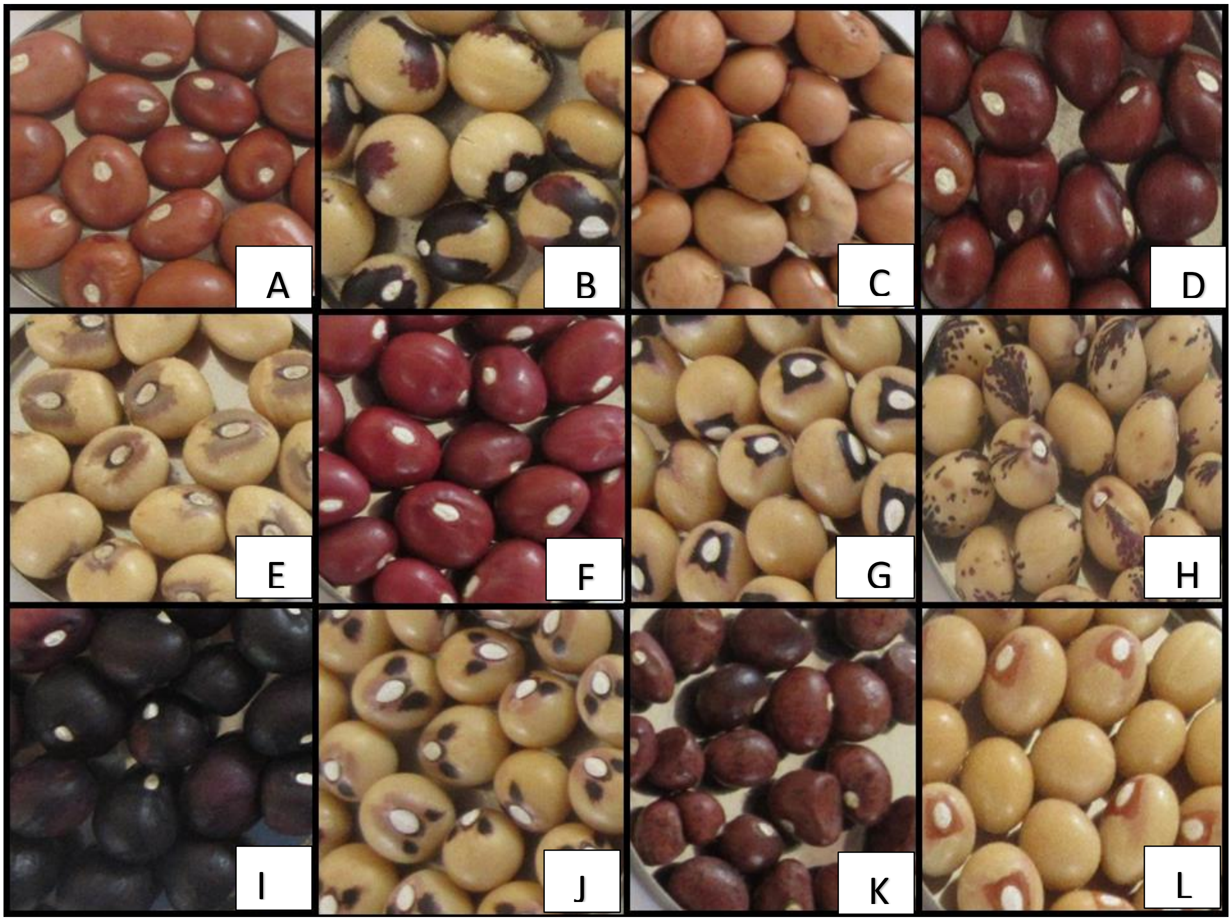

Figure 8: Bambara groundnut seed coat colour and seed eye colour of some accessions used.

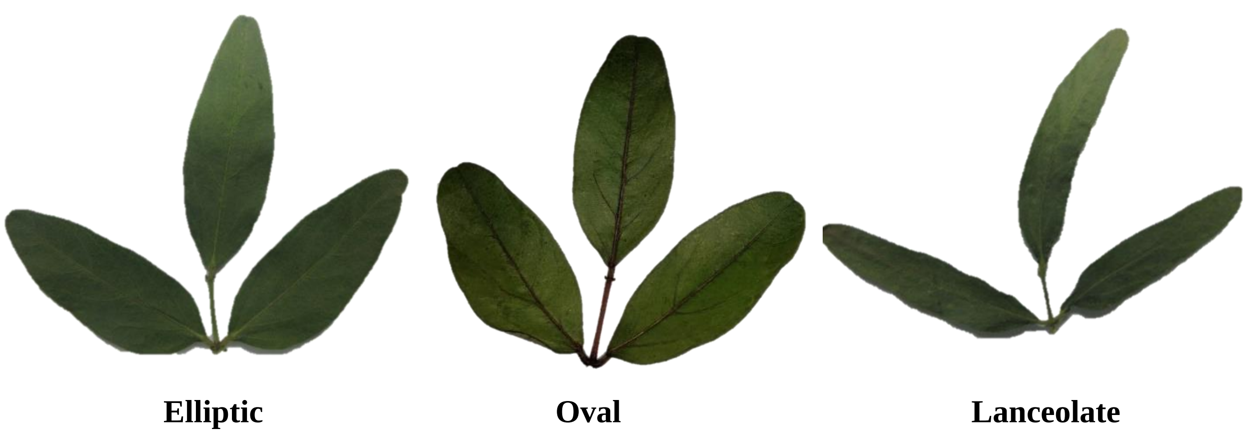

Figure 9: Bambara groundnut terminal leaflet shape.

4.3.1.2 Cluster analysis

Cluster analysis revealed five main clusters for the germplasm accessions (Figure 8). Two accessions from Malawi showed similarity as they belong to the same cluster that included some of the accessions sourced from Namibia. ZAM 01 from Kitwe, Zambia, revealed a close relationship with Namibian accession DIPC that originally obtained from Botswana and sourced from Omahenene Research Station. Some of the Namibian germplasm accessions are in the same cluster with Malawi and Zambia accessions that may result from the exchange of seeds across the border. The distance ranged from 0.804 to 0.004, with a decrease in similarity.

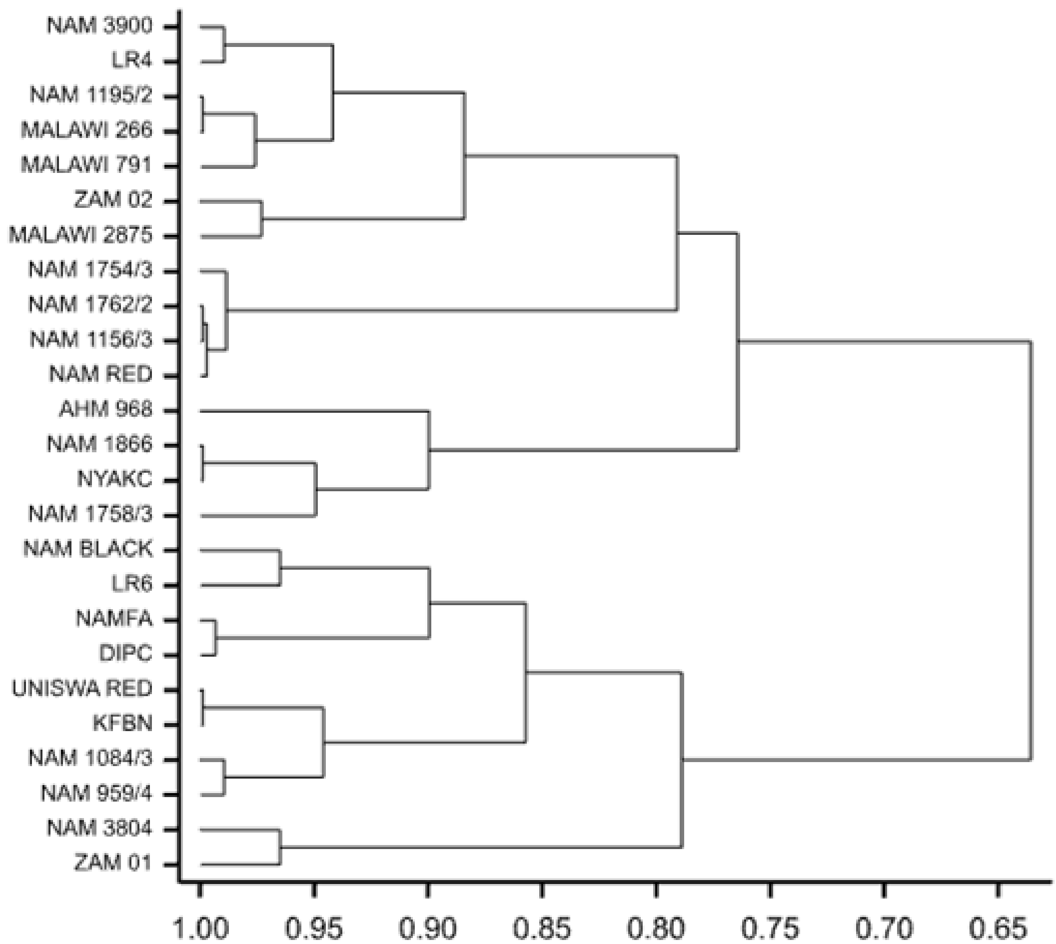

Figure 10: Phenogram showing the relationship among accessions based on similarity.

4.3.1.3 Diversity Index

Estimated Shannon-Weiner (H') for the Bambara groundnut qualitative characters assessed in the study were generally high. All traits showed a high level of polymorphism (H'>0.500). The indices ranged from 0.58 (pod texture) to 2.15 (growth habit) with an average of 0.92.

Table 14: Diversity index values on qualitative traits of 25 Bambara groundnut accessions

Qualitative trait	Shannon-Weiner index(H')

Seed shape	0.67
Seed testa colour	0.75
Seed eye pattern colour	1.22
Growth habit	2.15
Terminal leaflet shape	0.88
Seed hilum	0.00
Stem hairiness	0.82
Pod colour	1.49
Pod texture	0.58
Pod shape	0.59
Average diversity index	**0.92**

4.4 Evaluation of agronomic variation of Bambara groundnut

4.4.1 Descriptive statistics for Bambara groundnut quantitative data

The characters that revealed high variation were the yield and yield characters with a high coefficient of variation (CV), such as the number of pods per plant (66%), number of pods with two or more seeds (72%), fresh pod weight per plant (74%), dry pod weight plant(63%),100 pod weight (32%),100 seed weight (34%), harvest index (61%), pod yield (61%) and seed yield (57%). For the vegetative growth characters, the CV is depicted as follow: the number of leaves (37%), the number of branches is (37%), fresh biomass (52%) and dry biomass (43%). The analysis of variance of the study indicated a significant difference among the accessions for variables studied (Table 9). The characters such as plant height, terminal leaflet length, terminal leaflet width, number of leaves, number of pods per plant, fresh pod weight, dry pod weight, pod yield, and grain yield are highly significant at a 1% level of probability. The variables which are significant at 5% level of probability are the number of stems per plant, seed length, seed width, 100-seed weight, fresh biomass, and dry biomass.

Table 15: Descriptive statistics summary of 25 Bambara groundnut variables

Characters	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**	***P*-value**
D50F	30	41	35.57	2.04	0.06	0.266
PH(cm)	12.57	25	19.56	2.49	0.13	<0.001
TLW(mm)	13.33	27	20.04	3.03	0.15	<0.001
TLL(mm)	40	71.8	57.3	7.04	0.12	<0.001
NL	39	310	131.95	49.08	0.37	<0.001
NBP	13	103.6	44.03	16.3	0.37	0.022
NPP	2	46.8	16.21	10.74	0.66	<0.001
NSP	0	10.04	2.57	1.86	0.72	0.326
FPWP(g)	1.32	75.42	23.78	17.8	0.74	<0.001
DPWP(g)	1	31.13	12.14	7.65	0.63	<0.001
100PW(g)	35.41	268.14	96.36	31.32	0.32	0.13
100SD(g)	27.7	184.13	66.05	22.41	0.34	0.024
SL(mm)	9.02	17.07	13.35	1.65	0.12	0.027
SW(mm)	6.25	12.14	10.08	1.01	0.1	0.011
FB(g)	4.87	50.03	23.05	12.16	0.52	0.01
DB(g)	2.96	26.04	12.19	5.24	0.43	0.022
SP%	32.1	99.75	70.23	15.76	0.22	0.299
HI	0.01	1	0.37	0.23	0.61	0.662
PY(kg/ha)	47.62	563.57	214.77	131.59	0.61	<0.001
SY (kg/ha)	39.76	470.9	176.07	100.41	0.57	<0.001

Legend: D50F: Days to 50% flowering, **PH**: Plant height, **TLW**: Terminal leaflet width, **TLL**: Terminal length, **NBP**: Number of branches, **NPP**: Number of pods per plant, **NSP**: Number of pods with two or more seeds, **SL**: Seed length, **SW**: Seed width, **FPWP**: Fresh pod weight per plant, **DPWP**: Dry pod weight per plant,**100PW**:100 Pod weight, **100SD**: 100 Seed weight, **FB**: Fresh Biomass, **DB**: Dry Biomass, **SP**: Shelling Percentage, **HI**: Harvest Index, **PY**: Pod Yield, **SY**: Seed Yield

Table 16: Principal Component Analysis (PCA) of four components

	Eigen Vector			
	F1	**F2**	**F3**	**F4**
Eigenvalue	9.0418	2.8683	2.0884	1.3613
Variability (%)	45.2089	14.3417	10.4421	6.8065
Cumulative %	45.2089	59.5506	69.9928	76.7993
Variable				
D50F	0.1185	0.0074	-0.3635	0.3709
PH	0.1605	**0.3439**	-0.3513	-0.2032
TLW(mm)	**0.2740**	0.0591	0.0212	-0.3061
TLL(mm)	**0.2057**	0.2740	-0.1963	-0.0727
NL	**0.1460**	-0.3541	-0.2810	-0.1777
NBP	0.1427	**-0.3174**	-0.1814	-0.0126
NPP	**0.2571**	-0.1091	0.3540	0.0631
NSP	0.1732	-0.1621	0.0513	0.5414
FPWP(g)	**0.2986**	-0.1004	0.2357	-0.0430
DPWP(g)	**0.2987**	-0.0976	0.2555	-0.0345
100PW(g)	**0.2296**	0.2588	-0.1404	-0.2269
100SD(g)	0.2058	**0.3663**	0.0322	-0.0263
SL(mm)	0.2184	**0.2597**	-0.0148	0.3608
SW(mm)	0.2112	**0.2192**	-0.1352	0.2435
FB(g)	**0.2731**	-0.1736	-0.1244	0.0721
DB(g)	**0.2819**	-0.1456	-0.1942	0.0267
SP%	-0.0069	0.2560	0.2799	0.3044
HI	0.1384	-0.2865	**-0.2474**	0.0946
PY(kg/ha)	**0.2869**	-0.0353	0.2464	-0.1478
GY (kg/ha)	**0.2891**	-0.0492	0.2282	-0.1389

Legend: D50F: Days to 50% flowering, **PH**: Plant height, **TLW**: Terminal leaflet width, **TLL**: Terminal length, **NBP**: Number of branches, **NPP**: Number of pods per plant, **NSP**: Number of pods with two or more seeds, **SL**: Seed length, **SW**: Seed width, **FPWP**: Fresh pod weight per plant, **DPWP**: Dry pod weight per plant,**100PW**:100 Pod weight, **100SD**: 100 Seed weight, **FB**: Fresh Biomass, **DB**: Dry Biomass, **SP**: Shelling Percentage, **HI**: Harvest Index, **PY**: Pod Yield, **GY**: Seed Yield

4.4.2 Principal Component Analysis

The principal component analysis was used to deduce the relative importance or contribution of the individual agro-morphological traits to the total agro-morphological traits variability. Results indicated that four principal components accounted for the entire 76.8% variability. The first principal component accounted for about 45.2% of the variation, and all variables were grouped under this component except shelling percentage. Therefore, this component would be suitable for yield selection, as all yield components were included. The second component, representing 14.3% of the total variability, was associated with the variables such as days to 50% flowering, plant height, terminal leaf width, terminal leaf length, hundred pod weight, hundred seed weight, seed length, and seed width. The third principal component accounted for 10.4 % of total variability based on the vegetative traits and some yield components, terminal leaf length, number of pods with two or more seeds, fresh biomass per plant, dry biomass per plant, pod yield per hectare and grain yield per hectare. The fourth principal component accounted only for 6.8% of the total variation and comprised of days to 50% flowering, number of pods per plant, number of pods with two or more seeds, seed length, seed width, seed length, fresh biomass per plant, dry biomass per plant, shelling percentage and harvest index.

4.4.3 Principal Component Biplot

The variation observed among the Bambara groundnut germplasm accessions used in this study were depicted by the PCA biplot (Figure 10). The germplasm accessions were divided within four quadrants produced by the PCA biplot, which presented 59.55% of the variation for the two-axis PC1 and PC2 45.21% and 14.34%, respectively. Results showed that germplasm accessions NAM 1866, NAM 959/3, NAM 1156, MW 799, and NAM 1084 were in one quadrant, and four were from Namibia, one from Malawi. Another quadrant had LR6, NAM 1758/3, NAM 1762/2, UNISWA RED, NAM BLACK, NAM RED, and DIPC, whereby one germplasm accession was initially acquired from Swaziland. Another germplasm accession came from Botswana, and other accessions were from Namibia. The other quadrant comprised of LR4, ZAM 01, ZAM

02, NAM3804 and NAM 1195/2 accessions were Namibia, and MW 266 and MW 2875 were from Malawi. The last quadrant had NAM 3900, AHM 968, KFBN, NAMFA, NYAKC, and NAM 1754/3 germplasm accessions are all from Namibia. Hence germplasm accessions in the one quadrant were showing a strong relationship and association. Figure 10 also showed characters that were associated with PC1 and PC2 in component one; the descriptors contribute more are seed yield, number of pods per plant and dry biomass in component two are shelling percentage, number of leaves, number of biomass per plant and harvest index. The positive correlation was observed in pod yield and seed yield, while in component one and positive correlation of seed length and seed width in component two.

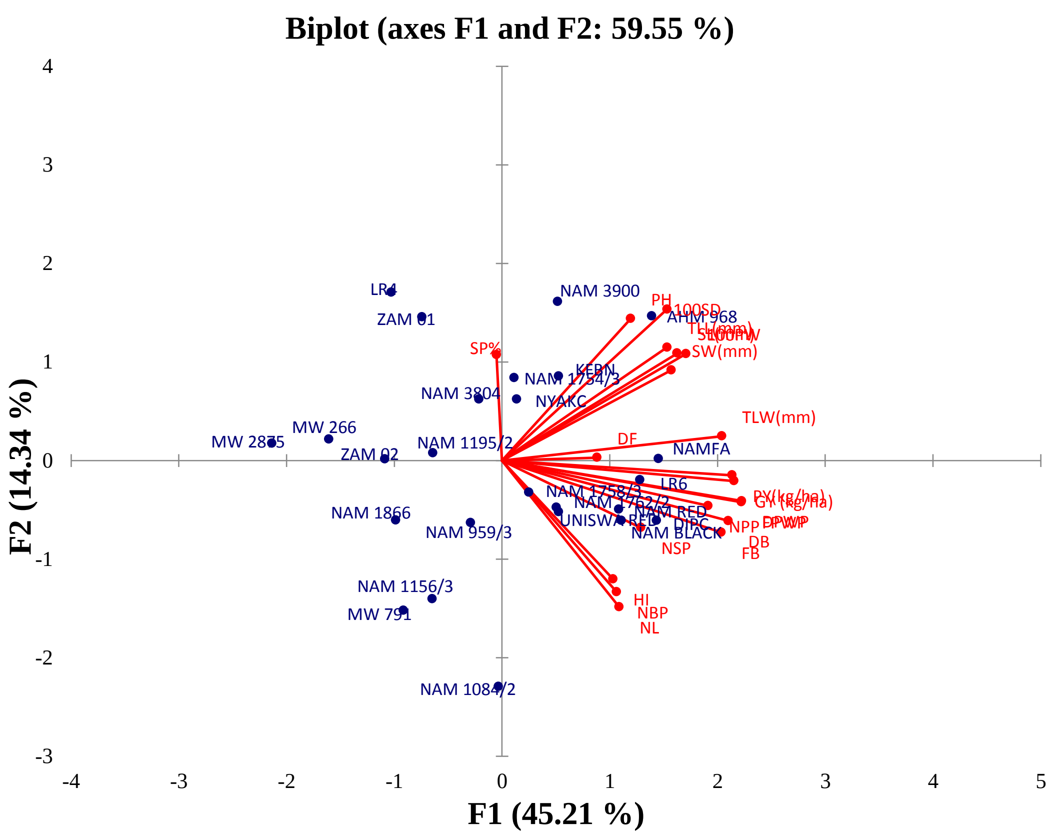

Figure 11: Configuration of the Bambara groundnut accessions under principal component axis 1 and 2

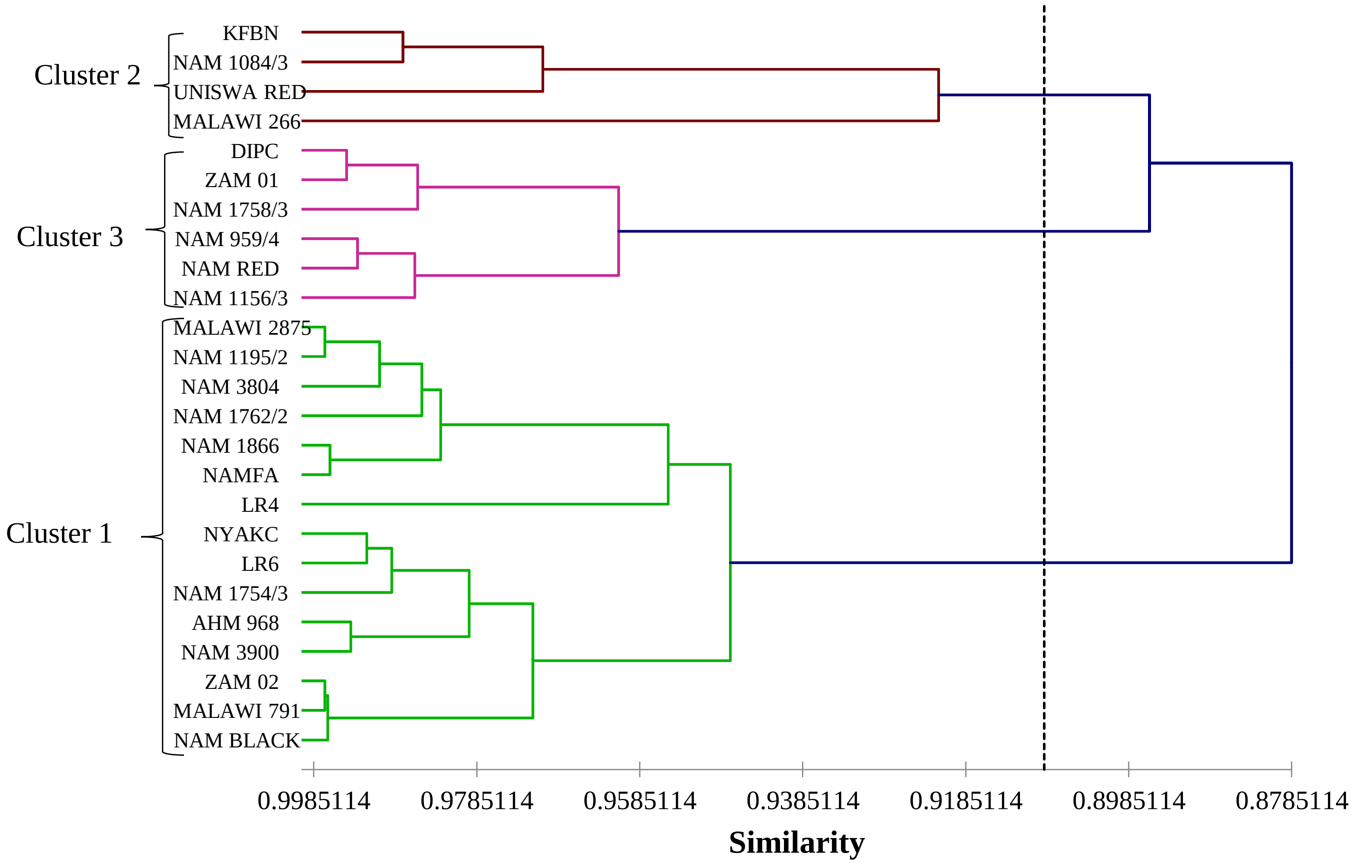

Figure 12: Dendrogram showing distinctive cluster constructed based on similarity among accessions.

4.4.5 Cluster analysis

The dendrogram from the average linkage method (UPGMA), grouped the twenty-five (25) accessions into three clusters, based on the data from quantitative traits as presented in Figure 10. The germplasm accessions were separated with a similarity distance from 0.99 to 0.87. Cluster one and two were similar at level 0.87, and cluster one was at the same level of 0.89. The first cluster consisted of fifteen accessions namely NAM 3900, AHM 968, NAM BLACK, LR6, NAM 3804, NAM 1195/2, MALAWI 791, ZAM 02,

NAMFA, NAM 1762/2, NAM 1866, NYAKC, MALAWI 2875 and LR4, In this cluster, there were two sub-clusters which were made up of different accessions. The second cluster included four germplasm accessions, including UNISWA RED, NAM 1084/3, KFBN, and MALAWI 266 in which one accession originated from Swaziland, one from Malawi and two accessions were from Namibia. The third cluster comprised of six accessions, including NAM 1758/3, ZAM 01, NAM RED, DIPC, NAM 1156/3, and NAM 959/4 whereby four germplasm accessions were from Namibia, one from Zambia and the other from Botswana.

4.4.6 Correlation analysis

Pearson's correlation coefficients in (table 11) showed different types of interrelationships among measured variables. Grain yield was significant and positively correlated with pod yield (r = 0.98), fresh pod weight (r = 0.71), dry pod weight (r = 0.81), number of pods per plant (r = 0.68), terminal leaf width (r = 0.61), terminal leaf length (r = 0.40), fresh biomass (r = 0.48) and dry biomass (r = 0.46).Plant height showed significant and positive correlation between terminal leaf length (r = 0.71) and terminal leaf width (r = 0.49). Terminal leaf length and terminal leaf width were positively correlating and highly significant (r = 0.53; p = <0.001). The number of branches per plant and number of leaves per plant was positively correlating (r = 0.74). The positive correlation was observed between fresh biomass and dry biomass (r = 0.91). Seed length and seed width showed a significant and positive correlation (r = 0.81). The dry pod weight per plant was positively correlated with pod yield (r = 0.82). Dry pod weight per plant and fresh pod weight per plant (r = 0.84) were positive correlating, and also fresh pod weight per plant and number of pods per plant ($r = 0.80$) are significant and positively correlated.

Table 17: Pearson correlation coefficient(r)(upper values) and *p*-value (lower values) of quantitative descriptors

Variables	D50F	PH	TLW(mm)	TLL(mm)	NL	NBP	NPP	NSP	FPWP	DPWP	100PW	100SD	SL(mm)	SW(mm)	FB	DB	SP%	HI	PY(kg/ha)	GY (kg/ha)
D50F	**1**																			
	0																			
PH	0.1513	**1**																		
	0.1950	**0**																		
TLW(mm)	**0.2114**	**0.4866**	**1**																	
	0.0687	**< 0.0001**	**0**																	
TLL(mm)	**0.3674**	**0.7097**	**0.5346**	**1**																
	0.0012	**< 0.0001**	**< 0.0001**	**0**																
NL	0.0771	0.1249	**0.2493**	0.1333	**1**															
	0.5106	0.2856	**0.0310**	0.2542	**0**															
NBP	0.0073	0.0789	0.1810	0.0595	**0.7418**	**1**														
	0.9508	0.5013	0.1203	0.6122	**< 0.0001**	**0**														
NPP	0.1859	0.0254	**0.4319**	**0.2865**	**0.3143**	**0.4622**	**1**													
	0.1103	0.8287	**0.0001**	**0.0127**	**0.0060**	**< 0.0001**	**0**													
NSP	0.1840	-0.0213	0.1542	0.0923	0.0973	**0.2362**	**0.3860**	**1**												
	0.1140	0.8563	0.1867	0.4310	0.4061	**0.0413**	**0.0006**	**0**												
FPWP	0.0765	0.1572	**0.5491**	**0.3035**	**0.3566**	**0.4005**	**0.8092**	**0.3854**	**1**											
	0.5140	0.1780	**< 0.0001**	**0.0081**	**0.0017**	**0.0004**	**< 0.0001**	**0.0006**	**0**											
DPWP	0.1307	0.1793	**0.5813**	**0.3403**	**0.3911**	**0.4302**	**0.8764**	**0.4748**	**0.8448**	**1**										
	0.2636	0.1238	**< 0.0001**	**0.0028**	**0.0005**	**0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**										
100PW	0.1494	**0.4166**	**0.4376**	**0.3225**	**0.2096**	**0.3484**	**0.3767**	**0.3017**	**0.4331**	**0.5404**	**1**									
	0.2009	**0.0002**	**< 0.0001**	**0.0048**	**0.0711**	**0.0022**	**0.0009**	**0.0085**	**0.0001**	**< 0.0001**	**0**									
100SD	**0.2453**	**0.3771**	**0.3752**	**0.3705**	0.0954	**0.2346**	**0.3639**	0.1568	**0.3041**	**0.4335**	**0.7667**	**1**								
	0.0339	**0.0009**	**0.0009**	**0.0011**	0.4155	**0.0428**	**0.0013**	0.1791	**0.0080**	**0.0001**	**< 0.0001**	**0**								
SL(mm)	0.1479	**0.2461**	**0.3575**	**0.2921**	-0.0074	-0.0810	**0.1997**	0.1815	0.1702	**0.2199**	0.0962	0.0818	**1**							
	0.2054	**0.0333**	**0.0016**	**0.0110**	0.9495	0.4899	**0.0858**	0.1191	0.1444	**0.0580**	0.4117	0.4856	**0**							
SW(mm)	**0.2735**	**0.2688**	**0.3973**	**0.2770**	0.0410	-0.0374	**0.1994**	0.1348	**0.2355**	**0.2224**	0.1752	0.1486	**0.8123**	**1**						
	0.0176	**0.0197**	**0.0004**	**0.0161**	0.7272	0.7504	**0.0863**	0.2487	**0.0419**	**0.0551**	0.1327	0.2031	**< 0.0001**	**0**						
FB	**0.1943**	**0.2202**	**0.3989**	**0.3716**	**0.3954**	**0.3214**	**0.4273**	**0.3415**	**0.4835**	**0.5493**	**0.3933**	**0.2691**	0.1124	**0.2093**	**1**					
	0.0949	**0.0577**	**0.0004**	**0.0010**	**0.0004**	**0.0049**	**0.0001**	**0.0027**	**< 0.0001**	**< 0.0001**	**0.0005**	**0.0196**	0.3370	**0.0715**	**0**					
DB	0.1397	**0.2850**	**0.4090**	**0.3847**	**0.5272**	**0.4291**	**0.4090**	**0.2999**	**0.5171**	**0.5520**	**0.4456**	**0.2722**	0.1341	**0.2289**	**0.9057**	**1**				
	0.2321	**0.0132**	**0.0003**	**0.0007**	**< 0.0001**	**0.0001**	**0.0003**	**0.0090**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.0182**	0.2513	**0.0482**	**< 0.0001**	**0**				
SP%	0.0969	-0.0593	-0.1095	0.0632	**-0.2032**	-0.1811	-0.0527	**-0.2213**	-0.1868	-0.1782	**-0.3326**	**0.3246**	-0.0757	-0.0701	-0.1622	**-0.2508**	**1**			
	0.4081	0.6131	0.3498	0.5904	**0.0805**	0.1199	0.6534	**0.0563**	0.1086	0.1261	**0.0036**	**0.0045**	0.5186	0.5502	0.1644	**0.0300**	**0**			
HI	0.1687	0.0467	0.0920	0.1742	0.1851	0.0797	0.0633	0.1496	0.0753	0.0987	-0.0515	**-0.2501**	0.1177	0.1782	**0.5421**	**0.4143**	**-0.2203**	**1**		
	0.1479	0.6906	0.4322	0.1349	0.1118	0.4965	0.5893	0.2002	0.5209	0.3993	0.6610	**0.0305**	0.3144	0.1261	**< 0.0001**	**0.0002**	**0.0576**	**0**		
PY(kg/ha)	0.1472	**0.2543**	**0.6091**	**0.4176**	**0.3081**	**0.2560**	**0.6921**	**0.2641**	**0.6855**	**0.8182**	**0.3645**	**0.3054**	**0.2544**	**0.2406**	**0.4639**	**0.4479**	-0.0997	0.1890	**1**	
	0.2076	**0.0277**	**< 0.0001**	**0.0002**	**0.0072**	**0.0266**	**< 0.0001**	**0.0220**	**< 0.0001**	**< 0.0001**	**0.0013**	**0.0077**	**0.0276**	**0.0376**	**< 0.0001**	**< 0.0001**	0.3946	0.1044	**0**	
GY (kg/ha)	0.1322	**0.2608**	**0.6144**	**0.4087**	**0.2837**	**0.2484**	**0.6847**	**0.3094**	**0.7051**	**0.8142**	**0.3725**	**0.2975**	**0.2420**	**0.2353**	**0.4836**	**0.4604**	-0.1178	**0.2193**	**0.9808**	**1**
	0.2582	**0.0238**	**< 0.0001**	**0.0003**	**0.0137**	**0.0317**	**< 0.0001**	**0.0069**	**< 0.0001**	**< 0.0001**	**0.0010**	**0.0095**	**0.0364**	**0.0421**	**< 0.0001**	**< 0.0001**	0.3143	**0.0587**	**< 0.0001**	**0**

Values in bold are different from 0 with a significance level alpha=0.1

Legend: D50F: Days to 50% flowering, **PH**: Plant height, **TLW**: Terminal leaflet width, **TLL**: Terminal length, **NBP**: Number of branches, **NPP**: Number of pods per plant, **NSP**: Number of pods with two or more seeds, **SL**: Seed length, **SW**: Seed width, **FPWP**: Fresh pod weight per plant, **DPWP**: Dry pod weight per plant,**100PW**:100 Pod weight, **100SD**: 100 Seed weight, **FB**: Fresh Biomass, **DB**: Dry Biomass, **SP**: Shelling Percentage, **HI**: Harvest Index, **PY**: Pod Yield, **GY**: Seed Yield

4.5 Discussion

4.5.1 Phenotypic characterisation of Bambara groundnut crops, seeds, and pods

All phenological characters studied showed morphological variation among accession except for seed hilum. Similar results were reported by Ntundu et al. (2006) in Tanzania, Ndiang et al. (2014) in Cameroon and Gbaguidi et al. (2017) in Benin and hence this qualitative information could be integrated into a breeding program of Bambara groundnut. The Shannon Weiner Index (H') for the qualitative variables characterised in the study was very high, indicating the variability among accessions descriptors with an average of 0.92 (Molosiwa, 2012). The dendrogram revealed the variability in accessions and grouped them into five (5) main classes were based on similarity. Therefore there was variability among Bambara groundnut accessions in this study.

4.5.2 Evaluation of agronomic variation of Bambara groundnut

Descriptive and analysis of variance for Bambara groundnut quantitative data

The genetic variability observed in breeding materials is an indication of desirable characters of crops that can be integrated into the breeding program (Choudhary, Payasi, & Patle, 2017). The observed significant differences indicated that considerable genetic variation existed among evaluated accessions using characters investigated. Madukwe, Onuh, & Christo, 2011 and Mohammed, 2014 reported highly significant differences among Bambara groundnut accessions with selected characters. The assessment of genetic diversity in agro-morphological variability and characterisation is the first step in breeding (Ndiang et al., 2014; Buah, Abu, & Leduah, 2011). There are many studies done assessing genetic diversity in which different agro-morphological characteristics are included as reported by Goli (1995); Anchirinah & Bennet-Lartey (2002); Massawe et al. (2002); Sesay, Edje, & Magagula (2003); Fleissner (2006), Ouedraogo et al. (2008); Akter, Biswasb, Azad, Hasanuzzama, & Marifuzzaman (2010); Molosiwa (2012); Shengro, Rensburg, & Adebola (2013); Mohammed, Shimelis, & Laing (2016); Gbaguidi, Dansi, Dossou-Aminon, & Gbemavo (2017). The results revealed that significant variability existed among the accessions as many characters are highly significant, and those characters can be used as pre-breeding materials for a Bambara groundnut improvement program. The significant difference in plant height, where plants are of different height, terminal leaf length and width and leaf shape were also different (Mohammed, Shimelis, & Laing, 2016). Plants had a different number of leaves that contributed to crop biomass as fresh and dry biomass are also significantly different. Masindeni (2006) reported variations in the number of pods per plant. In this study, the seed yield for NAM BLACK is 24.10 g per plant, and for NAM RED 23.15g is per plant, this yield is comparable with yield obtained by other researchers, Berchie, et al., 2010, in Ghana recorded 23.6 g per plant. Seed length and seed width were different as seeds had a different shape and belonged to a different accession, which may cause variation. Hundred pod weight does not vary, but a hundred seeds weight is significantly different because seeds have different sizes.

Principal Component Analysis

By using principal component analysis, the day to 50% flowering, plant height, terminal leaf length, terminal leaf width, number of leaves, number of branched per plant, number of pods with two or more seeds, fresh pod weight per plant, dry pod weight per plant, hundred pod weight, hundred seed weight, seed length, seed weight, fresh biomass, dry biomass, shelling percentage, harvest index, pod yield and seed yield were important in accession grouping and suggesting consideration in agronomic superior trait selection as this made up 45.2% of the first component (PC1). It is assumed that those farmers had selected Bambara groundnut for specific agro-morphological traits using these accessions as similar observation was done by Ntundu, et al. (2006) reported that farmers used leaf morphology, seed colour and size criteria for selection in Tanzania.

Principal Component Biplot

The principal component biplot further explained agro-morphological similarity and variation among Bambara groundnut germplasm accessions as grouped in PC1 and PC2. The quantitative traits studied lead to the grouping of accessions into four quadrants that presented 59.55%. The accessions were scattered in all quadrants, showing genetic variability of characters and those which were close to each. Other quadrant had ZAM 01, ZAM 02, NAM 3804, NAM 1754/3, LR4, MW 266 and MW 2875 accessions it might due to the exchange of seeds across African countries as there were germplasm accessions from Zambia, Namibia, and Malawi.

The accessions showed grouping or pairing, irrespective of place of origin within axes. This implies the sharing of features for the 20 quantitative traits that were studied. Some studies by Ntundu, et al., (2016) and Molosiwa, (2015) reported Bambara groundnut accessions grouped according to the place of origin which is in disagreement with the results obtained from this study. Moreover, the accessions that scattered far apart within axes or quadrant were distantly related to each other within the same quadrant, for example, accession LR4 and NAM 1195/2 are far from each other within a quadrant. The strong association was observed in accessions such as NAM RED and UNISWA RED which were in the same quadrant and close to each other, so it applies that this was having common feature or traits such as high yield and both have red seed coat colour. The grouping, as mentioned above of Bambara groundnut accessions showed a relationship with individuals with common feature or origin. The accessions within quadrant that are originated from different places it might be that the accessions are the same but due to the exchange of seeds, it might that they have different names and originated from the same place (Shengro, Rensburg, & Adebola, 2013).

Cluster analysis

The grouping of germplasm accessions into three clusters was due to the relationship within and among accessions. Accessions NAM 3900, AHM 968, NAM BLACK, LR6, NAM 3804, NAM 1195/2, MALAWI 791, ZAM 02, NAMFA, NAM 1762/2, NAM 1866, NYAKC, MALAWI 2875 and LR4 were in one cluster implied some common traits in those accessions and illustrated some extent of similarity with principal component biplot. The germplasm accessions in the third cluster and second cluster were having grouped accession with similar agro-morphological attributes; for instance, the third cluster had germplasm accessions, which are all having cream seed coat colour. The similarity among accession would result from same accessions bearing the different name but grown in a different region thus the name but is the same seed material thus genomic characterisation may be necessary for Africa to have distinct information of the germplasm accessions. Similar results were reported by Mohammed 2016. Therefore it could be concluded that plant breeders might use accessions belonging to different clusters for hybridisation to get maximum heterosis.

Correlation analysis

The correlation coefficient is an essential parameter in plant breeding since it measures the degree of genetic or non-genetic association between two or more characters (Jonah et al., 2012). In this study, the correlation coefficients detected between Bambara groundnut yields and its yield components were positively correlated; for example, seed yield and pod yield, implying that the more the pods, the higher the seed yield. These results are in agreement with those obtained by Gonné, Félix-Alain, & Bargui (2013), who found a high correlation between seed yield and pod yield in Bambara groundnut. Moreover, seed yield was positively correlated with the number of pods with two or more seeds, the number of pods per plant, fresh pod weight per plant, and dry pod weight per plant. Similar results were reported by Ouedraogo et al. (2008). The dry pod weight per plant was positively correlated with pod yield. Dry pod weight per plant and fresh pod weight per plant were positively correlated; also, fresh pod weight per plant and the number of pods per plant were positively correlated. These are the characters that contribute to Bambara groundnut seed yield, hence crucial for yield improvement. Bambara groundnut farmers would prefer high-yielding varieties to secure food. A positive correlation was observed between fresh biomass and dry biomass, an association which may be valuable for biomass production as some farmers use parts of the plant biomass (leaves and roots) as livestock feed. Moreover, there was a significant positive correlation between seed length and seed width of the Bambara groundnut. The Bambara groundnut farmers prefer big sized seeds, as indicated by Fleissner (2006). Therefore, this association would be critical for seed size improvement.

4.6 Conclusion

Agro-morphological traits showed that a considerable measure of variability exists among the Bambara groundnut accessions studied. The accessions illustrated differences in seed yield per plant, number of pods per plant, seed size, and biomass. The cluster analysis grouped accessions into three major clusters. Principal component analysis indicated the agro-morphological traits that contributed to the variation among accessions and the biplot further grouped accessions into two main components still indicating diversity. Correlation analysis showed a significant and positive correlation between traits.

CHAPTER 5

EXPERIMENT 3: CONSTRUCTION OF SELECTION INDEX FOR BAMBARA GROUNDNUT YIELD

5.1 Introduction

Bambara groundnut is one of the critical orphan food crops of the communal farming community. The yield of this crop is meagre as indicated by farmers during the needs assessment study across the five constituencies in Northern Namibia. In plant breeding, successful yield improvement depends on the amount of genetic variability present in the population and the extent to which the desirable characters are heritable (Oladosu et al., 2018). Seed yield in Bambara groundnut is a quantitative trait, which depends on the yield components; thus, the improvement of yield components may assist in the improvement of seed yield of Bambara groundnut. The direct selection for seed yield is often misleading because the yield trait is influenced by environmental factors (Monpara & Chatrola, 2010). The yield components do not equally contribute toward seed yield; that is why the combination of components may be helpful to improve seed yield. For Bambara groundnut, the economic part known as the pods are developed underground, the prediction of its performance based on aerial morphological characters is quite difficult (Weiss, 2000). The most preferred method to improve characters such as yield is simultaneous selection based on related characters (Bos & Caligri, 2007), using selection index, which is multiple regressions of genotypic values on phenotypic values of several characters (Falconer, 1989). The selection index is superior in improving complex traits (Hasel & Lush, 1942; Jesus Céron-Rojas & Crossa, 2018).

The selection index is most commonly and best construction method used for selection of several characters at a time (Shah & LataRaval, 2016). Some researchers (e.g., Akter et al., 2010) used selection index and discriminant function analysis for improvement of different crops such as groundnut, rice, mung beans, and wheat. Plant breeders get more successful results using the selection index for the expected genetic advance by using a direct and indirect selection of the different characters (Smith et al., 1981; Rabiei et al., 2004). The selection indices method aimed at determining suitable combinations of characters to indirectly improve the yield (Dobariya et al., 2008).

5.2 Methodology

5.2.1 Study site, materials, and experimental design

The study was carried out at the Crop Science Experimental Field, University of Namibia Ogongo Campus during the 2017/2018 cropping season. The experimental entries consisted of 25 accessions, including one control. The accessions were obtained from Namibia Botanical Research Institute, Omahenene Research Station, Chitedze Research Station and Kitwe (Table 9). The experimental design was a square lattice design with three replications and 15 blocks totalling 75 experimental units. The discriminant function technique was used to construct a selection index, the method developed by Smith (1936), following the simultaneous selection model.

5.2.2 Data collection and analysis

Data were collected on seed yield of the 25 Bambara groundnut accessions. The yield component data included seed yield per hectare (X1), biological yield (X2), dry pod weight per plant (X3) and pod yield per hectare (X4). For the construction of the selection indices, the characters, which had desirable correlations as well as moderate to a higher direct effect on pod yield per plant, were considered and sizable direct effects on grain yield were considered. The model suggested by Robinson *et al.* (1951) was used for the construction of selection indices and the development of the required discriminant function. In this context, seed yield per hectare (X1) as an independent variable, along with its three components biological yield (X2), dry pod weight per plant (X3) and pod yield per hectare (X4) were identified and considered for the construction of selection indices. A total of 15 selection indices were constructed using the four characters. The respective genetic advance through selection was also calculated as per the formula suggested by Robinson et al. (1951). The relative efficiency of different discriminant functions in relation to straight selection for grain yield were assessed and compared, assuming the efficiency of selection for grain yield per plant as 100%. The data were analysed to construct selection indices, genetic advance and relative efficiency. Genetic Advance (GA) assuming selection of superior 5% of the genotypes was estimated following the methods illustrated by Robinson et al. (1951) as:

$$GA = \frac{K \times \sqrt{\sigma^2 p} \times \sigma^2 g}{\sigma^2 p}$$

where GA is the expected genetic advance, K is the standardised selection differential at 5% selection intensity (K-2.063), σ^2p is the phenotypic variance, and σ^2g represent the genotypic variance. Relative efficiency over selection for seed yield was computed for all traits as:

$$RI = \{GA\ (D)/GA\ (S)\} \times 100$$

where:

RI = Relative efficiency indices.

GA (D) = Genetic advance through discriminant function

GA (S) = Genetic advance through a straight selection

5.3 Results

Selection indices for seed yield and other traits were constructed and examined to identify their relative efficiency. The results on selection indices, discriminant functions, expected genetic gain and relative efficiency are presented in Table 19. The results showed that the genetic advance and relative efficiency assessed for different indices varied from straight selection when the selection was based on component traits which further changed considerably with the inclusion of two or more characters. A total of 15 selection indices (Table 19) based on four traits constructed in all possible combinations revealed that the selection efficiency was high over straight selection when the selection was based on individual components. Dry pod yield per plant (g) showed a genetic advance of 18.55%, which was the highest than that of others calculated for other characters suggested that biological yield per plant (g) proved to be a better selection index based on one trait. The two traits, seed yield per hectare and biological yield had the highest genetic gain of 30.98% (Table 19) when the selection is simultaneously based on by a discriminant function. For the three traits, the genetic advance increased to 41.23%. The combination of the four traits had a genetic gain of 44.30%.

Table 18 presents the relative efficiency of various selection indices indicated that single traits index measured for seed yield as straight selection, the relative efficiency decreased to less than 100%. The highest selection efficiency of 169.41%, when including one trait in the selection function. The selection efficiency for two traits was 282.92% for three traits, 376.53%. The relative efficiency of the four traits was 404.57%.

Table 18: Selection indices for yield and their relative efficiency in bambara groundnut

No.	Selection Index	Discriminant Function	Expected Genetic Advance(%)	Relative Efficiency (%)
1	X_1	$0.022X_1$	10.95	100.00
2	X_2	$0.091X_2$	17.74	162.01
3	X_3	$0.187X_3$	18.55	169.41
4	X_4	$0.015X_4$	17.31	158.08
5	$X_1 + X_2$	$0.022X_1 + 0.005X_2$	20.74	189.41
v6	$X_1 + X_3$	$0.022X_1 - 0.004X_3$	30.98	282.92
7	$X_1 + X_4$	$0.028X_1 - 0.004X_4$	20.23	184.75
8	$X_2 + X_3$	$0.012X_2 + 0.176X_3$	20.17	184.20
9	$X_2 + X_4$	$0.012X_2 + 0.015X_4$	25.37	231.69
10	$X_3 + X_4$	$0.012X_3 + 0.015X_4$	22.31	203.74

11	$X_1+X_2+X_3$	$0.022X_1+0.006X_2-0.009X_3$	30.72	280.55
12	$X_1+X_3+X_4$	$0.028X_1+0.0001X_3-0.004X_4$	41.23	376.53
13	$X_1+X_2+X_4$	$0.027X_1+0.005X_2-0.004X_4$	30.05	274.4
14	$X_2+X_3+X_4$	$0.011X_2+0.003X_3+0.015X_4$	34.09	311.32
15	$X_1+X_2+X_3+X_4$	$-0.027X_1-0.005X_2+0.004X_3+0.004X_4$	44.30	404.57

X_1 = Seed yield per hectare X_2 = Biological yield X_3 = Dry pod weight per plant X_4 = Fresh pod weight per hectare

5.4 Discussion

Farmers from Northern Namibia indicated during a needs assessment survey that low yield of the Bambara groundnut is a challenge; hence selection index would be a useful model for yield selection. The selection index was constructed to identify a suitable combination of traits using a simultaneous selection model considering four yield traits. The study revealed that the index that had more than one characters gave the highest genetic advance, suggesting the utility of constructing selection indices for effecting simultaneous improvement in several traits. Hazel and Lush (1943) indicated that the superiority of selection based on index increases with an increasing number of traits under selection. Other authors that supported the findings are Smith (1936), Rao (1974), Asgthar & Mehdi, (2010), Babariya et al. (2014) and Gupta et al. (2015) that inclusion of many traits in the equation resulted in increasing genetic advance and that the selection indices improve the efficiency than the straight selection for yield alone. Therefore, with the above findings, indirect selection through individual traits over straight selection for pod yield per plant alone would not be effective.

Selection index advantaged plant breeders as time and labour are saved in the selection program of a particular crop, in this case, Bambara groundnut. It is desirable to include a few traits in the selection to avoid too much labour. For instance, if our four traits gave high genetic advance, practically, it is more laborious to use in the selection program. Practically, the plant breeder might be interested in working with few traits with maximum genetic advance. For this study, the improvement of seed yield in the Bambara groundnut could be achieved by selecting the parents with the combination of two traits, biological yield per plant and pod yield per hectare. Selection efficiency improved with several traits added in combination with yield. This method of selection has also been used in crops such as lentil by Nath et al. (2014), wheat (Shah & LataRaval, 2016), groundnut (Raghuwanshi et al., 2015), mungbean (Indu, Niyaria, Raghuwanshi, & Saxena, 2016; Choudhary, Payasi, & Patle, 2017), Okra (Monpara & Chatrola, 2010), sweet corn (Asgthar & Mehdi, 2010) and rice (Dutta, Dutta, & Borua, 2013).

5.5 Conclusions

Previously, Bambara groundnut seed yield improvement mainly used a direct selection method. The present study demonstrated the use of an indirect selection method as a tool for selecting superior varieties in the Bambara groundnut germplasm. The indirect selection of seed yield was conducted using the discriminant function. The best traits combinations identified were seed yield, dry pod weight per plant, fresh pod weight, and biological yield, with the highest GA of 44.30% and relative efficiency of 404.57%. However, the plant breeder would prefer to work with fewer traits while maximizing yield. So the suitable choice would be a combination of three traits, which were seed yield, dry pod weight per plant and fresh pod weight that had a GA of 41.23% and selection efficiency of 376%. This selection method for seed yield appears to be more effective and efficient compared to the conventional method, the straight selection method.

CHAPTER 6

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

In all the constituencies studied, women were the majority in terms of their involvement in Bambara groundnut production than men. The findings of this study suggested that there is a considerable number of Bambara groundnut farmers' preferences that need requires consideration for the strategic improvement of the crop. Farmers in the study area responded that the Bambara groundnut is one of the crops that can be mix-cropped with others. There are unimproved varieties that farmers have been cultivating for more than forty-one (41) years and are named according to colours and performance. However, most of the varieties currently used have not been improved to increase yield. Also, farmers indicated their preferred traits, including seed size, high yield, bushy type and cream seeds. The farmers further stated that they used seeds from the previous harvest annually. Bambara groundnut being a self-pollinated crop, there is a possibility of losing genetic diversity. Bambara groundnut farmers indicated that the crop leaves are used as fodder for livestock, and some reported that leaves are also used for medicinal purposes. The field experiment demonstrated that there is variation among accessions as revealed by the results of the multivariate analysis technique. The Smith-Hazel selection index identified best traits combination that has high genetic advance and fair relative efficiency, and such traits can be considered for the improvement of the crop.

6.2 Recommendations

In Anamulenge, Okatana, Ondobe, Okankolo and Kapako constituencies, women were the majority involved in Bambara groundnut production than men. Hence more men need to be encouraged to participate in Bambara groundnut farming regardless of culture and norms, which may contribute to increased production. The farmer's preferred traits such as high yield, seed size, seed coat colour, early maturity, and drought tolerance need to be incorporated into a national breeding program so that smallholder farmers can benefit from such improved varieties. Bambara groundnut farmers preferred certain varieties, namely Olunya, Okaongoti, Engowa, Okambishi, Egogani, and others, although these may have different names based on colours and performance, which suggest the need to standardize names to avoid duplication of varieties. It was also found that most farmers in the study area had been farming with the crop for decades, denoting its significance among the local communities. This situation warrants intervention by government and other research institutions to initiate a crop improvement program to generate high-yield Bambara groundnut cultivar and facilitate commercialization, consequently, improving household nutrition, food and feed status and income generated through the sales of this crop. The accession used in this study displayed high phenotypic variability, so they could be used to start a national crop improvement programme for Bambara. Besides, the study recommends the use of an indirect selection of characters in Bambara groundnut breeding program to reduce the higher cost associated with the direct selection method and increase crop performance and final seed yield. The molecular markers are recommended to detect variation in germplasm accession used in this study.

7. REFERENCES

Abu, H. B., & Buah, S. S. (2011). Characterization of Bambara Groundnut Landraces and their Evaluation by Farmers in the Upper West Region of Ghana. Journal of Developments in Sustainable Agriculture, *6*, 64–74.

Adu-Dapaah, H., & Sangwan, R. (2004). Improving Bambara groundnut productivity using gamma irradiation and in vitro techniques. *Africa Journal of Biotechnology*, 260-265.

Akpalu, M., Sarkdie-Addo, J., & Akpalu, S. (2012). Effect of Spacing on growth and Yield of five Bambara groundnut (*Vigna subterranean* (L.) Verdc) landrace. Journal of Science and Technology, *32*(2), 10–11.

Akter, S., Biswasb, K. A., Azad, K., Hasanuzzama, M., & Marifuzzaman, M. (2010). Correlation and discriminant function analysis of some selected characters in fine rice (*Oryza sativa* L.) available in Bangladesh. International Journal Sustainable Crop Production, *5*(4), 30–35.

Aliyu, S., Massawe, F., & Mayes, S. (2016). Genetic and population structure of Bambara groundnut (*Vigna substerranea* (L.) Verdc,) Synopsis of the past two decade of analysis and implication for crop improvement. Genetic Resource Crop Evolution *63*, 925–943.

Amadou, H., Bebeli, P., & Kalsikes, P. (2001). Genetic diversity in Bambara groundnut (*Vigna subterranean* L.) germplasm revealed by RAPD markers. Genome, 995–999.

Amarteifio, J. (2003). A review of nutrient composition of Bambara groundnut (Vigna subterrenea(L) Verdc) grown in Botswana: In proceedings of the international

Bambara groundnut symposium. Botswana Sept 8-12: Botswana College of Agriculture.

Amarteifio, J., Tibe, O., & Njogu, R. (2006). The mineral of Bambara groudnut (Vigna subterranea(L) Verdc) grown in Southern Africa. *African Journal of Biotechnology*, *5*, 2408-2411.

Anchirinah, V., & Bennet-Lartey, S. (2002). Monitoring Genetic Diversity of Bambara Groundnut (*Vigna subterranea* (L.) Verdc.) in two districts of the Upper West Region of Ghana through Ethnobotanics and Genetic Erosion Studies. In promotion of Bambara Groundnut.paper presented at the First Biennial National Agricultural Research System Workshop, International Conference Centre, Accra, Ghana, World Crops, Vol 23,1971,195–196.

Asgthar, M., & Mehdi, S. (2010). Selection indices for yield and quality traits in sweet corn. Pakistan Journal Botany, *42*(2), 775–789.

Atoyebi, O., Oyatomi, O., Osilesi, O., Adebawo, O., & Abberton, M. (2017). Morphological characterisation of selected African accessions of Bambara groundnut (*Vigna subterranea* (L) Verdc*). International Journal of Plant Research*, *7*, 29–35.

Azam-Ali, S., Sesay, A., Karikari S, K., Massawe, F., Anguilar-Manjarrez, J., Bannayan, M., & Hampson, K. (2001). Assessing the potential of an underutilised crop-A case stidy using Bambara groundnut. *Exp.Agric*, *37*, 433-475.

Babariya C, A., Dobariya K, L., Sapovadiya M, H., & Vavdiya P, A. (2014). Discriminant function method of selection in groundnut (*Arachis hypogaea* (L.). *Electronic Journal of Plant Breeding*, 112–116.

Bamshaiye, O., Agegbola, J., & Bamishaiye, E. (2011). Bambara groundnut: An Underutilized Nut in Africa. *Advances in Agricultural Biotechnology*, *1,* 60–71.

Berchie, J., Adu- Dapaah, H., Dankyi, A., Plahar, N. Q., Haleegoah, J., Asafu- Agyei J, N., & Addo, J. (2010). Practices and Constraints in Bambara Groundnuts Production, Marketing and Consumption in the Brong Ahafo and Upper-East Regions of Ghana. *Journal of Agronomy*, *9,* 111–118. doi: 10.3923/ja.2010.111.118

Bernardo, R. (2008). Molecular markers and selection for complex traits in plants: Learning from the last 20 years. *Crop Science*, *48*, 1649–1664.

Brink, M., Ramolemana, G. M., & Sibuga, K. P. (2006). *Vigna subterranea* (L.) Verdc. Plant Resources of Tropical Africa.

Bos, I. and Caligari, P. (2007). *Selection methods in plant breeding*. (2nd edition), Germany: Springer Science & Business Media B. V.

Buah, H., Abu, B., & Leduah, S. S. (2011). Characterization of Bambara groundnut landraces and their evaluation by farmers in the Upper West Region of Ghana. *Journal of Developments in Sustainable Agriculture*, *6*, 64–74.

Caballero, A., Quesada, H., & Rolan-Alvarez, E. (2008). Impact of amplified fragment length polymorphism size homoplasy on the estimation of population genetic and the detection of selective loci. *Genetics*, *179*, 539–554.

Challinor, A., Wheeler, T., Graforth, C., Craufurd, P., & Kassam. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climate Change*, *83*, 381–399.

Chamber, R. (1994). Paradigm shifts and the practice of participatory research and development. Institute of development studies. doi:10.3168/jds.S0022-0302(94)77044-2

Chivenge, P., Mabhaudhi, T., Modi, A. T., & Mafongoya, P. (2015). The Potential Role of Neglected and Underutilised Crop Species as Future Crops under Water Scarce Conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, *12*, 5685–5711. doi:10.3390/ijerph120605685

Choudhary, P., Payasi, S., & Patle, N. (2017). Genetic study and selection indices for grain yield of mungbean. *Legume Research*, *40*(5), 836–841.

Cochran, W. G. (1977). Sampling techniques (3rd ed.). New York: John Wiley & Sons.

DAFF. (2016). Production of Bambara Groundnut. Retrieved from http://www.daff.gov.za/Daffweb3/Portals/0/Brochures%20and%20Production%20 guidelines/Bambara.pdf: http://www.daff.gov.za

Dobariya, K. L., Odedra, R. K., Jivani, L. L., Ponkia, H. P. and Khanpara, M. D. (2008). Selection indices for yield improvement in groundnut (*Arachis hypogaea* L.). *Intl. J. of Bioscience Reporter*, *6*(2), 299–330.

Dutta, P., Dutta, P., & Borua, P. (2013). Morphological traits as selection indices in rice: A Statistical View. Universal Journal of Agricultural Research, *1*(3), 85–96. doi:10.13189/ujar.2013.010308

FAO. (2015, April 30). FAOSTAT Online Database. Retrieved from http://faostat3.fao.org/home/E.: FAOSTAT Online Database

Falconer, D. S. (1989). *Introduction to quantitative genetics*, 3rd Ed., John Wiley and Sons. Inc., New York.

Feldman, A., Wai, K. H., Massawe, F., & Mayes, S. (2019). Bambara Groundnut is a Climate-Resilient Crop: How Could a Drought-Tolerant and Nutritious Legume Improve Community Resilience in the Face of Climate Change? In A. Sarkar, S. Sensarma, & G. van Loon, Sustainable Solutions for Food Security (pp. 151–167). Switzerland: Springer, Cham. doi:10.1007/978-3-319-77878-5_8

Ferdous, M., Shamsuddin, A., Hasna, D., & Bhuiyan, M. R. (2010). Study on the relationship and selection index for yield and yield contributing characters n spring wheat. *Journal of Bangladesh Agriculture University*, *8*(2), 191–194.

Fisher, R. A. (1936). The use of multiple measurements in taxonomic problems. *Ann. Eugen*, ***7***, 179.

Fleissner, K. W. (2006). The improvement of Bambara groundnut production in Northern Namibia. Windhoek by means of breeding strategies and agronomic investigations: *Agricola*. 57-60

Gbaguidi, A. A., Dansi, A., Dossou-Aminon, Gbemavo, I. D., Orobiyi, A., Sanoussi,F . Yedomonhan,H (2017). Agromorphological diversity of local Bambara groundnut (*Vigna subterranea* (L.) Verdc.) collected in Benin. *Genetic Resource and Crop Evolution*, 65,1159-1171.

Goli, A. (1995). Characterisation and evaluation of IITA's Bambara groundnut collection. Proceedings of the workshop on conservation and improvement of Bambara groundnut (*Vigna subterranea* (L) Verdc) Zimbabwe: *International Plant Genetic Resources Institute* (IPGRI).

Gonné, S., Félix-Alain, W., & Bargui, B. (2013). Assessment of Twenty Bambara Groundnut (*Vigna subterranea* (L.) Verdcourt) Landraces using Quantitative

Morphological Traits. *International Journal of Plant Research*, *3*(3), 39–45. doi: 10.5923/j.plant.20130303.04

Gupta, Vachhani, Kachhadia, Vaddoria, M and Praveen Kumar 2015. Selection indices in Virginia groundnut (*Arachis hypogaea* L.). *Electronic Journal of Plant Breeding*, *6*(2), 560–565

Minka, S., & Brunete, M. (2000). Partial chemical composition of Bambara pea (Vigna subterranea(L) Verdc). *Food Chemistry, 68,* 273-276.

Mkandawire, C. H. (2007). Review of Bambara groundnut (*Vigna subterranea* (L) Verdc) production in sub-saharan Africa. *Agricultural Journal, 2,* 464–470.

Haleegoah, J., Adu-Dapaah, H., Afun, J., Asumadu, H., Gyasi-Boakye, S., Oti-Boateng, C., & Padi, F. (2005). Cowpea production guide. Ministry of Food and Agriculture- Food Crops Development Project, Amayem Press.

Happy, D., Hussein, S., Lainga, M., Patrick, O., & Mponda, O. (2018). Groundnut production constraints, farming systems, and Farmers preferred traits in Tanzania. *Journal of Crop Improvement*, *32*(6), 1542–7536. doi:https://doi.org/10.1080/15427528.2018.1531801

Hall, A., Cisse.N, Thiaw, S., Elawad, H., Ehlers, J., Ismail, A., . . . McWatters, K. (2003). Development of cowpea cultuvars and germplasm by the Bean/Cowpea CRSP. *Field Crops Research, 82,* 103-134.

Hammer, K., Heller, J., & Engels, J. (2001). Monographs on underutulised and negelcted crops. *Genetic Resource Crop Evolution, 48*, 3-5.

Hasel, L. N. & J. L. Lush. (1942). The efficiency of three methods of selection. *J. Hered.*, *33*(11). 393–399.

Hazel, L. N. and Lush, J. L. (1943). The genetic basis for constructing selection indexes. *Genetics, 28*(6): 476-490.

Hedge, S., & Mishra, K. (2009). Landraces of copea,Vigna unguiculata (L) Walp,As potential sources of genes for unique characteristics in breeding. *Genetic Resource Crop Evolution, 56*, 615-627.

Hepper, F. (1963). Plants of the 1957-58 West Africa Expedition II: The Bambara groundnut (*Voandzeia subterranea*) and Kersting's groundnut Krestingiella geocarpa) wild in West Africa. Kew bulletin, *16*, 395–407.

Hillocks, R., Bennett, C., & Mponda, O. (2012). Bambara nut: A review of utilization, market potential and crop improvement. *Africa Crop Science Journal, 20*, 1–16.

https://en.climate-data.org/africa/namibia-89/. (2019, 04 16). Retrieved from https://en.climate-data.org: https://en.climate-data.org/africa/namibia-89/

Ibrahim, A., Dansi, A., Salifou, M., Ousamane, A., Alzouma, A., & Alou, W. (2018). Farmers' practices, utilisation, conservation and marketing of Bambara groundnut (Vigna subterranea(L.) Verdc.) in Dosso region, Western Niger. *Genetic Resource and Crop Evolution* 65, 1907-1914

Indu, Niyaria, R., Raghuwanshi, S., & Saxena, A. (2016). Selection Indices for Yield Components in Mung Bean (*Vigna radiata* (L.) R. Wilczek) during Summer Season. *Journal of Pure and Applied Microbiology*, *10*(4), 2937–2941. doi:10.22207/JPAM.10.4.60

IPGR, I. (2000). Descriptors for Bambara groundnut. Rome, Italy: *International Plant Genetic Resources Institute.*

Jesus Céron-Rojas, J., & Crossa, J. (2018). Linear Selection Indices in Modern Plant Breeding. Mexico: Springer International Publishing.

Jonah, P. (2011). Phenotypic and Genotypic Correlation in Bambara groundnut (Vigna subterranea (L) Verdc in Mubi Adamawa State. *World Journal of Agricultural Science*, *7*(30), 298-303.

Jonah, P., Aliyu, B., Kadams, A., & Wamannda, D. (2012). Variation in pod yield characters and heritaility estimates in some cultvars of Bambara groundnut (Vigna subterranea (L) Verd. *Academic Journal of Plant Science*, *5*(2), 50-55.

Joohi R, Singh O.P, Pathak V.N & Samar P.V (2019). Assessment of genetic variability, heritability, genetic advance and selection indices for yield contributing traits in Indian mustard (*Brassica juncea) International Journal of Chemical Studies*; *7*(4): 1096-1099.

Juliet, M., Vincenzo, F., Cathrine, C., & Anita, R. L. (2017). Hard-to-cook phenomenon in Bambara groundnut (*Vigna subterranea* (L.) Verdc.) processing: Options to improve its role in providing food security. *Food Reviews International*, *33*(2), 167–194. doi:10.1080/87559129.2016.1149864

Kankam, F., & Adomako, J. (2014). Efficacy of Neem Seed Powder on Root Knot Nematodes (Meloidogyne spp.) Infecting Bambara Groundnut (*Vigna subterranea*). *Asian Journal of Agriculture and Food Science*, *2*(2).

Karikara, S., & Tabone, T. (1997). Constructive traits and selective indices of Bambara groundnut (*Vigna subterranea* (L) Verdc) landraces for drought tolerance under Botswana conditions.

Karikari, S., Wiggleworth D, J., Kwerepe B, C., Balole T, V., Sebolai, B., & Munthali D, C. (1997). Conservation and improvement of Bambara groundnut (Vigna subterranea (L.) Verdc.). *International Plant Genetic Research Institute*, Harare.

Kone, M., Patat-Ochat, M., Conreux, C., Sangwan, R., & Ochatt, S. (2007). In vitro morphogenesis from cotyledon distinction between landraces of Bambara groundnut (Vigna subteranea (L) Verd) an underutilised grain grain legume. *Plant Cell Tissues Organ Culture, 88*, 61-75.

Kutcher, M., Ferguson, A., & Cohen, M. (2013). A principal component analysis of coagulation after trauma. Journal of Trauma Acute Care Surgery, *74*(5), 1220–1230. doi:10.1097/TA.0b013e31828b7fa1

Langercrantz, U., Ellengren, H., & Anderson, L. (1993). The abundance of various polymorphic micro statellite motifs differs between plants and vertebrates. *Nucleis Acid Research*, *21*, 1111–1115.

Mabhaudhi, T., Modi, A., & Beletse, Y. (2013). Growth, phenological and yield responses of a Bambara groundnut (*Vigna subterranea* L. Verdc). Water SA, *39*, 191–198.

Madukwe, D., Onuh, M., & Christo, I. (2011). Agronomic and Physiological Performance of Bambara Groundnut. *World Journal of Agricultural Sciences 7*(2), 166–171.

Masindeni, D. R. (2006). Evaluation of Bambara groundnut (*Vigna subterranea*) for yield stability and yield related characteristics. Free State: University of Free State.

Massawe, f., Dickinson, M., Roberts, J. A., & Azam-Ali, S. (2002). Genetic diversity in Bambara groundnut (*Vigna subterranea* (L) Verdc) landraces revealed by AFLP markers. *NRC Research Press*, 1175–1180. doi: 10.1139/G02-093

Massawe, F., Mwale, S., Azam-Ali, S., & Roberts, J. (2005). Breeding in Bambara groundnut (*Vigna subterranea* (L.) Verdc.): strategic considerations. African Journal of Biotechnology, *4*(6), 463–71.

Mayes, S., Wai, K. H., Hui, H. C., Gao, X., Aloyce, C. K., & Amoahbe, K. I. (2019). Bambara groundnut: an exemplar underutilised legume for resilience under climate change. *Planta*, *250*(3), 803–820.

Minka, S., & Brunete, M. (2000). Partial chemical composition of Bambara pea (*Vigna subterranea(*L) Verdc). *Food Chemistry, 68*, 273-276.

Mohammed, M., Shimelis, H., & Laing, M. (2016). Preliminary investigation on some agronomic and morphological variation of within and between Bambara groundnut landraces. *Journal of Agricultural Science and Technology, 18,* 1909–1920.

Mohammed, S. (2014, January). Pre-breeding of Bambara Groundnut (*Vigna subterranea* [L.] Verdc.). Doctor of Philosophy (PhD) in Plant Breeding. Pietermaritzburg, South Africa.

Mojtaba, K., & Mehdi, R. (2015). Molecular Marker in Plants: Concepts and Applications. *Genetics*, 4024–4031.

Molosiwa, O. (2012). Genetic diversity and population structure analysis of Bambara groundnut (*Vigna subterranea*) landraces using morpho-agronomic and SSR markers. UK.

Monpara, B., & Chatrola, M. (2010). Selection indices for improvement of fruit yield in okra [*Abelmoschus esculantus* (L.) Moench]. *Advance Research Journal of Crop Improvement*, 1(2), 62–66.

Mubaiwa, J., Fogliano, V., Chidewe, C., & Annita, R. (2018). Bambara groundnut (*Vigna subterranea* (L.)Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PLOS ONE 13*, 13, 10:0205776. doi:https://doi.org/10.1371/journal.pone.0205776

Mukakalisa, D., Kandawa-Schulz, M., & Mapaure, I. (2006). Genetic Diversity in Landrace of Bambara groundnut found in Namibia using RAPD markers. International Society of Horticultural Science.

Nath, U., Rani, S., P, Paul, M., Alam, M., & Horndburg, B. (2014). Selection of superior lentil genotype (*Lens esculenta*) genotype by assessing characters association and genetic diversity. *The Scientific World Journal*, 1–6.

Ndiang, Z., Bell, J., Fokam, P., Quattara, B., Simo, C., & Dibong, D. (2014). Agro-morphological variability in twelve Bambara groundnut (*Vigna subterranea* (L) Verdc.) accessions in Cameroon. Science, *Technologies et Development*, *16*, 38–45.

NSA. (2011, 01 01). Population census. Windhoek, Namibia.

Ntundu, W. H., Inga, B. C., Christiansen, J. L., & Andersen, S. B. (2004). Analysis of Genetic diversity in Bambara groundnut [*Vigna substerranea* (L) Verdc] landraces using amplified fragment length polymorphism (AFLP) markers. *African Journal of Biotechnology*, *3*(4), 220.

Ntundu, W., Shillah, H., Marandu, W., & Christiansen, J. (2006). Morphological diversity of Bambara groundnut (*Vigna subterranea* (L.)Verdc.) landraces in Tanzania. *Genetic Resources and Crop Evolution*, *53*, 367–378.

Odongo, F. O., E.Oyoo, M., Wasike, V., O.Owuoche, J., Karanja, L., & Korir, P. (2015). Genetic diversity of Bambara groundnut (Vigna subterranea (L,) Verdc.) landrace in Kenya using microsatellite markers. *Academic Journals*, *14*, 283–291.

Okpuzor, J., Ogbunugafor, H. A., Okafor, U., & Sofidiya, M. O. (2010). Identification of protein types in Bambara nut seeds: Perspective for dietary protein supply in developing countries. EXCLI Journal, *9*, 17–28.

Oladosu, Y., Rafii, M., Magaji, U., Abdullah, N., Miah, G., Chukwu, C. S., . . . Kareem, I. (2018). Genotypic and Phenotypic Relationship among Yield Components in Rice under Tropical Conditions. *Hindawi BioMed Research International*, 1–10. doi:https://doi.org/10.1155/2018/8936767

Omoikhoje, S. (2008). Assessment of the nutritive value of Bambara groundnut as influenced by cooking time. *Livestock Research for Rural Development*. 20, 55. Retrieved from http://www.lrrd.org/lrrd20/4/omoi20055.htm

Ouedraogo, M., Ouedraogo, J. T., Tignere, J. B., Balma, D., Dabire, C. B., & Konate, G. (2008). Characterisation and evaluation of accessions of Bambara groundnuts (Vigna subterranea) in Burkina Faso. *Science & Nature*, *5*(2), 191–197.

Oyiga, B., & Uguru, M. (2011). Interrelationship among pod and seed yield traits in Bambara groundnut (Vigna subterranea L.Verdc) in the derived savanna agro-ecology of south-eastern Nigeria under two planting dates. *International Journal of Plant Breeding*, 106–111.

Piepho, H. P. (2018). Allowing for the structure of a designed experiment when estimating and testing trait correlations. T*he Journal of Agricultural Science*, *156*(1), 59–70. doi: 10.1017/S0021859618000059,

Pungulani, L., Kadyampakeni, D., Nsapato, L., & Kachapila, M. (2012). American *Journal of Plant Sciences*, 3, 1802-1808. doi:http://dx.doi.org/10.4236/ajps.2012.312A221

Raghuwanshi,S.S, Kachadia,V. J.H, Jivani L.L, Malay, K. A, & Bhati S. S. (2015). Selection indices in groundnut (*Arachis hypogaea* L.), *Electronic Journal of Plant Breeding*, doi: 10.5958/0975-928X.2016.00019.3

Rao, L. (1974). Analysis of genetic variability and formulation of selection indices for yield in soybean [*Glycine max* (L.) Merrill]. *Mysore J. agric. Sci.*, 8(1):156.

Robinson, H. F., Comstock, R. E. & Harvey, V. H. (1951). Genotypic and phenotypic correlations in corn and their implications in selection. *Agron. J.*, 41: 353–359.

Sesay, A., Edje, O., & Magagula, C. (2003). Agronomic performance and morphological traits of field grown Bambara groundnut (Vigna subterranea) landraces in Swaziland. Proceedings of the international Bambara groundnut symposium (pp. 47–63). Botswana: Botswana College of Agriculture.

Shah, S., & LataRaval, D. (2016). Selection indices in Bread Wheat [Tritium aestivum L.]. *Electronic Journal of Plant Breeding*, 7(2), 459–463. doi:10.5958/0975-928X.2016.00059.4

Shengro, A., Rensburg, W. J., & Adebola, P. (2013). Assessment of genetic variability in Bambara groundnut (Vigna subterranea L. Verdc.) using Morphological Quantitative traits. *Academic Journal of Agricultural Research*, 045–051.

Sibuga, K., Lana A, F., Tarimo, A., & Temu, H. (1994). *Evaluating potential for Bambara groundnut as a food crop in semi-arid Africa, An approach for assessing the yield potential and ecological requirements of an underutilised crop.* Tanzania: Report 2.Sokoine Univeristy of Agriculture,Morogoro.

Siddhi, S., & Mehtaand LataRaval, D. (2016). Selection indices in Bread Wheat [Triticum aestivum L.]. *Electronic Journal of Plant Breeding*, 7 (2), 459–463.

Smith, H. (1936). A Discriminant Function for Plant Selection. *Annals of Eugenics*, 240–250.

Somta, P., Chankaew, S., Rungnoi, O., & Srinives, P. (2011). Genetic diversity of the Bambara groundnut (Vigna subterranea (L) Verdc) as assesses by SSR markers. *Genome*, 54(11),898-910

Tadele, Z. (2009). New Approaches to Plant Breeding of Orphan Crops in Africa. Proceedings of an International Conference. Bern.

Tweneboah, C. (2000). Modern Agriculture in the Tropics, Food crops. Co-wood Publishers.

Valombola, J., Akundabweni, L., Awala, S., & Hove, K. (2019). Agronomic and morphological diversity of Bambara groundnut (Vigna subterranea (L.) Verdc.) accessions in North-Central Namibia. *Welwitschia International Journal of Agricultural Science*, *1*(1), 88–99. Retrieved from http://journals.unam.edu.na/index.php/WIJAS/article/view/1369/1173

Weiss, E. A. (2000). *Oilseed Crops*. (Second Ed.), Black Wellm Science Ltd., London. 53–92

Zerihun, T. (2009). New Approaches to plant breeding of orphan crops in Africa: Proceedings of an International Conference. Bern, Switzerland.

Zhang, Q., Jia, R., Meng, C., Ti, C., & Wang, Y. (2015). Diversity and population structure of a dominant deciduous tree based on morphological and genetic data. *Journal of Plant Science*. doi: AoB PLANTS, 7 plv103. doi: 10.1093/aobpla/plv103

Appendices

Appendix 1: A copy of the Bambara groundnut farmers' questionnaire

Bambara groundnut production survey in Omusati, Oshana, Oshikoto, Ohangwena, and Kavango West region for five constituencies (Anamulenge, Okatana, Omuntele, Ondobe, and Kapako)

Farmer's Detail

Questionnaire No.:………………… Date of the interview:……………………

Region:…………………………….. Constituency:……………………………

Village:…………………………… Gender of the respond:…………………..

Age:………………………………. Marital status:……………………………

Education level:…………………… Occupation:………………………………

Household size: Adult……………… Owners of the house: Man ☐ Woman ☐

Children:…………

Agronomy Practices

What is the size of your crop field (ha, m^2, etc)? (Tick where appropriate)

Size	
<1ha	
>ha	

The major uses of the crop field (Tick where appropriate)

Crops

Mahangu	
Sorghum	
Cowpea	
Bambara groundnut	
Maize	
Other specify	

Do you grow Bambara groundnut? Yes ☐ No ☐

If Yes, How long have you been growing Bambara groundnut (Tick where appropriate)

Years

<10 (less than)	
11-20	
21-30	

31-40	
>41 (greater than)	

Do you grow Bambara groundnut as a sole crop or intercrop? (Tick where appropriate)

Cropping system

Sole crop	
Intercropped	
Other specify	

If yes, a crop intercropped with which crop(s)?..

Do you apply any fertiliser on bambara groundnut? Yes☐ No☐
If Yes, what type of fertiliser:………………….

How much is the yield do you get per area? (Tick where appropriate)

Weight

<10kg	
11-20	
21-30	
31-40	
41-50	
>51	

Do Bambara groundnuts survive during the drought? Yes☐ No☐
If Yes, Why?
....

The utilisation of Bambara groundnut
What do you use Bambara groundnut for?
………………………………………………………………………………………………
………………………………………………………………………………………………

In what form do you consume bambara groundnut? (Tick where appropriate)

Consumption form

Fresh pod	
Dry seeds	
Roasted	
Others specify	

Do you use leaves of Bambara groundnut leaves? Yes ☐ No ☐

If Yes,

Purpose?...

Other uses of Bambara groundnut?

……………………………………………………………………………………………

……………………………………………………………………………………………

Do you use other parts or by-product of Bambara groundnuts? e.g. roots, empty pods etc ☐

☐ . Yes No

If Yes, What do you use Bambara groundnut for?

……………………………………………………………………………………………

……………………………………………………………………………………………

What nutritional value do you get from Bambara groundnut?..

Do you process any product from Bambara groundnut? Yes ☐ No ☐

If Yes, Name of the Product processed?.......................................

Marketing

Do you sell bambara groundnuts? Yes ☐ No ☐

If Yes, Where do you sell your products?..

Do you sell fresh Bambara groundnut or dry seeds?..............................

Do you think bambara groundnut generates income for small scale farmers? Yes ☐ No ☐

What quality do you consider when selling Bambara groundnut?..

Where do you get Bambara groundnut seeds? (Tick where appropriate)

Source of seed

Stored from the previous harvest	
Buy from Open Market	

Neighbour	
Other specify	

How do you determine seeds to be planted?

Seed selection criteria

Sort according to seed colour	
Sort according to seed size	
Sort according to taste	
Other specify	

If colour, What colour is the of the Bambara groundnuts varieties do you grow or prefer?...

What seed size do you prefer? Large ☐ Medium ☐ Small ☐

Other preferences of Bambara groundnut as a farmer?...

Farmers' preferences

Which Bambara groundnut varieties do you grow/prefer (Tick where appropriate)

No idea	
Variety(ies) name	

Preferred traits

Seed colour	
Seed size	
Taste	
Maturity	
Pods with two or more seeds	
Other preferences specify	

Variety improvement

Do you think the current varieties grown need improvement? Yes ☐ No ☐

If Yes, what trait(s) should be improved? (Tick where appropriate)

Trait to be improved

Yield	
Seed size	

Insect resistance	
Other specify?	

Reasons for improving that particular trait?

....

....

What challenges do you face in the production of Bambara groundnut? (Tick where appropriate)

Challenges

Low yield	
Unimproved varieties	
Insects	
Diseases	
Seed availability	
Poor Germination	
Others specify	

General Questions

Do you receive extension services on Bambara groundnut? Yes☐ No☐

If Yes, type of service

…………………………………………………………………………………………

Have you ever received training on Bambara groundnut production and management?

Yes ☐ No ☐

What did the training cover?

…………………………………………………………………………………………

If No, Do you think you need any training on Bambara groundnut production and type of training needed?

....

Any Comment or Question:

…………………………………………………………………………………………

…………………………………………………………………………………………

Appendix 2: Earthed Bambara groundnut crops at the Crop Science Experimental Field, UNAM Ogongo Campus, 2017/2018 cropping season

Appendix 3: Fisher's discriminant function

```
> library(readxl)
> Trial <- read_excel("Johana Data/Trial.xlsx",
+     col_types = c("numeric", "numeric", "numeric",
+         "numeric", "numeric"))
> View(Trial)
> library(MASS)
> fit<-lda(Y~x1,data=Trial)
> fit
Call:
lda(Y ~ x1, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1
1  79.51693
2 154.23228
3 294.46720

Coefficients of linear discriminants:
          LD1
x1 0.02186303
> fit<-lda(Y~x2,data=Trial)
> fit
Call:
lda(Y ~ x2, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
        x2
1 16.55906
2 22.60214
3 29.97976

Coefficients of linear discriminants:
          LD1
x2 0.09107342
> fit<-lda(Y~x3,data=Trial)
> fit
Call:
lda(Y ~ x3, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
       x3
1  6.2732
2 10.6732
3 19.4872

Coefficients of linear discriminants:
         LD1
x3 0.1867227
> fit<-lda(Y~x4,data=Trial)
> fit
```

```
Call:
lda(Y ~ x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x4
1  93.95344
2 183.83915
3 366.51958

Coefficients of linear discriminants:
          LD1
x4 0.01507385
> fit<-lda(Y~x1+x2,data=Trial)
> fit
Call:
lda(Y ~ x1 + x2, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1       x2
1  79.51693 16.55906
2 154.23228 22.60214
3 294.46720 29.97976

Coefficients of linear discriminants:
          LD1          LD2
x1 0.02158283  0.005679511
x2 0.00512338 -0.092825735

Proportion of trace:
   LD1    LD2 
0.9991 0.0009 
> fit<-lda(Y~x1+x3,data=Trial)
> fit
Call:
lda(Y ~ x1 + x3, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1      x3
1  79.51693  6.2732
2 154.23228 10.6732
3 294.46720 19.4872

Coefficients of linear discriminants:
            LD1         LD2
x1  0.022122851 -0.01369844
x3 -0.004152465  0.22219125

Proportion of trace:
   LD1    LD2 
0.9999 0.0001 
> fit<-lda(Y~x1+x4,data=Trial)
> fit
Call:
```

```
lda(Y ~ x1 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1        x4
1  79.51693  93.95344
2 154.23228 183.83915
3 294.46720 366.51958

Coefficients of linear discriminants:
            LD1         LD2
x1  0.027570870 -0.04903383
x4 -0.004375594  0.03853743

Proportion of trace:
  LD1   LD2 
0.998 0.002 
> fit<-lda(Y~x2+x3,data=Trial)
> fit
Call:
lda(Y ~ x2 + x3, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
        x2      x3
1 16.55906  6.2732
2 22.60214 10.6732
3 29.97976 19.4872

Coefficients of linear discriminants:
         LD1         LD2
x2 0.0124943 -0.09695560
x3 0.1758819  0.09610539

Proportion of trace:
   LD1    LD2 
0.9954 0.0046 
> fit<-lda(Y~x2+x4,data=Trial)
> fit
Call:
lda(Y ~ x2 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
        x2        x4
1 16.55906  93.95344
2 22.60214 183.83915
3 29.97976 366.51958

Coefficients of linear discriminants:
          LD1          LD2
x2 0.01154033 -0.091625253
x4 0.01463930  0.004395702

Proportion of trace:
   LD1    LD2 
```

```
0.9984 0.0016
> fit<-lda(Y~x3+x4,data=Trial)
> fit
Call:
lda(Y ~ x3 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
       x3        x4
1  6.2732  93.95344
2 10.6732 183.83915
3 19.4872 366.51958

Coefficients of linear discriminants:
          LD1         LD2
x3 0.01205530 -0.22421467
x4 0.01451159  0.01086232

Proportion of trace:
LD1 LD2 
  1   0 
> fit<-lda(Y~x1+x2+x3,data=Trial)
> fit
Call:
lda(Y ~ x1 + x2 + x3, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1       x2      x3
1  79.51693 16.55906  6.2732
2 154.23228 22.60214 10.6732
3 294.46720 29.97976 19.4872

Coefficients of linear discriminants:
            LD1          LD2
x1  0.022069838 -0.002326832
x2  0.006257004 -0.093715726
x3 -0.008774199  0.130760911

Proportion of trace:
   LD1    LD2 
0.9987 0.0013 
> fit<-lda(Y~x1+x3+x4,data=Trial)
> fit
Call:
lda(Y ~ x1 + x3 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1      x3        x4
1  79.51693  6.2732  93.95344
2 154.23228 10.6732 183.83915
3 294.46720 19.4872 366.51958

Coefficients of linear discriminants:
            LD1         LD2
```

```
x1  0.027567321 -0.04926217
x3  0.000149694  0.01312484
x4 -0.004380053  0.03808099

Proportion of trace:
  LD1   LD2 
0.998 0.002 
> fit<-lda(Y~x1+x2+x4,data=Trial)
> fit
Call:
lda(Y ~ x1 + x2 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
         x1       x2        x4
1  79.51693 16.55906  93.95344
2 154.23228 22.60214 183.83915
3 294.46720 29.97976 366.51958

Coefficients of linear discriminants:
            LD1         LD2
x1  0.027189377 -0.03701923
x2  0.004584035 -0.04943527
x4 -0.004275311  0.03147412

Proportion of trace:
   LD1    LD2 
0.9973 0.0027 
> fit<-lda(Y~x2+x3+x4,data=Trial)
> fit
Call:
lda(Y ~ x2 + x3 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
        x2      x3        x4
1 16.55906  6.2732  93.95344
2 22.60214 10.6732 183.83915
3 29.97976 19.4872 366.51958

Coefficients of linear discriminants:
           LD1          LD2
x2 0.011126968 -0.097045052
x3 0.003026058  0.065652212
x4 0.014513753  0.001474978

Proportion of trace:
   LD1    LD2 
0.9983 0.0017 
> fit<-lda(Y~x1+x2+x3+x4,data=Trial)
> fit
Call:
lda(Y ~ x1 + x2 + x3 + x4, data = Trial)

Prior probabilities of groups:
        1         2         3 
0.3333333 0.3333333 0.3333333 

Group means:
```

```
         x1       x2      x3        x4
1  79.51693 16.55906  6.2732  93.95344
2 154.23228 22.60214 10.6732 183.83915
3 294.46720 29.97976 19.4872 366.51958

Coefficients of linear discriminants:
            LD1         LD2
x1 -0.027237832 -0.03667789
x2 -0.005096088 -0.05534785
x3  0.003840718  0.05417463
x4  0.004149699  0.02886571

Proportion of trace:
   LD1    LD2
0.9971 0.0029
```

Appendix 4: Research permission letter

CENTRE FOR POSTGRADUATE STUDIES

University of Namibia, Private Bag 13301, Windhoek, Namibia
340 Mandume Ndemufayo Avenue, Pioneers Park
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UNAM
UNIVERSITY OF NAMIBIA

RESEARCH PERMISSION LETTER

25 October 2017

Student Name: Ms Johanna Shekupe VALOMBOLA

Student number: 200306855

Programme: ***MSc (Crop Science)***

Approved research title: : Pre-Breeding Tools for Investigating Population Differences among Bambara Groundnut (*Vigna Subterranea*) Accessions in Namibia

TO WHOM IT MAY CONCERN

I hereby confirm that the above mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

25 Oct 17

Date

Dr M Hedimbi
Director: Centre for Postgraduate Studies
Tel: +264 61 2063275
E-mail: directorpgs@unam.na