EFFECT OF DIFFERENT SEED PRIMING METHODS ON GERMINATION, SEEDLING ESTABLISHMENT AND VIGOUR IN SORGHUM (*Sorghum bicolor* (L.) Moench.) AND BAMBARA GROUNDNUT (*Vigna subterrenea* (L.) Verdc.)

By

SANGARE SALL SAFIATOU

August, 2012

EFFECT OF DIFFERENT SEED PRIMING METHODS ON GERMINATION, SEEDLING ESTABLISHMENT AND VIGOUR IN SORGHUM (*Sorghum bicolor* (L.) Moench.) AND BAMBARA GROUNDNUT (*Vigna subterrenea* (L.) Verdc.)

A THESIS SUBMITTED TO THE DEPARTMENT OF HORTICULTURE, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY KUMASI, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE (SEED SCIENCE AND TECHNOLOGY)

BY

SANGARE SALL SAFIATOU

AUGUST 2012

CERTIFICATION

I hereby certify that except for references to other people's work, which I have duly acknowledged, this is the result of my own research work and it has neither in part nor wholly been presented elsewhere for another degree.

……... ……

SANGARE SALL SAFIATOU (MRS) PROF. NANA SAKYIWA OLYMPIO (MRS)

(STUDENT) (SUPERVISOR)

Date…….. Date……..

DR. I. D. ATOKPLE DR. BEN BANFUL

(CO- SUPERVISOR) (HEAD OFDEPARTEMENT)

Date…… Date……

DEDICATION

This thesis is dedicated to my late Daddy and Mummy for their love and care,

And my entire Family for their love, patience and support

ACKNOWLEDGEMENTS

All praises to the Almighty Allah for seeing me through the successful completion of this course.

I wish to express my sincere gratitude and appreciation to my Project supervisor, Prof. (Mrs) Nana Sakyiwa Olympio an Associate Professor at the Department of Horticulture KNUST, Kumasi who coordinates the AGRA-MSC Programme in Seed Science and Technology.

I wish to express my profound gratitude to Prof. Richard Akromah an Associate Professor at the Department of Crop and Soil Sciences, Dean of Agriculture Faculty, KNUST, Kumasi. Coordinator of the AGRA EACI programme that sponsored these studies.

My sincere appreciation also goes to the Co-supervisors, Dr. I. D. K. ATOKPLE of the Savanna Agricultural Research Institute (SARI), Nyankpala and Dr. GEORGE NYARKO a Senior Lecturer at the Department of Horticulture UDS Nyankpala, Tamale who, inspite of their tight research schedules made it possible for the successful completion of this work. I also thank the Director of SARI and Dean of the Agriculture Faculty of UDS for giving me the opportunity to carry out my research work in the Institute and University and on their Experimental Fields and Laboratory. To them I say many thanks!

Special thanks go to Dr. Aboubacar Toure, AGRA who is a Programme Officer for Crop Improvement and Variety Adoption.

He aroused my interest in becoming a Seed and Technology Scientist. God bless you. He has been a role model.

My appreciation goes to the Institute of Rural Economy (IER) Bamako/ Mali especially to my Boss Dr. Adama Coulibaly and Dr. Mamadou Doumbia Head of Soil, Plant and Water Laboratory.

I wish to express my appreciation also to Alhassan Abdulay Lansah, Joseph Appiah, Bawa Abdul-Aziz, Owusu Moses who assisted in one way or the other during the execution of this work.

I would like to acknowledge Ibrahima Zan Doumbia my comrade from Mali, my course mates Mrs Kerkula Lovetta Gleekia, Sadia Alimatu Osman and Abraham Yeboah. You mean a lot to me.

Finally, my sincere appreciation goes to Alliance for a Green Revolution in Africa (AGRA) for providing this scholarship and especially to Dr. RUFARO MADAKADZE, the Programme Officer of the Education for African Crop Improvement (EACI), for the time and patience that she had to monitor the successful completion of both the course work and the field study. Long live AGRA.

This work would not have been completed without the moral and spiritual support from my family especially my dear husband, Adama Sall.

ABSTRACT

Two experiments were designed to study the effect of hydro- priming (water) and osmo-priming (Mannitol and NaCl at -1.5 M Pa) and seed size on germination, seedlings establishment, vigour and biomass at maturity of three varieties of *Sorghum bicolor* L. Moench and *Vigna subterrenea* L. Verdc. The experiments were (1) a laboratory test with seeds germinated in wet sand for 10 days in a completely randomized design with four replications to determine germination traits, shoot and root lengths and (2) a field experiment in a Randomized Complete Block Design with three replications at the Savanna Agricultural Research Institute from August 2011 to January 2012. Seeds of three varieties of sorghum, 'Dorado', 'Kapaala' and 'Kadaga' were primed with Mannitol and NaCl (-1.5 M Pa) for 72 hours at 25° C and also in water for 24 h at 28 ± 3°. Large and small seeds of three varieties ('Cream with black eye', 'Cream with brown eye' and 'Red') of Bambara groundnut were separately primed with Mannitol and NaCl (-1.5 M Pa) for 120 h at 25° C and also primed in water separately for 24 h at 28 ± 3°. The laboratory results showed that osmo-priming of sorghum and Bambara significantly improved germination percentage, germination index, and mean germination time and seedling vigour, compared to other seed treatments. Likewise hydro-priming significantly improved seedling dry weight as compared to other seed treatments. The field results of the Bambara groundnut also showed that osmo-primed seeds had the least average delay (lag period) from the start of imbibitions to radicle emergence, were the earliest to start to

germinate, obtained higher number of pods per plant in comparison with the other seed treatments. Hydro-priming significantly increased the number of plants per plot compared to other seed treatments.

Seed biomass had effect on the overall percentage and seedling vigour. In all Bambara groundnut varieties, the smaller seeds had the faster germination, the higher percent germination and seed vigour. On the contrary, plants grown from large seeds produced greater dry matter compared to those grown from small seeds for all varieties.

TABLE OF CONTENTS

Title	Page
TITLE PAGE……..	ii
CERTIFICATION……	iii
DEDICATION…….....	iv
ACKNOWLEGMENTS……...	v
ABSTRACT…….	vi
TABLE OF CONTENT……..	vii
LIST OF TABLES……...	xv
LIST OF FIGURES……..	xvii
LIST OF APPENDICES……..	xviii
CHAPTER ONE……	1
INTRODUCTION……	1
CHAPTER TWO.....	8
2. LITERATURE REVIEW.....	8
2.1 Origin and Domestication of Sorghum.....	8
2.2 Sorghum Production Constraints.....	9
2.3 Taxonomy and origin of Bambara groundnut …….	10
2.4 Botany of Bambara groundnut …….	14
2.5 Uses……	15
2.6 Agronomy of Bambara groundnut…….	17

2.7 Future prospects …… 18

2.8 Germination …….. 19

2.9 Seed priming ……. 20

2.10 Seed priming methods……... 21

2.10.1 Hydro-priming……... 21

2.10.2 Osmo-priming …… 22

2.10.3 Drum Priming …….. 24

2.10.4 Matric priming ……. 24

2.11Seed Vigor…… 25

2.12 Seed size…….. 27

CHAPTER THREE……. 28

3.0 MATERIELS AND METHODS …….. 28

3.1 Seed priming in the Laboratory……. 28

3.1.1 Materials…….. 28

3.1.2 Priming agents……. 28

3.1.3 Osmotic potential of salt……. 28

3.1.4 Methodology……... 29

3.2. Determination of seed viability and seedling vigour in pot……. 31

3.2.1 Methodology…….. 31

3.2.2 Experimental design…….. 31

3.2.3 Data Collected……. 32

i) Germination percentage (%)…… 32

ii) Coefficient of velocity …… 32

iii) The germination index (GI)…… 33

iv) Mean germination time……... 34

v) Seedling fresh weight…….. 34
vi) Seedling dry weight…… 34

3.3 Statistical Analysis……. 34

3.4 Field experiment…… 35

3.4.1Geographical location and Description of study Site…….. 35

3.4.2 Experimental Design and Field Layout……... 37

3.5 Cultural Practices……... 38
3.5.1 Field Preparation……. 38

3.5.2 Sowing and Thinning ……. 38

3.5.3 Weed Control and Fertilizer Application…… 38

3.5.4 Plant Protection…….. 39
3.6 Data Collection……. 39

i) Germination percent……. 39
ii) Mean germination time…… 40
iii) Final plants establishment…….. 40

iv) Number of Leaves per Plant……... 40

v) Height of Plant……. 40
vi) Days to 50% flowering……... 41

vii) Number of Pods per Plant (Bambara groundnut)…….. 41

viii) 1000 Seed Weight of Bambara groundnut……. 41

ix) Pods Weight per Plant……. 41
x) Biomass Retained After Pod Harvest per Plot……. 41
xi) Biomass Retained At Maturity for Sorghum…….. 41

3.7 Data analysis……... 42

CHAPTER FOUR……. 43
4.0 RESULTS…….. 43

4.1 Plant house experiment…….. 43

4.1.1 Effect of the priming methods and variety on the viability, vigour, mean germination time and seedling dry weight of sorghum varieties……. 43

4.1.2 Priming method, size and variety main effects on viability, vigour and dry weight of Bambara groundnut seed……. 47

4.2 Field experiment……. 51

4.2.1 Effect of priming method and variety on viability, plant stand 20 days after sowing, number of leave and biomass retained at maturity …… 51

4.2.2 Interaction of priming method by variety main effect on number of leaves and plant stand 20 days after sowing in sorghum……... 54

4.2.3 Variety main effect on days to 50% flowering and height of Bambara groundnut……. 56

4.2.4 Interaction effect of seed size by priming type by variety on number of pod per plant…… 57

CHAPTER FIVE…… 59

5.0 DISCUSSIONS…….. 59

5.1 Seed priming methods…… 59

5.1.1 Germination……. 59

5.1.1.1Germination percentage…… 60

5.1.1.2 Germination Index…… 60

5.1.2 Vigour…….. 61

5.1.2.1 Coefficient of Velocity……. 61

5.1.2.2 Vigour Index…… 61

5.1.3 Crop establishment…….. 62

5.1.4 Effect of priming methods in the time of germination of sorghum and 62

Bambara groundnut…….

5.2 Seed size effects……. 63

5.2.1Germination and vigour……... 63

5.2.2 Seedling dry weight…… 64

5.3 Interaction among priming methods X variety X seed size 64

CHAPTER SIX……... 65

6.0 Conclusion and recommendations……. 65

6.1 CONCLUSION……. 65

6.2 RECOMMENDATIONS……... 66

REFERENCES……. 67

APPENDICES 90

LIST OF TABLES

TITLE OF TABLES	Page
Table 2.1: Countries of origin of the Bambara groundnut accessions held at IITA……	14
Table 3.2: Mean relative humidity and rainy days by month during the experiments……	37
Table 4.3: Variety main effect on the proportion of sorghum seeds germination and vigour index……	44
Table 4.4: Effect of priming methods on seedling traits studied on sorghum varieties…….	46
Table 4.5: Seeds size main effect on germination percentage, germination index and vigour index on Bambara groundnut varieties..	49
Table 4.6: Priming methods main effect on germination percentage, coefficient of velocity and the vigour index of Bambara groundnut varieties……..	50
Table 4.7: Means germination percentage, number of plant and biomass at maturity for sorghum varieties……	53
Table 4.8: Mean germination time, coefficient of velocity and number of plant/ plot at maturity of sorghum varieties comparison by Fisher's	54

protected least significant difference test…….

Table 4.9: Priming methods and variety effects on mean number of sorghum leaves per plant comparison by Fisher's protected least significant difference test…….. 55

Table 4.10: Priming methods and variety effects on mean number of sorghum plant stand 20 days after sowing comparison by Fisher's protected least significant difference test…… 55

Table 11: Mean days to 50 % flowering and plant height for Bambara groundnut varieties comparison by Fisher's protected least significant difference test…… 56

Table 12: Mean number of pod per plant in Bambara groundnut varieties comparison by Fisher's protected least significant difference test……. 58

LIST OF FIGURES

TITLE OF FIGURES	Page
Figure 3.1: Monthly rainfall distribution and mean minimum and maximum temperature at Nyankpla in 2011……..	36
Figure 4.2: Effect of priming method on seedling dry weight of sorghum	45
Figure 4. 3: Priming methods main effects on sorghum seeds germination percentage…….	47
Figure 4.4: Effect of seed size on seedling dry weight of Bambara groundnut varieties……..	49
Figure 4.5**:** Priming methods main effect on mean germination time of Bambara groundnut varieties …….	50
Figure 4.6**:** Priming methods main effect on germination index of Bambara groundnut varieties……..	51
Figure 4.7: Length of sowing date to days to 50 % flowering of three varieties of sorghum which had been primed in Mannitol, NaCl for 72 hours at -1.5 M Pa and water for 24 hours ……	53

LIST OF APPENDICES

TITLE OF APPENDIX	Page
Appendix I: Plant house experiment……..	90
Appendix1.1 Analysis of variance of sorghum varieties seeds germination index….	90
Appendix 1.2 Analysis of variance of sorghum varieties seedlings vigour index…...	90
Appendix 1.3 Analysis of variance of sorghum varieties seedlings dry weight per plant……..	91
Appendix 1.4 Analysis of variance of coefficient of velocity of sorghum varieties seeds…….	91
Appendix 1.5 Analysis of variance of sorghum varieties seeds germination percentage…….	92
Appendix 1.6 Analysis of variance of seed germination percentage of Bambara groundnut varieties……..	92
Appendix 1.7 Analysis of variance of Bambara groundnut varieties seedling dry weight per plant……	93
Appendix 1.8 Analysis of variance of Bambara groundnut varieties seed germination index……	94
Appendix 1.9 Analysis of variance of coefficient of velocity of Bambara groundnut varieties seedlings……..	95
Appendix 1.10 Analysis of variance of Bambara groundnut varieties seedlings	96

vigour index…….

Appendix 1.11 Analysis of variance of Bambara groundnut seed mean germination time…… 97

Appendix II: field experience…….. 98

Appendix 2.1 Analysis of variance of Seed germination percentage of Sorghum varieties…… 98

Appendix 2.2 Analysis of variance of number of plants per plot of sorghum varieties…… 98

Appendix 2.3 Analysis of variance of day to 50 % flowering of sorghum varieties 99

Appendix 2.4 Analysis of variance of sorghum plant biomass……... 99

Appendix 2.5 Analysis of variance of sorghum varieties Mean Germination Time 100

Appendix 2.6 Analysis of variance of Coefficient of velocity of sorghum varieties seedlings……. 100

Appendix 2.7 Analysis of variance of sorghum varieties number of leaves 101

Appendix 2.8 Analysis of variance of the numbers of plants stands 20 days after sowing…….. 101

Appendix 2.9 Analysis of variance of days to 50 % flowering of Bambara groundnut varieties…….. 102

Appendix 2.10 Analysis of variance of Bambara groundnut plant height…….. 103

2.11 Analysis of variance of Bambara groundnut number of pods per plant…. 104

CHAPTER ONE

INTRODUCTION:

Sorghum is the fifth most important world cereal following maize, wheat, rice and barley (Onwueme and Sinha, 1999). It is grown mainly in the semi-arid areas of the tropics and subtropics and in most West African countries, sorghum alone accounts for 50 % of the total cereal crop land area (FAO, 2005). It is one of the most principal sources of energy, protein, vitamins and minerals for millions of the poorest people in the regions. Sorghum is one of the most important cereals in West Africa too. Total cereal production (Axtell, 1998) is about 70 % of the worlds' food production of the 700 million ha planted to cereals in the world; 45 million are planted to sorghum and about 80 % of this is grown in developing countries (Dendy, 1995). Approximately 70 million metric tons of sorghum grain is produced annually as a dietary staple for some 500 million people in 30 countries.

In northern Ghana, it is cultivated throughout the savannah agro ecological zones, covering about 41 % of the total land area of the country (Atokple, 1999). The crop is consumed in the form of stiff porridge ('tuo zaafi'); thin porridge ('koko') or fried dumpling ('maasa'). Sorghum utilization in brewing local opaque beer ('pito') is an important cottage industry in Northern Ghana and has existed in the country for over five centuries (Atokple, 2003). In addition to its uses as grain, sorghum crop residues and green plants also provide sources of animal feed, building material and fuel for cooking. Many of the types grown traditionally are photoperiod sensitive, flowering at the end of the wet period, so that the grains

ripen under dry conditions. Generally, the area of sorghum in Africa has steadily increased over the years but the average yield trends are downwards. Paramount among the yield reducing factors are predominant cultivation of inherently low yielding varieties, poor soil fertility, drought, striga, pests and diseases.

The Bambara groundnut (Vigna subterranea) is the third important crop among the grain legumes of the African lowland tropics after the popular groundnut and cowpea. The crop has several agronomic advantages including high nutritional value, drought tolerance and ability to produce some yield in soils that are too poor for cultivation of other species such as common beans and groundnuts (Anchirinah et al., 2001; Azam-Ali et al., 2001). It is very adaptable to high temperatures but also tolerates rainfall (Dakora and Muofhe, 1996) and has an advantage over other leguminous crops in that it is well adapted to prolonged periods of drought. It serves as an important source of protein in the diet of a large percentage of the African population in Nigeria, Mali, Ghana, Chad, Niger, Burkina Faso, Togo, Ivory Coast, Benin and South Africa (Linnemann and Azam-Ali, 1993). Nutritionally, it contains 17.4 % protein, 53.1 % carbohydrate, 6.1 % fat, 6.1 % fibre, 3.4 % ash, 0.098 % calcium, 0.007 % iron, 1.2 % potassium and 0.003 % sodium (Rowland, 1993; Amarteifio et al., 1997). Bambara groundnut is an important source of protein because of its high content of lysine and methionine, especially for rural and urban dwellers who cannot afford the high cost of animal protein (Collinson et al., 2000). The seeds are consumed by humans, pigs, and poultry, while the haulm is used as fodder to feed livestock (Doku and Karikari, 1971). Recent research has also established using Bambara groundnut in various

food products such as vegetable milk (Brough et al., 1993) and weaning food (Wambete and Mpotokwane, 2003). The gross energy value of Bambara groundnut seed is greater than that of several pulses (Amarteifio et al., 2002; Lacroix et al., 2003). Bambara groundnut fixes atmospheric nitrogen in symbiosis with Brady rhizobium strains through a nodulation process and so it is useful in crop rotation (Dakora and Muofhe, 1996; Gueye et al., (1998)). In addition to its traditional and continuing importance in Africa, it is also being tested for introduction into India, where similar problems, particularly with water availability, also exist (Basu, M. S. Pers. Comm. And EU Framework Programme 6 'Bamlink') cited from Shravani et al. (2007). The International Institute for Tropical Agriculture (IITA; Nairobi) holds the germplasm mandate for this crop, but the Consortium of International Agricultural Research Centres do not currently have a research mandate (Shravani et al. (2007).

In 1982, world Bambara groundnut production was around 330,000 t (Linnemann, 1994). A total of 150,000-160,000 t or 45-50 % of the world production of the crop came from West Africa (Kiwallo, 1991). Earlier, Hepper (1963) reported that the germination of the cultivated form is more rapid than that of the wild form (typically 15 days compared to 31 days or longer).The worldwide demand for the crop is much higher than its current production (Swanevelder, 1998). The yields of Bambara groundnut are extremely low and variable because the environments in which it is normally grown are characterized by various biotic and abiotic stresses (Massawe et al., 2003). According to Linnemann and Azam-Ali (1993), farm pod yields vary between 650 and 850 kg ha−1 for most of the semi- arid tropics.

In northern Ghana, the length of the growing period is mainly a function of the date of the first rains (Sivakumar, 1988) and varies widely from year to year. However, due to the erratic rainfall pattern in the Sahelian regions, the first rain suitable for planting is often followed by several dry days that cause the planting to fail and requires the farmers to replant. One of the most important factors to consider when preparing to establish any plant in the field is the physical condition and performance ability of the seed (Smith, 2006).

In arid regions, cereal production is widely limited by poor stand establishment (Jones and Wanbi, 1992). In drought-prone environments particularly, cereal germination tends to be irregular and can extend over long periods (Bougne et al., 2000). The resulting poor crop stands leave gaps in the canopy, which are rapidly filled by vigorously growing weeds at the onset of the short rainy season. These weeds compete with the crop plants for light, water and nutrients (Kropff and Van Laar, 1993). Perfect field conditions (weather, moisture, fertility, lack of competition, etc.) may exist, yet a suitable stand may never become established if poor quality seed is used. Healthy plants with well developed root systems can better withstand adverse conditions and a vigorous early seedling growth has been shown to be associated with higher yields (Harris et al., 2000). Seed germination is negatively affected by drought (Damirkaya et al., 2006). Since sorghum and Bambara groundnut are grown in drought prone areas of the world, water scarcity and the timing of availability increasingly constrain the production. In particular, the rainy season of the semi-arid African Sahel is projected to start later and become shorter (Biasutti et al., 2009). Water stress during early crop emergence

and the reproductive developmental stages of plants can kill seedlings and delay or completely inhibit flowering respectively. A delay of the rains would likely induce delays in planting and -given that the time of maturity for some traditional cultivars is set by day length - a shorter growing season can result in yield reduction (Dingkuhn et al., 2006). The issue of seedling emergence in Bambara groundnut is of paramount importance considering the hard seed coat which makes moisture permeability relatively difficult as well as the dry areas where the crop is mostly grown which makes moisture availability also more difficult (Berchie et al., 2010). This has a practical implication for days to flowering, podding and days to maturity. In West Africa the unpredictable and erratic rainfall, poor soils and low quality seed all contribute to poor crop establishment. Good crop stand establishment is a pre-requisite for the efficient use of resources such as water and light and plant stand is a major determinant of yield. This is particularly true in the semi-arid tropics where there is a delicate balance between supply of, and demand for water. High and rapid germination and emergence determine good stand establishment, and the related vigorous early growth of seedlings often produced higher yields. Observations in many semi-arid areas suggest that stand establishment, particularly of cereals such as sorghum and millet (a crop of immense importance to the world's poor people), is often extremely poor. One potential way of improving establishment is to develop seed treatments that can increase seed vigour or germination rates. Once sown, seeds spend a great deal of time just absorbing water from the soil. If this time is minimized, seed germination and seedling emergence can be significantly speeded up. The easiest way to do this

is to soak seeds in water before sowing (Harris, 1999); a phenomenon called hydro-priming. In recent years, seed osmo-priming has been tested in over 1000 trials in India, Pakistan, Nepal, Bangladesh and Zimbabwe on a range of crops including maize (Zea mays), sorghum (Sorghum bicolor), rice (Oryza sativa),wheat (Triticum spp.) and Chickpea (Cicer arietinum) (Harris et al., 1999, 2001).

The vigour of seeds can be improved by techniques generally known as seed priming, which enhances the speed and uniformity of germination (Demir and Van De Venter., 1999).

Seed priming is a controlled hydration process followed by re-drying that allows seeds to imbibe water and begin internal biological processes necessary for germination, but which does not allow the seed to actually germinate. The priming process gives the seed a "head-start" at germination and emergence when planted in the soil (Glen et al., 1988). Accelerating and homogenizing the germination process is a prerequisite for a good crop establishment, the efficient use of resources, and eventually to increase yields (Harris, 1996). Seed priming is reported as an efficient method for increasing of seed vigour and improvement of germination and seedling growth (Ascherman-Koch et al., 1992; Jumsoon et al., 1996). A robust seedling establishment enhances competitiveness against weeds, improves tolerance to environmental stresses and maximizes biological and grain yields (Hosseein et al., 2011). There are several reports that under diverse environmental stresses such as salinity, water deficiency and high and low temperatures osmo-priming leads to cellular, sub-cellular and molecular changes in seeds and subsequently promotes seed vigour during germination and emergence in different plant species (Godfery

et al., 2004; McDonald, 2000; Numjun et al., 1997). Seed vigour and seedling establishment have, in several species, been related to the time course of germination (Matthews and Powell, 2011). Seed size plays a major role in germination and establishment of vigorous seedlings that is essential to achieving high yield.

The present study was therefore designed to identify the best seed priming methods for enhanced germination and improved crop establishment in sorghum and Bambara groundnut, to evaluate different priming methods in sorghum and Bambara groundnut; establish the methods that would reduce the time of germination in sorghum and Bambara groundnut seeds and to determine the relationships among priming and plant vigour in sorghum and Bambara groundnut.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Origin Domestication and Distribution of Sorghum

Sorghum bicolor (L) Moench is of tropical origin, but it has been adapted through selection to temperate regions. It was probably domesticated in North Eastern Africa in the area extending from the Ethiopian- Sudanese boarder to Chad (De Wet et al., 1976). The greatest variation in sorghum genus was found in the North-East quadrant of Africa, north of latitude 10 0 N and longitude 25 0 E (Onwueme and Sinha, 1999). Thus Africa is considered to be the centre of origin for several cultivated sorghum. Many annual and perennial species of sorghum were found in the wild form (Onwueme and Sinha, 1999). In 1972, genetic variation in sorghum was partitioned into five basic races (bicolor, guinea, caudatum, kafir and durra) and all combinations of their hybrid derivatives, for a total of 15 races (Harlan and De Wet, 1972).

Sorghum was taken from the Eastern Africa to India probably during the first millennium B.C. and from there to China (Reddy et al., 2002). The crop was introduced to the United States from Africa in about the middle of the nineteen

century. It was grown along the Atlantic coast and then carried westward to the drier regions (Onwueme and Sinha, 1999). Sorghum is cultivated in 100 countries worldwide, covering areas in the Americas, Africa, Asia and the Pacific. In Africa, the crop is third in importance after maize and wheat. 59 % of world sorghum area is in Africa. The Asian countries occupy 25 % of world sorghum area. North and Central America covers 12 % of sorghum area and 4 % is in South America (Onwueme and Sinha, 1999). The developing countries in Asia and Africa contribute more than 49 % of total sorghum production in the world. Asia alone contributes 32 % of world sorghum production. North and Central America produces 15 % of sorghum and 4 % is in South America. Sorghum production in Asia is concentrated mainly in India and China and contributes about 86 per cent. The five largest producers of sorghum in the world are the United States (25 %), India (21 %), Mexico (almost 11 %), China (9 %) and Nigeria (almost 7 %) (FAO, 1991). Together, these five countries account for 73 % of total world production of sorghum. Eighty percent (80 %) of the world's total land area devoted to sorghum is in developing countries. In Africa, sorghum is grown in a large belt that spreads from the Atlantic coast to Ethiopia and Somalia, bordering the Sahara in the North and the Equatorial Forest in the south. This area extends through the drier parts of Eastern and Southern Africa, where rainfall is too low for the successful cultivation of other crops. The leading countries for sorghum crop in tropical Africa are Nigeria, Sudan, Ethiopia, Burkina Faso, Niger and Ghana (FAO, 1991).

2.2 Sorghum Production Constraints

Sorghum is rated as one of the most favoured plants cultivated by man through the

ages, as a host for insect pest. Numerous lists have been produced cataloguing well over 150 species as pests or potential pests of sorghum (Teetes, 1982). In the developing countries where sorghum is a significant food crop, the low yields pitifully quoted as 500- 700 kg/ha were due to the pests attack (Davies, 1982). The strategies revolved around the key pest of sorghum such as: Sorghum midge, Striga, grain mould and head bugs. Other pests which sometimes injured sorghum are in the pest status category of occasional pest (Teetes, 1982). The crop is usually grown under stress conditions (particularly moisture and temperature) in semi-arid environments. Drought resistance in sorghum and millet is a complex trait affected by a number of interacting plant and environmental factors.

2.3 Taxonomy and origin of Bambara groundnut

Bambara groundnut belongs to the family Leguminosae, subfamily Papilionoideae, although further refinement of its taxonomy has been subject to some controversy. The crop was first mentioned in the 17th-century literature (Marcgrav de Liebstad, 1648), where it is referred to as 'mandubi d'Angola'. In 1763, Linnaeus described it in Species, Plantarum, and named it Glycine subterranea, in accordance with his system of nomenclature. Du Petit-Thouars (1806) found the crop in Madagascar, under the vernacular name 'voanjo', subsequently written as 'voandzou' in French. He then proposed the name Voandzeia subterranea (L.) Thouars, which was widely used by subsequent researchers for over a century. Recently, detailed botanical studies were undertaken by Maréchal et al. (1978), who found great similarities between Bambara groundnut and plant species of the genus Vigna. This confirmed studies done by Verdcourt, who seized the opportunity in 1980 to propose the

current name Vigna subterranea (L.) Verdc. Investrigators interested in the origin of Bambara groundnut (Dalziel, 1937; Jacques-Felix, 1946; Rassel, 1960; Hepper, 1963; Begemann, 1988) all agreed that the crop originated from the African continent. The common name actually appears to be derived from a tribe, the Bambara, who now live mainly in Mali. The exact area of origin of the crop in Africa has been a matter of debate, however. No spontaneous or wild forms of the crop have been found in Mali, although Guillemin et al., 1832 reported the probable occurrence of wild forms in nearby Senegal. Bambara groundnut was found by Dalziel (1937) in its genuinely wild state in 1901, in the North Yola province of Nigeria. He reported that Ledermann also found the wild plant the same year, near Garoua in northern Cameroon. Dalziel's finding was confirmed by Hepper (1957). The distribution of wild Bambara groundnut is now known to extend from Jos Plateau and Yola in Nigeria, to Garoua in Cameroon, and probably beyond. As further confirmation, Begemann (1988) carried out detailed analyses of the seed-pattern diversity within the large collection of Bambara groundnut at IITA. The authors found that samples collected less than 200 km from the putative centre of origin, between Yola and Garoua, consistently showed greater seed-pattern diversity. Diversity indices for the number of days to maturity, pod length, number of stems per plant and internodes length, were comparatively higher for accessions from Nigeria and Cameroon. The conclusion confirmed the hypothesis that the centre of origin of Bambara groundnut is in the region of north-eastern Nigeria and northern Cameroon.

Bambara groundnut is an herbaceous, intermediate, annual plant, with creeping

stems at ground level. Differences in the length of internodes result in bunched, intermediate (semi-bunched) and spreading types. The general appearance of the plant is bunched leaves arising from branched stems which form a crown on the soil surface. Stem branching begins very early, about 1 week after germination, and as many as 20 branches may be produced. Each branch is made up of internodes, and those near the base are shorter than the more distant ones. The plant has a well- developed tap root with profuse geotropic lateral roots. The roots form nodules for nitrogen fixation, in association with appropriate rhizobia. Leaf and flower buds arise alternately at each node. Leaves are pinnately trifoliate, glabrous with erect petiole, thickened at the base. Two stipels subtend the terminal leaflet, while only one is assigned to each of the two lateral leaflets. The oval leaflets are attached to the rachis with marked pulvini. The terminal leaflet is slightly larger than the lateral leaflets, with an average length of 6 cm and an average width of 3 cm. The flowers are borne on hairy peduncles, which arise from the nodes of the stems. Usually, two flowers are attached to the peduncle by pedicels. A good knowledge of the flower structure is essential for breeding the crop, Heller, 1995. The flowers are typically papilionaceous. The peduncles reach their maximum length at the initiation of pod formation, but their pedicels reach theirs at the time of anthesis. The interval between the openings of successive flowers in a raceme varies from 24 to 48 hours; that of flowers on the same peduncle does not exceed 24 hours, but rarely do they open at the same time. When flowers open during the early hours of the morning, they are yellowish-white, but towards the evening, the colour changes through various shades of

yellow to brown. Flowers that are produced towards the end of the plant's life are usually light brown. The flower has a pair of hairy epicalyces. The calyx consists of five hairy sepals (four on the upper side and one on the lower side). The four upper sepals are almost completely joined, while the lower sepal is largely free. The epicalyx and calyx completely enclose the corolla in the early budding stage. The epicalyx drops off during the course of entry of the fertilized flower into the soil, but the calyx persists on the developing pod. The standard encloses the wing and keel until the flower opens. When the standard petal opens, it is bent over to about half its length. The stamens are diadelphous, nine with partly fused filaments, and one isolated vexillary stamen. Upon pollination and fertilization, the peduncle elongates to bring the ovaries to or just below ground level. Apparently, reproductive development is not completely inhibited by light. The pod grows first, and reaches its mature size about 30 days after fertilization. The seed develops in the following 10 days. Mean temperature during the seasons influences the time taken to achieve physiological maturity. Bunch types tend to mature earlier than spreading types. Fruit development has been reported to be influenced by photoperiod (Linnemann and Azam-Ali 1993). Long photoperiods delay or even continuous light was shown to delay flowering by 6-11 days in a few genotypes (Nishitani et al., 1988). The pods usually develop underground, and may reach up to 3.7 cm, depending on the number of seeds they contain. Most varieties have single-seeded pods, but pods with three seeds were frequently found in ecotypes collected in Congo (Goli and Ng, 1988). Mature pods are indehiscent, often wrinkled, ranging from a yellowish to a reddish dark brown colour. Seed

colour also varies, from white to creamy, yellow, brown, purple, red or black. Various testa patterns are found, including mottled, blotched or striped, in addition to the predominantly uniformly coloured seeds.

Table 2.1: Countries of origin of the Bambara groundnut accessions held at IITA

Country	N° of accessions	Country	N° of accessions
Benin	27	Mali	28
Botswana	5	Niger	33
Burkina Faso	97	Nigeria	310
Cameroon	207	Senegal	36
Central African Republic	103	South Africa	1
Chad	70	Sudan	7
Congo	42	Swaziland	11
Côte d'Ivoire	4	Tanzania	28
Ethiopia	1	Togo	139
Gambia	11	Zimbabwe	245

Ghana	120	Zambia	284
Kenya	2	Unidentified	101
Madagascar	49		
Malawi	59		
Total	2008		

Source: Begemann et al., 1988

2.4 Botany of Bambara groundnut

A well-developed taproot with many profuse geotropic short lateral roots 20 cm long. The roots form nodules for nitrogen fixation, in association with appropriate rhizobia. The stem has lateral stems which develop from the root. The petioles are about 15 cm long, stiff and grooved, and the base is green or purple in colour. Leaves and flower buds arise alternately at each node. Leaves are pinnately trifoliate, glabrous with erect petiole and thickened at the base. Two stipels are subtend to the terminal leaflet, while only one is assigned to each of the two lateral leaflets. The oval leaflets are attached to the ranchis with marked pulvini. The terminal leaflet is larger than the lateral leaflets, with an average length of 6 cm and an average width of 3 cm. Flowering starts 30 to 35 days after sowing and may continue until the end of the plant's life. The flowers are self- pollinated. The petals are often undeveloped or fail to open in the bud and the flowers are cleistogamous. After fertilization the flower stem elongates. The sepal enlarges and the fruit develops above or just below the soil surface. The unripe pod is yellowish green, with up to six pods while the mature pods may be yellowish green or purple. The

pod is small, about 1-5 cm long, round or slightly oval shaped and wrinkled with mostly one or sometimes two seeds. The seeds are round, up to 1, 5 cm in diameter, smooth and very hard when dried. They are cream, brown, and red, mottled, with or without haulm coloration.

2.5 Uses

Bambara groundnut is essentially grown for human consumption. The seed makes a complete food, as it contains sufficient quantities of protein, carbohydrate and fat. Several workers have examined the biochemical composition of the seed (Linnemann, 1987). On average, the seeds were found to contain 63 % carbohydrate, 19 % protein and 5 % oil. The gross energy value of Bambara groundnut seed is greater than that of other common pulses such as cowpea, lentil and pigeon pea (FAO, 1982).

Bambara groundnut seeds are consumed in many ways. They can be eaten fresh, or grilled while still immature. At maturity, they become very hard, and therefore require boiling before any specific preparation. In many West African countries, the fresh pods are boiled with salt and pepper, and eaten as a snack. In Côte d'Ivoire, the seed is used to make flour, which makes it more digestible. In East Africa, the beans are roasted, then pulverized, and used to make a soup, with or without condiments. Bread made from Bambara groundnut flour has been reported in Zambia (Linnemann, 1990). Roasted seeds can be boiled, crushed and eaten as a relish. Another common use of Bambara groundnut is to make a paste out of the dried seeds, which is then used in the preparation of various fried or steamed

products, such as ‘akara’ and ‘moin-moin’ in Nigeria (Obizoba, 1983). Another favourite Nigerian dish is ‘okpa’, which is a doughy paste that is wrapped in banana leaves and boiled. In Ghana, the beans used to be canned in gravy at GIHOC cannery in Nsawam. The product was thus available throughout the year, and over 40 000 cans of various sizes were produced annually (Begemann, 1986). Recently, a trial of Bambara groundnut milk was carried out which compared its flavour and composition with those of milks prepared from cowpea, pigeon pea and soybean (Brough et al., 1993). Bambara groundnut was ranked first, and while all milks were found to be acceptable, the lighter colour of the Bambara groundnut milk was preferred

2.6 Agronomy of Bambara groundnut

Cultivation of Bambara groundnut on a large scale and in pure stand is not very common. The crop is mostly grown by women, intercropped with major commodities such as maize, millet, sorghum, cassava, yam, peanut and cowpea. Grown in rotation, Bambara groundnut improves the nitrogen status of the soil (Mukurumbira, 1985).

Many farmers grow the crop on a flat seedbed, but the use of ridges or mounds is also common in a few countries. Planting density is usually low in farmers’ fields, especially when crops are not in rows. Farmers do not normally apply chemical fertilizers to Bambara groundnut fields. The nitrogen requirement is met by natural

N2 fixation, as indicated by several nodulation studies (Somasegaran et al., 1990). Yield increase as a result of phosphate or potassium application has not always been confirmed (Nnadi et al,. 1981).

Bambara groundnut has a reputation for resisting pests, and compares favourably with other legumes such as groundnut or cowpea in this regard. In humid environments, however, fungal diseases such as Cercospora, leafspot, Fusarium wilt and Sclerotium rot are common (Begemann, 1986b, 1988a). In such circumstances, spraying with the fungicide benlate (1 kg/ha) has proved beneficial.

Viral diseases are widespread in most environments, especially in areas where other grain legumes such as cowpea are grown. Common diseases are cowpea mottle virus (CMeV) and cowpea aphid-borne mosaic virus (AbMV) (Ng et al., 1985). A sold at markets, as pods or seeds. In dry areas, materials for planting the following season are usually kept by farmers as pods. This reduces or eliminates attacks by insects' combination of unusually heavy virus attack and Cercospora leaf spot on one particular accession (TVSU 218) resulted in zero yield during a trial at Kaboinse, Burkina Faso (Goli et al., 1991).

Harvesting of Bambara groundnut is done by pulling or lifting the plant. For the bunched-habit type, most pods remain attached to the root crown. Detached pods left in the ground are collected manually. In a dry environment, harvesting takes place when the entire foliage dries up. In humid ecosystems, however, pod-rotting or early seed germination (in the pod) may take place while the leaves are still partially green. Harvesting is then recommended before full foliage drying Heller et al. (1995).

Harvested pods are air-dried for several days before threshing. The raw product is sold at markets, as pods or seeds. In dry areas, materials for planting the following season are usually kept by farmers as pods. This reduces or eliminates attacks by insects Heller et al. (1995).

2.7 Future prospects

Bambara groundnut is a promising commodity which needs more publicity, both as a crop and as a food. Even in tropical Africa, few people in the forest zones are aware of its existence. It should be emphasized that it is a low-cost, dependable crop that grows in harsh environments where many other crops fail. Its high nutritive value should also be made known to the general public, and, in particular, to the rural poor. However, to ensure the wider adoption of Bambara groundnut, the general mode of consumption of the crop needs improving. Modern processing methods need to be used Heller et al. (1995).

2.8 Germination Processes

Germination and establishment as an independent organism are critical phases in the life of a plant when they are the most vulnerable to injury, disease, and water stress (Raven et al., 2005). The germination index can be used as an indicator of phytotoxicity in soils. Seed germination depends on both internal and external conditions. The most important external factors include temperature, water, oxygen and sometimes light or darkness (Raven et al. 2005). Various plants require different variables for successful seed germination. Often this depends on the

individual seed variety and is closely linked to the ecological conditions of a plant's natural habitat Raven et al., (2005). The pre-sowing treatments cause initiation of the early metabolic processes and the re-drying of seeds arrest, but do not reverse, the initial stages of germination so that on the availability of suitable conditions, the time taken to germinate is reduced (Hosseein et al., 2011). Rapid embryo growth resulted when the obstacle to germination was removed (Basra et al., 2003). Germination is one of the most salt-sensitive plant growth stages and severely inhibited with increasing salinity both in glycophytes and halophytes (Hosseein et al., 2011). Many factors can influence the imbibitions and germination process, among them integument composition and permeability, water availability in the environment, hydrostatic pressure, temperature, and seed physiological condition (Vertucci, 1989). The water uptake in seeds follows a triphasic pattern with an initial rapid uptake phase known as imbibitions (Phase-I); followed by lag period (phase-II) where the water potential of the seed is in balance with the environment and major metabolic activities prepare the seed for radical elongation) and then a second increase in water uptake associated with seedling growth (phase-III) (where cell elongation and division lead to radicle emergence) (Karssen et al., 1989). Seeds are desiccation tolerant during phase-I and phase-II but become intolerant during phase-III. At each phase, water uptake is controlled by the availability of water to the seed. In seed priming regime, seed water potential is at a level sufficient enough to initiate metabolic events in phase-II of germination process but which prevents radicle emergence (Simon, 1984).

2.9 Seed Priming

Priming is usually followed by re-drying of seeds to allow storage and handling. It involves exposing seeds to an external water potential which is low enough to restrict germination and yet permit pre-germinative physiological and biochemical activities (Bradford, 1986). Priming may help seed production in the tropics by ensuring that seed plants grow uniformly and vigorously (Harris et al., 2001).The principle of priming is based on the fact that it is possible to hydrate seed in some ways at a moisture level sufficient to initiate the early events of germination but not sufficient to permit radical protrusion (Moradi and Younesi, 2009). Seed priming treatments such as osmo-priming, hydro-priming, matrico-priming, hormonal-priming have been employed to accelerate germination, seedling growth and yield in most of the crops under normal and stress conditions (Basra et al., 2003).). It has been declared that priming had resulted in more germination speed especially in drought stress and low temperatures in sorghum, sunflower and melon (Sivritepe et al., 2003). Osmo-priming is the most common type of seed priming which involves controlled hydration of seeds by exposure to water (Nyarko et al., 2006), either alone or in combination with solid media or osmotic agent, allowing seeds to imbibe, but removing the water and drying seeds to original moisture content prior to radicle emergence (Murray and Wilson, 1987) cited from Smith, 2006. Commonly used osmotic priming agents include inorganic salts such as CaCl2, KNO3, Na2 SO4 and organic agents such as polyethylene glycol (PEG), mannitol and sorbitol (Pill et al., 1991). It has been reported that Priming of cabbage seed with PEG had no adverse effect on the embryo, either at the imbibitions or the

emergence stage (Nyarko et al., 2006). There have been several reports of the benefit of priming to seed quality after sowing. Water priming of Bambara groundnut for about 24 hours increased seedling emergence (Berchie et al., 2010) and also osmotic priming with water potential improves germination percent at - 0. 2 - 0.5 and at -1. 5 M Pa of wheat (Murungu et al., 2011). Hydro-priming method has also been used successfully in wheat, sunflower, chickpea and cotton.

2.10 Seed priming Methods

2.10.1 Hydro-priming:

Hydro- priming also involves soaking in water and drying back to storage moisture prior to sowing of the seeds (Harris et al., 1991). This decreases the time that the seed spends in the seedbed simply imbibing water. Once sown, seeds spend significant amounts of time to minimum (through seed priming) germination rate of seed can be increased and seedling emergence improved (Hartman et al., 2002). Prior to radicle emergence, seeds are dried to initial (pre-primed) moisture content for storage prior to sowing. One such technique involves the spraying of a water mist over the seeds and allowing the moisture to equilibrate (Van Pijlen et al., 1996). With another hydro priming technique known as hydration, seeds are submersed in aerated water for the priming duration (Thornton and Powell, 1992). Seeds can also be soaked in water and then exposed to air maintained at near 100 % relative humidity (Fujikura et al., 1993). Temperature and the duration of treatment must be carefully monitored and adjusted to prevent both radicle protrusion and microbial growth (Burgass and Powell, 1984; Coolbear et al., 1987). Moreover

hydro-priming increases germination and seedling growth under salt and drought stresses. Hydro-priming is a simple method of priming treatment. It does not require any special technical equipment and owing to the use of distilled water as a priming medium. It is probably the cheapest priming method. Similarly Fujikura et al., 1993 presented hydro-priming as a simple and inexpensive method of seed priming. Hydro-priming has been utilized on a variety of plant species, including cauliflower (Brassica oleracea var. botrytis Fujikura et al., 1993), strawflower (Helichrysum bracteatum (Vent.) Andrews; (Grzesik and Nowak, 1998), mustard (Brassica 18 rapa L.; Srinivasan et al., 1999), watermelon (Citrullus lanatus (Thunb.); Demir and Van de Venter 1999), Kentucky bluegrass (Poa pratensis L.); (Pill and Necker, 2001), wheat (Triticum aestivum L.; Giri and Schillinger, 2003), corn (Clark et al., 2001; Murungu et al., 2004) and onion (Allium cepa; Caseiro et al., 2004)

2.10.2 Osmo-priming:

Osmo-priming is the most common type of seed priming in which seeds are soaked in aerated low water potential solution (Farooq et al., 2005). Although, the mechanism of seed priming treatments is not fully understood, it has been observed that physiological and biochemical changes take place during the seed treatments (Basra et al., 2005; Ghiyasi et al., 2008), which could allow seeds to begin the germination sequences before sowing. Osmotic priming consists of the incubation of seeds for a specific period of time at a specific temperature in an osmoticum of -1.0 to -1.5 M Pa, usually salt or polyethylene glycol (PEG, molecular weight 6000) dissolved in water (Karssen et al., 1989). Osmo-priming, sometimes referred to as

osmo-conditioning, is similar to hydro-priming. As with hydro-priming, seeds are allowed to imbibe water, begin the germination process up to the second phase of the tri-phasic water uptake, and then dried to storage moisture before radicle emergence occurs (Bennett et al., 1992). However, various osmotica are added to the water during the imbibitions period to prevent full hydration of the seeds. These osmotical include sugars, salts, PEG, and mannitol. The solutions created provide osmotic potentials low enough to prevent germination and radicle emergence during priming (Smith, 2006).The concentration of the hydrating solution is an important factor in osmo-priming. High levels of some osmotica may negatively affect seed water potential, may be toxic to the seed, or may be economically unsustainable (Taylor and Harman, 1990). Salim and Todd (1968) applied large numbers of inorganic chemicals at different concentrations to seeds of diverse crop species and concluded that the seed, the chemical and the concentration had all to be right for success. Other limitations with osmo-priming include difficulty in handling of polyethylene-glycol for priming large seed lots (Heydecker and Coolbear, 1977) and chemical waste disposal after priming. Rapid germination and emergence is an important determinant of successful establishment Harris et al., 1991cited from Ehsan et al., 2009.

2.10.3 Drum Priming:

A specific method and device for hydro-priming using water and a rotating cylinder has been developed (Rowse, 1991; Rowse, 1992). Seeds are placed into the rotating cylinder and water is added via mist in small amounts over time until the seed within the cylinder reaches a predetermined target moisture concentration.

This process eliminates the concern for the disposal of spent hydrating solution (as in osmotic priming) or spent solid carrier disposal (as in solid matric priming) (Rowse, 1996). A device that can be assembled and utilized for drum priming of seed is described in detail by Warren and Bennett (1997). Both maize (Warren and Bennett, 1997) and onion (Caseiro et al., 2004) have been primed using a similar device. However, drum priming onion seeds was detrimental, as it resulted in lower final germination percentages and slower germination rates (Caseiro et al., 2004).

2.10.4 Matric priming:

Matric priming (also called matric conditioning, solid matric priming or solid matric conditioning) accomplishes the same type of controlled, limited hydration as hydro-priming and osmo-priming. However, unlike hydro- and osmo-priming, matric priming utilizes a solid medium (the matrix) to deliver water and nutrients to the seed prior to emergence of the radicle (Taylor and Harman, 1990). Khan (1992) recommended the use of vermiculite or calcinated clay as the solid medium due to their good water holding capacity and ease of removal from the seed after the priming process is complete. A clear advantage of matric priming is the ability to provide ample oxygen to the seed during the hydration process (John Easton, personal communication, 2005). However, as with osmo-priming, waste disposal after priming may become an issue (Warren and Bennett, 1997).

Matric priming is a newer technique, and its effects on germination and vigour have been reported for fewer seed species. Matric priming has improved

strawflower seed performance and seedling emergence (Grzesik and Nowak, 1998). The authors also demonstrated that matric priming can also increase seedling frost resistance and decrease effects of water stress on seed performance. Kentucky bluegrass exhibited the best results when matric primed and then germinated immediately following the priming treatment (without drying seed), compared to osmotic and hydro-priming (Pill and Necker, 2001). Seeds were exposed to a growth regulator solution (-1.5 M Pa for four days at 20°C) with a 50:50 matrix of No. 5 fine vermiculite and water (w/w) and in a sealed container to prevent evaporation. In a similar study by Yamamoto and Turgeon (1998), as cited by Smith (2006) matric priming of Kentucky bluegrass resulted in faster, more uniform germination, but results varied in magnitude by seed lot/cultivar. Matric priming Kentucky bluegrass seed had greatest benefit with low-vigour seed lots.

2.11 Seed Vigour

Seed vigour can be defined as those seed properties which determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field condition (AOSA, 2002). It is important to test the quality, vigour, and performance ability of a seed lot to know its true ability (AOSA, 1988), as sometimes the stated germination percentage on a seed tag may vary greatly from actual emergence in the field. This difference may often be attributed to seed vigour. The vigour of the seed can have consequences, positive or negative, on the emergence of the planted seed. The International Seed Testing Association (ISTA, 1995) defines seed vigour as "the sum of those properties which determine the

potential level of activity and performance of the seed or seed lot during germination and seedling emergence. Seeds which perform well are termed 'high vigour seed,' while those which perform poorly are called 'low vigour seed" (Perry, 1978). Principal known causes affecting the vigour of seeds include genetic constitution, environment and nutrition of the mother plant, stage of maturity at harvest, seed size, weight or specific gravity, mechanical integrity, deterioration, aging, and pathogens (Perry, 1978). The underlying reason for testing seed vigour is to determine a more accurate value of a seed lot (AOSA, 2002). A vigour measurement is more than a germination test. Vigour tests should incorporate some stress factors that the seed may encounter when planted in the field. Stress factors may include excessive heat, drought, excess moisture, cold, aged seed due to prolonged storage, or lack of light. Performance aspects therefore related to seed vigour include the rate and uniformity of seed germination, field traits including extent, rate and uniformity of seedling emergence, and performance after storage and transport, particularly in regards to the retention of germination capacity (Smith, 2006).

Perry (1978) suggested using both direct and indirect tests to determine seed vigour. Direct vigour tests incorporate an expected environment stress that the seed may encompass in the field into a laboratory test. Indirect tests measure other characteristics of seed that are correlated to an aspect of field performance. Because no single method satisfies all requirements for understanding seed vigour, "a method or combination of methods should be chosen to suit the crop or the environment into which it will be sown" (Perry, 1978).

2.12 Seed size:

Seed size is an important seed quality characteristic affected by variety, environment and management practices (Jumsoon et al., 1996). The influence of seed size on crop establishment has been studied extensively. Generally, decreasing seed size reduced seedling establishment (Damirkaya et al., 2006; Mauromicale and Cavallaro, 1997).

Seedling establishment and speed of emergence influence the time required for seedlings to reach the autotrophic phase. Most investigators have reported a positive relationship between seedling vigour, improved stand establishment and higher productivity of cereal crops with plants originating from large seeds compared to those grown from smaller seeds. Chastin et al. (1995) suggest that larger seeds produce seedlings with greater early growth and increased competitive ability against weeds and pests. Amico et al. (1994) concluded that higher vigour that occurred in larger seed is due to the larger food reserves in these seeds. Larger seeds have the ability to store greater amounts of carbohydrate in their endosperm or cotyledons than small seeds (Milberg and Lamont, 1997).

The relative performance of individual plants during the early stages of life, i.e. germination and seedling establishment, can have important effects on subsequent adult growth and fitness (Stanton, 1984; Winn, 1985, 1988; Wulff, 1986 a; Roach, 1987; Houssard and Escarre, 1991). The finding that early seedling performance can itself be markedly influenced by seed size variation (Gross, 1984; Stanton, 1987; Wulff, 1986b; Roach, 1987) has prompted much discussions of the ecological and evolutionary significance of seed size variation (Temme, 1986;

Mazer, 1987; Haig and Westoby, 1988; Westoby, Jurado and Leishman, 1992 cited from Bretagnolle et al., 1995). Larger seeds have the ability to store greater amounts of carbohydrate in their endosperm or cotyledons than small seeds (Milberg and Lamont, 1997). This may enable early development of an enlarged resource gathering system (root or photosynthetic tissue) to produce a faster growing plant (Hewitt, 1998). Seed size does not alter germination but affects growth, development and yield. Bigger seeds have several advantages when compared to smaller seeds, such as faster seedling growth, higher number of fertile tillers per plant and higher grain yield (Spilde, 1989). The advantage of bigger seeds is demonstrated when the crop is grown under environmental stresses, particularly drought (Mian and Nafziger, 1994). Baalbaki and Copeland (1997) reported that in wheat, seed size did not only influence emergence and establishment but also affected yield components and ultimately grain yield. A similar observation was made by Arunachalam et al. (2003), while working with the tree species, and this was attributed to the larger food reserves in the larger seeds. These results also are in conformity with Singh (2003) in wheat. These results also indicated that seed size had greater effect on percent than index of germination and emergence. With increased seed size, higher germination and emergence were reported in triticale (Kaydan and Yamur, 2008).

CHAPTER THREE

3.0 MATERIELS AND METHODS

3.1 Seed priming in the Laboratory

3.1.1 Materials

Three varieties of Bambara groundnut ('Cream with black eye', 'Cream with brown eye' and 'Red') and Sorghum ('Dorado', 'Kadaga' and 'Kapaala') were used.

3.1.2 Priming agents

The priming agents used were: i) Mannitol with a concentration of 11.15 g / l for 120 hours for Bambara seeds and 72 hours for sorghum seeds at 25°C;

ii) Sodium Chloride with a concentration of 3.62 g / l for 120 hours for Bambara seeds and 72 hours for sorghum seeds at 25°C and iii) tap water for 24 hours at 28 ± 3°C.

3.1.3 Osmotic potential of salt

The osmotic potential (P) for all salts used in the experiment was -1.5 M Pa and it was performed at temperature of 25°C. This osmotic potential of the solution was calculated using the formula suggested by Thill et al (1979).

g =

Where, g = gram of solute, P = osmotic pressure, V = volume in litters, m = molecular weight of chemical used, R = 0.0825 atmospheres per degree per mole and T = absolute temperature. The absolute temperature (in Kelvin °K) is determined as follow:

T° Kelvin = T° C + 273.15.

3.1.4 Methodology

Seeds were hand sorted to eliminate broken and damaged seeds. Bambara seeds after cleaning were sorted into sizes (small and larger seed) by weight, length and width. Large seeds ranged from 10.5 to 12.7 mm in length, 9.0 to 11.4 mm in width and seed weight of 1.03 to 1.05 g per seed. The small seeds ranged between 0.99 and 1.1 mm in length and 0.80 - 1.0 mm in width (seed weight: 0.504 to 0.611 g per seed). Four hundred seeds from each classification category among the three different varieties (‘Cream with black eye’, ‘Cream with brown eye’, ‘Red’) of Bambara groundnut and from the three different sorghum varieties, ‘Dorado’, ‘Kadaga’ and ‘Kapaala’ were also used.

Five replicate dishes with 20 seeds per replicate were used for each treatment on Bambara groundnut and two replicate dishes with 50 seeds per replicate for sorghum. Seeds were surface sterilized in 10 % Parozone bleach for five minutes and washed four times in distilled water. The sterilized seeds were primed in salt (Mannitol and Sodium Chloride) for 72 hours for sorghum and 120 hours for Bambara groundnut. Seeds were placed in 5 cm sterilized petri dishes lined with 3

layers of Whatman No. 1 filter paper soaked in Mannitol and Sodium chloride (-1.5M Pa) at 25°C for 120 hours (Bambara) and 72 h for (Sorghum). Seeds of both crops were also soaked separately in tap water (in a 400 ml flat bottom flask) for 24 hours at 28 - 30° C.

After the pre-sowing treatment, all seed samples was washed four times in distilled water

(Nyarko et al., 2006) and surface dried on tissue paper before planting. Seed priming in different salts and water were staggered so that planting were done at the same time.

3.2. Determination of seed viability and seedling vigour in pot

3.2.1 Methodology

The pot experiment was conducted during the period of October to December 2011 in the Department of Horticulture, University for Development Studies: to determine seed viability and vigour of treated seeds.

The sand (which was used as a media) was sieved using 0.4mm mesh as recommended in International Seed Testing Association Rules (a range of 0.8 mm to 0.05 mm) and readily sterilized by heat using the oven at 150 ° C for one hour. Sterilized sand was filed in each of the thirty six plastic containers (13.2 liters) which had six holes perforated at the base to drain excess water.

3.2.2 Experimental Design

Primed seeds of Bambara groundnut and sorghum as described earlier were grown

in the plastic containers. Experimental units were arranged in a completely randomized design (CRD) with four replications.

A dibber was used to make 50 small holes in the leveled sand in each container. Two seeds were sown in each of the holes at 3 cm depth for sorghum. For Bambara, 30 small holes were made per container and a seed was sown in each of these holes at 5 cm depth. Watering was done when necessary to keep the moisture content for better seedling growth conditions. The plants were carefully uprooted from each container after 10 days of sowing and the fresh weight of plant, length of shoots and roots was measured. Plant samples were later dried in an oven at 60 C for 48 hours and measured by weighing scale to obtain the dry weights.

3.2.3 Data Collected

Data on the following parameters were taken;

i) Germination percentage (%)

Germination percentage was recorded the 10th day after planting and calculated using the formula:

Germination percentage = x 100

ii) Coefficient of velocity

The time of seedling emergence was recorded daily. The `coefficient of velocity (CV) (Scott et al., 1984), a measure of vigour, was calculated as follows:

CV = x 100

Where Ni = number emerging on day i; and Di = days from sowing.

Generally CV increases as more seeds germinate and with shorter germination time. The CV gives an indication of the speed and uniformity of seedling growth (i.e., a higher CV means higher vigour).

The final proportion of seeds germinating was recorded on day 10, in accordance with the International Seed Testing Association Regulation (ISTA, 1993).

After the tenth day, ten seedlings were randomly selected from each treatment. The lengths of shoots and roots were measured by using a ruler. They were put in labelled envelopes, fresh weight for each sample was determined and later oven-dried at 60° C for 48 hours. The dry weight was taken by using an electronic scale. Seedling vigour was calculated using the formula:

Vigour index = (Shoot length + Root length) x Germination percent.

iii) The germination index (GI)

The germination index was calculated by the formula as described in the Association of Official Seed Analysts (AOSA, 1983):

GI = +…….+

iv) Mean germination time

Mean germination time (MGT) was calculated using the formula described by Ellis and Roberts 1980:

MGT =

Where: nd – number of seeds that germinated on the day (d)

d - Serial number of the day

v) Seedling fresh weight

The fresh weight of ten seedlings from each treatment was determined by using an electronic scale.

vi) Seedling dry weight

The ten seedlings from each treatment was put in labelled envelopes and oven dried at 60°C for 48 hours. The dry weight was determined by using an electronic scale.

3.3 Statistical analysis

Data collected was subjected to analysis of variance (ANOVA) using the GenStat statistical package (12th edition) and means separated by standard error of the difference (SED).

3.4 Field experiment

In order to determine the effect of priming methods and seed size (by weight or length) on the germination, growth and biomass allocation on Sorghum and Bambara groundnut, an experiment was conducted in the research field of the Savanna Agricultural Research Institute from August 2011 to January 2012.

Data on germination percent mean germination time, final plant establishment, days to emergence, days to 50 % flowering; number of leaves per plant, plant height, number of pod, seed weight per plant were measured on Bambara groundnut and Sorghum.

3.4.1 Experimental Sites and Climatic Conditions

The experimental site, Savanna Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) Nyankpla is located on latitude 9°, 23’ 13.9” and longitude 01° 00’ 10.2” with an altitude of 183 m above sea level lies within the Northern Guinea Savanna Zone with a mean annual rainfall of about 1000 mm. The temperature distribution is fairly uniform with a mean annual surrounding 28.3°C. The annual relative humidity of 54 % varies greatly falling during the dry season and rising during the rainy season as showed in Table 3.3. The rainfall distribution, minimum and maximum temperatures of the location during the evaluation period are presented in (Fig.3.1). The total amount of the rainfall was 2153.4 mm in 65 days with maximum and minimum temperatures of 34.4 ± 0.2° C and 23.2 ± 2° C respectively.

Figure 3.1: Monthly rainfall distribution and mean minimum and maximum temperature at Nyankpla in 2011

Table 3.2: Mean relative humidity and rainy days by month during the experiments

Month	Relative humidity		Rainy days
	RH min %	RH max %	
Early planting			
April	12	99	3
May	52	97	7
June	56	96	10
July	60	98	8
Late planting			
August	67	99	14
September	62	99	13
October	57	96	8

November 28 89 0

3.4.2 Experimental Design and Field Layout

The experimental design was Randomized Complete Block (RCBD) with three replications; treatments were randomized within the varieties. The field was divided into two and each containing three blocks measuring 55.40 x 4.0 meters; 24 plots for Bambara groundnut and 12 plots for sorghum. The plot size was 4 m by 3.2 m. The distance between adjacent plots was 1 m and that between replications (blocks) is 2.0 m. For each plot, four rows were established with inter-row spacing of (75 cm), but intra-row spacing differed according to the specie. Bambara seeds were sown at 75 x 20 cm and one seed per hill. Sorghum seeds were sown at 75 x 25 cm.

3.5 Cultural Practices

3.5.1Field Preparation

The field was ploughed, harrowed and ridged by the tractor. The ridges were spaced at 0.75 m. Each experimental unit was made up four rows of 4 m long. The experimental area was demarcated before treatments were assigned to the plots.

3.5.2 Sowing and Thinning

Sowing was done using local dibbling stick to make holes on the ridges. Seeds were sown with one seed per hole for Bambara and 2 seeds for sorghum when the soil was adequately wet. Planting depth were approximately 3- 5 cm and seeds covered with soil to achieve good germination and good seedling establishment.

Immediately after planting, 250 ml of Roundup (with active ingredient glyphosate) and 200 ml primagram (with S- metolachlor 290 g / l) were mixed with 16 liters of water in a knapsack sprayer to spray the field. Bambara groundnuts were sown on 13th and sorghum on 18th of September 2011. Two weeks after germination, seedlings were thinned to one plant per hill.

3.5.3 Weed Control and Fertilizer Application

Three hand weeding were done to control weeds. The first weeding was done four weeks after sowing. The ridges were also reshaped to control weed. Compound NPK fertilizer, (23-10-5) was applied at the rate of 100 kg / ha. Ten days after the application of NPK, the second split dose of nitrogen was applied as sulphate of ammonia at the rate of 50 kg / ha on sorghum experimental unit while single super phosphate (SSP) at the rate of 60 kg / ha was applied on Bambara experimental unit.

3.5.4 Plant Protection

Furadan granules were applied to kill all the black ants' holes to prevent them taking up the seeds from the holes and two weeks later it was put in the heart of each seedlings to prevent shoot fly infestation in sorghum. Immediately after planting bird scarers were employed to drive the bird and others animals taking up the seeds or destroyed seedling after emergence. Bambara groundnut plants were sprayed every three week with Dimex 400 AC against insect pests.

3.6 Data Collection

Various data sets were obtained from measurements done for a number of traits. The following data were collected:

i) Germination percent

The number of seedlings germinated per plot was counted and recorded 10 days after sowing for sorghum and 15 days for Bambara groundnut.

Germination percentage = x 100

ii) Mean germination time

Mean germination time (MGT) was calculated using the formula;

MGT =

Where: nd - number of seeds that germinated on the day,

d - Serial number of the day (Ellis and Roberts 1980)

iii) Final plants establishment

It was determined as seedlings that had established at 20 days after sowing (DAS)

iv) Number of Leaves per Plant

The numbers of leaves were counted from ten randomly selected plants per plot by using a permanent marker at weekly interval.

v) Height of Plant

Plant height was measured from the base of the plant to the tip of the panicle at maturity for sorghum and from the base to the tip of the last leaf for Bambara groundnut. The measurements were taken from ten randomly selected plants per plot and the average computed.

vi) Days to 50% flowering

The number of days after planting the appearance of the first flush of flowers was noted. Days to 50 % flowering was scored when 50 % of the plants in the experimental unit reached flowering stage for sorghum and when half of the plants per plot produced flowers for Bambara groundnut.

vii) Number of Pods per Plant (Bambara groundnut)

At maturity, the number of pods per plants was calculated on plot basis. The harvest on each plot was counted and the total pods per plot were divided by the plant stand per plot.

viii) Pods Weight per Plant

Harvested pods were sundried for a week. The pods were counted and total weight per plot was measured in grammes (g) using an electronic scale

ix)1000 Seed Weight of Bambara

The weight of thousand seeds (g) for each treatment was determined by the use of an electronic scale by weighing one thousand randomly selected seeds per

treatment.

x) Biomass Retained after Pod Harvest per Plot

All plants in central rows were collected from each plot carefully. They were sundried for a week. Dry weight was determined using a hanging scale (spring balance).

xi) Biomass Retained at Maturity for Sorghum

At maturity, the biomass of all plants in the central rows was weighed; the fresh weight for all plant was determined and a sample weight of one kilogram was taken from each plot. They were put in labelled envelopes and oven dried at 60°C for 72 hours. The dried weight was determined using an electronic scale.

3.7 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using the GenStat statistical Package (12th edition). Mean separation was obtained using a Fisher's protected least significant difference test at 5% level of probability

CHAPTER FOUR

4.0 RESULTS

4.1 Plant house experiment

The results of seed germination and vigour (Coefficient of Velocity, Vigour and Germination index) parameters under different priming methods and seed sizes on Sorghum and Bambara groundnut varieties are showed in the following Tables and Figures.

4.1.1 Effect of the priming methods and variety on the viability, vigour, germination percentage and mean germination time and seedling dry weight of sorghum varieties.

The result indicated that priming methods and variety significantly affected germination percentage, germination index, CV (vigour), vigour index and mean germination time. There was no interaction effect ($P > 0.05$). Therefore, only the priming methods and variety main effects are presented (Table 4.3 - 4.4 and Figure 4.2 - 4.3).

Variety main effects were highly significant. Table 4.4 revealed that 'Kapaala' gave the best germination index (22.9 d-1) and obtained the most vigorous seedlings followed by 'Kadaga' and 'Dorado'.

Osmo-priming (NaCl and Mannitol at -1.5 M Pa) exhibited the best germination performance in terms of percentage germination (71 % for Mannitol primed seeds and 76 % for NaCl primed seeds) and index (20 d-1 for both Mannitol and NaCl primed seeds) coupled with higher Coefficient of velocity meaning higher vigour (53 d-1 for Mannitol primed seeds and 52 d-1 for NaCl primed seeds) compared to

hydro-priming (74 % and 50 d-1) and unprimed seeds (62 % and 49 d-1) (Table 4.3 and Figure 4.3). The difference between Mannitol primed seeds and hydro-priming was not significant; however, hydro-primed seed had the heaviest seedling dry weight (0.17 g) and had the highest vigour index (1489 cm %) (Table 4.4, Figure 4.2).

Table 4.3: Variety main effect on the proportion of sorghum seeds germination and vigour index.

Variety	Germination index
Kapaala	22.9
Kadaga	14.4
Dorado	10.9
SED	3.5
Probability (P)	0.005

Seeds primed in NaCl and Mannitol at 25°C for 72 hours, 24 hours in tap water at 28± 3° C and no primed seeds. SED = standard error of the difference

Figure 4.2: Effect of priming methods on seedling dry weight of sorghum. Bar represent two standard error of the difference

Table 4.4: Effect of priming methods on seedling traits studied on sorghum varieties.

Priming methods	Germination index (days -1)	Coefficient of Velocity (days -1)	Vigour index (cm %)
NaCl	19.5	52.67	1229
Mannitol	20.3	52.25	1102
Water	14.6	50.25	1489
Control	10.0	49.25	1052
SED	4.04	0.903	131.2
Probability (p)	0.05	0.001	0.009

Seeds primed in NaCl (3.62 %) and Mannitol(11.15 %) at 25°C for 72 hours, 24 hours in tap water at 28± 3° C. SED = standard error of the difference.

Figure 4.3: Priming methods main effects on sorghum seeds germination percentage. Error bars = ± 1 standard error of the mean germination percent predicted from ANOVA.

4.1.2 Priming methods, seed size and variety effects on viability, vigour and dry weight of Bambara groundnut seed.

For Bambara groundnut, the three- and two- ways interactions were not significant ($P > 0.05$) in terms of germination percentage and index, seed vigour and seedling dry weight. Therefore, only the priming methods and seed size main effects are presented (Tables 4.5, 4.6 and Figure 4.4). Relative viability, vigour and seedling dry weight did vary significantly ($P < 0.05$) between seed sizes. The highest germination percentage (66.4 %), germination index (12 d -1) and seedling vigour (1437 cm %) was noted in smaller seeds as showed in Table 4.5, while large seeds produced the highest seedling dry weight (1.30 g) (Figure 4.4).

The priming methods significantly affected all the parameters tested (Table 4.6 and Figure 4.5). The highest germination percentage (56 % for NaCl and 68 % for Mannitol) and the most vigorous seedling were noted in osmo-primed seeds (1161 cm %, 45 d -1 for NaCl and 1613 cm %, 45 d -1 for Mannitol) than that of the

hydro-primed seed and control. Control had higher germination percentage and more vigorous seedling (61 % and 1214 cm %) compared to hydro-primed seeds (47 % and 990 cm %) indicated in Table 4.6. Speed of germination was highest for osmo-primed seeds (6.091 days for Mannitol and 6.265 days NaCl) as indicated by lower values of mean germination time (MGT) (Figure 4.5). The highest mean germination time (7.291 days) was recorded by the control. Hydro-primed seeds (7.268 days) and Control (7.291 days) had rather similar speed of germination pattern.

For germination index, among osmo-priming methods, Mannitol primed seed gave higher germination index (13.83 d -1) than that of NaCl primed (10.52 d -1); difference was significant ($P < 0.05$). Although control appeared to be slightly higher (8.06 d -1) compared to hydro-primed seed (6.54 d -1), the difference was insignificant ($P > 0.05$) as indicated in Figure 4.6.

Table 4.5: Seeds size main effect on germination percentage, germination index and vigour index on Bambara groundnut varieties.

Seed size	Germination %	Germination Index (d-1)	Vigour index (cm %)
Large	50.0	7.9	1052.0

Small	66.4	11.6	1437.0
SED	5.0	1.1	146.1
Probability (P)	0.001	0.003	0.01.

SED = standard error of the difference

Figure 4.4: Effect of seed size on seedling dry weight of Bambara groundnut varieties. Error bars = 2 SED

Table 4.6: Priming methods main effect on germination percentage, coefficient of velocity and the vigour index of Bambara groundnut varieties.

Priming methods	Germination %	Coefficient of Velocity (d -1)	Vigour index (cm %)
NaCl	55.7	45.3	1161.0
Mannitol	67.6	45.2	1613.0
Water	47.2	40.8	990.0
Control	61.4	39.3	1214.0
SED	7.0	1.9	206.6
Probability (p)	0.033	0.026	0.003

SED = Standard error of difference. Seeds were primed separately in Mannitol and NaCl kept at 25° C for 120 hours and also soaked in tap water at 28± 3° C for 24 hours.

Figure 4.5: Priming methods main effect on mean germination time of Bambara groundnut varieties. Error bar = 2 SED

Figure 4.6: Priming methods main effect on germination index of Bambara groundnut varieties. Error bar = 2 SED

4.2 Field experiment

According to the results, priming methods did not have any significant effect on neither the growth parameters nor the biomass retained after pod harvest on Bambara groundnut.

4.2.1 Effect of priming methods and sorghum varieties on viability, plant stand 20 days after sowing, number of leave and biomass retained at maturity.

There was no interaction between priming methods and variety, therefore; only variety and priming methods main effects which were significant are presented (Table 4.7, 4. 8 and Figure 4.7).

Result indicated that 'Kapaala' and 'Kadaga' gave higher germination percentage (65.25 % and 62.25 %) as compared to 'Dorado' (54.42) (Table 4.7). 'Kadaga' had the highest number of plant per plot (27.08) and also was the earlier maturing variety (63.06 days after sowing) as indicated in Figure 4.7. 'Dorado' was the latest maturing (76.22 days after sowing); but, had significant increased biomass at

maturity (2387 kg / ha). It was similar to Kapaala which produced plant biomass of 2013 kg / ha, but both were statistically different ($P < 0.05$) to Kadaga (1363 kg / ha).

The response of different priming methods on MGT, coefficient of velocity, number of plant per plot and biomass at maturity on sorghum varieties was not similar as indicated in Table 4.8. Earlier germination was recorded for mannitol primed seeds as revealed by lower value of MGT (3.855 days), but difference among priming methods was not significant (4.357 days for NaCl primed seeds and 4.332 days for Hydro-priming).

Mannitol produced the most vigorous seedlings (26.01 d -1), NaCl primed seeds with 23.31 d -1 was similar to hydro primed (23.26 d -1). Control obtained the lowest Coefficient of velocity (20.35 d -1). Meanwhile osmo-primed seeds had the least number of plants per plot (17 for NaCl and 22 for Mannitol). Osmo-priming produced the heaviest plant biomass (2478 kg / ha for NaCl and 1979 kg / ha for mannitol) compared to hydro-priming (1691 kg / ha) and control (1536 kg / ha) as showed in Table 4.8. Mannitol primed seeds and NaCl primed seeds biomass was similar and also Mannitol priming was similar to hydro-priming and control.

Table 4.7: Means germination percentage, number of plant and biomass at maturity for sorghum varieties.

Varieties	Germination %	Number of plant	Biomass at maturity (kg / ha)
Kapaala	65.25	20.67	2013

Kadaga	62.25	27.08	1363
Dorado	54.42	17.67	2387
LSD (0.05)	4.791	4.690	537.4

Figure 4.7: Length of sowing date to days to 50 % flowering of three sorghum varieties

Table 4.8: Effect of priming methods on mean germination time, coefficient of velocity, number of plant per plot and biomass at maturity of sorghum comparison by Fisher's protected least significant difference test.

Priming methods	Mean germination time (d)	Coefficient of Velocity (d -1)	Number of plant	Biomass at maturity (kg / ha)
NaCl	4.3 b	23.3	17.0	2478.0
Mannitol	3.9	26.0	21.6	1979.0
Water	4.3	23.3	24.0	1691.0
Control	5.0	20.4	24.7	1536.0
LSD (0.05)	0.4	1.8	5.4	620.5

4.2.2 Effect of priming methods on number of leaves and plant stand 20 days after sowing of three varieties of sorghum.

The interaction of priming methods and variety had significant effect ($P < 0.05$) on the number of leaves per plant and plant stand 20 days after sowing (Table 4.9 and

4.10). With the exception of NaCl primed seeds, ‘Kadaga’ produced the least number of leaves under almost all the other priming methods. ‘Dorado’ had the highest number of leaves in almost the priming treatments, followed by ‘Kapaala’. ‘Dorado’ and ‘Kapaala’ showed similarity among priming methods in terms of number of leaves as showed in Table 4.9. All the varieties produced greater numbers of plants in hydro priming and control compared to osmo-priming. ‘Kapaala’ produced the highest plant population per plot with hydro-priming while it presented the least plant population in NaCl primed seed (Table 4.10).

Table 4.9: Effects priming methods by variety on mean number of sorghum plants leaves comparison by Fisher's protected least significant difference test.

Varieties	Priming methods			
	NaCl	Mannitol	Water	Control
Dorado	21.4	19.8	21.3	21.0
Kadaga	19.1	14.7	14.6	15.0
Kapaala	17.3	19.9	20.4	20.6
LSD (0.05)	2.7	2.7	2.7	2.7

Table 4.10: Effects priming methods by variety on mean number of sorghum plant stand 20 days after sowing comparison by Fisher's protected least significant difference test.

Varieties	Priming methods			
	NaCl	Mannitol	Water	Control

Dorado30	31.3	41.3	40.0	
Kadaga	51.7	54.3	57.0	56.3
Kapaala	18.8	25.3	60.3	52.3
LSD (0.05)	10.1	10.1	10.1	10.1

4.2.3 Variety main effect on height and days to 50 % flowering of Bambara groundnut.

There was neither significant difference for priming methods main effect nor interaction between priming methods and variety for days to 50 % flowering and plant height per plant of Bambara groundnut. Therefore, only variety main effect is presented (Table 4.11)

Significant differences were observed among variety with respect to days to 50 % flowering and height per plant ($P < 0.05$). Variety 'Red' was the latest maturing with 40 days to 50 % flowering. Also 'Cream with brown and black eye' varieties were the early maturing (39.45, 39.42 days after sowing respectively) as compared to 'Red'. 'Cream with black eye' was the tallest variety (32.46 cm). There were no differences between the height of 'Cream brown eye' and the 'Red' varieties as shown in Table 4.11.

Table 4.11: Mean days to 50 % flowering and plant height for Bambara groundnut varieties comparison by Fisher's protected least significant difference test.

Bambara Varieties	Day to 50 % flowering	Plant height
Red	40.2	30.2

Cream with black eye	39.4	32.5
Cream with brown eye	39.5	30.7
LSD (0.05)	0.5	0.9

4.2.4 Effect of seed size, priming method and variety on number of pod per plant of Bambara groundnut

The three way interactions (Seed size X priming methods X variety) were significant ($P < 0.05$) and are presented in Table 4.12. Large seed of 'Red' variety primed in Mannitol produced the highest number of pods per plant while it obtained the least number of pods when primed in NaCl. Also, large seed of 'Red' variety had the highest number of pod (56.2 pods) under all the priming methods except NaCl (12.6 pods).

Table 4.12: Interaction of seed size by priming methods by varieties on mean number of pods per plant of varieties of Bambara groundnut comparison by Fisher's protected least significant difference test.

Priming methods	Seed size					
	Large			Small		
	Varieties					
	Cream with black eye	Cream with brown eye	Red	Cream with black eye	Cream with brown eye	Red
NaCl	20.0	34.7	12.6	25.1	39.6	32.o

Mannitol	18.0	18.2	56.2	18.0	37.1	36.0
Water 27.1	28.8	41.0	22.5	25.0	32.0	
Control	16.4	37.0	39.4	26.0	32.0	25.0
LSD (0.05)	20.2	20.2	20.2	20.2	20.2	20.2

CHAPTER FIVE

5.0 DISCUSSION

5.1 Seed priming methods

In many rainfed areas, germination and subsequent seedling growth can be inhibited by adverse conditions in the field. There is evidence that in most field and horticultural crops, priming led to improvement of germination and seedling establishment. Priming methods had significant effect on the germination percentage and vigour of sorghum and Bambara groundnut varieties used in the present investigation. Hosseein et al. (2011) indicated that there have been numerous studies which showed the considerable effectiveness of hydro-priming on germination and later growth in different plant species under both saline and non-saline conditions, wheat (Iqbal et al., 2005) Acacia tortilis and A.coriacea (Rehman et al., 1998) and only under normal non-saline conditions e.g., maize (Zea mays), rice (Oryza sativa), chickpea (Cicer arietinum) (Harris et al.,1999) and white-flowered gourd (Lagenaria siceraria) (Jumsoon et al., 2000).

Improvement in seedling growth, development and establishment correlates with efficient water uptake of prime derived plants. Rajpar et al. (2006) reported that compared to control, primed seed took significantly fewer days to emerge and

reach maturity. It has been reported by Berchie et al. (2010) that soaking Bambara groundnut seeds in water for 24 hours has the possibility of improving plant stand.

5.1.1 Germination

5.1.1.1Germination percentage

In Bambara groundnut and sorghum, priming methods affected germination percentage significantly different. Primed seed gave higher germination than unprimed seeds. In fact priming induces a range of biochemical changes in the seed that required initiating the germination process i.e., breaking of dormancy, hydrolysis or metabolism of inhibitors, imbibitions and enzymes activation (Ajouri et al., 2004). The results are in line with Sivritepe et al., (2003) who declared that priming had resulted in more germination speed especially in drought stress, saline stress and low temperatures in sorghum, sunflower and melon. Basra et al. (2003) and Salinas (1996) reported that seed priming techniques improved germination percentage, emergence and seedling stand. Cayuela et al. (1996) observed that under salt stress the seedlings of tomato emerged earlier from seeds primed with NaCl than from non-primed seeds. Esmaielpour et al. (2006) and Mohammadi et al. (2009) also reported that seed priming by NaCl led to increasing of total emergence and emergence of cucumber.

5.1.1.2 Germination Index

The highest germination index was attained from osmo-primed seeds following by hydro-priming. There was significant difference between control and priming treatments such that germination index from primed seed was more than in the control. Huns and Sung (1997) cited from Hossein et al. (2011) reported that seed priming resulted in anti-oxidant increment as glutathione and ascorbate in seed. These enzymes led to higher germination speed via reduction of lipid proxidation activity.

5.1.2 Vigour

5.1.2.1 Coefficient of Velocity (CV)

Primed seeds actually gave higher CV values in both experiments. The results obtained in the present study confirmed the results obtained by Khan et al. (1980), where primed cabbage seeds kept at 15° C had accelerated emergence and gave increased plant fresh weight. Khan et al. (1980), cited from Nyarko et al. (2006), also reported that cabbage seeds primed and expose to vernalization temperature (0°- 5° C) for 8 weeks had a higher CV than non-primed seeds. In primed leek seeds, the significant benefit in germination performance was accompanied by marked increases in protein, DNA and nucleotide biosynthesis. During priming of tomato seeds, the breakdown of protein bodies was more extensive in endosperm cells at the micropylar region than was observed prior to germination in non-primed seeds (Haigh, 1988). Therefore, there is ample evidence that priming of Bambara and Sorghum seeds, prior to germination, prevent radicle elongation during germination process by removing the water and drying seeds to original moisture content and improved the rate of germination after sowing. It has been

reported that primed seeds showed better germination pattern and higher vigour levels than non- primed (Ruan et al., 2002).

5.1.2.2 Vigour Index

Seedling vigour increased by using seed priming methods in sorghum and Bambara groundnut. Also, highest seedling vigour was achieved by osmo-priming (Mannitol priming) in Bambara groundnut and by hydro-priming in sorghum. Priming improved seedling vigour in the current study.

During priming, the embryo expands and compresses the endosperm (Liptay et al., 1993). The compression force of the embryo and hydrolytic activities on the endosperm cell walls may deform the tissues that have lost their flexibility upon dehydration (Lin et al., 1993), producing free space and facilitating root protrusion after rehydration.

5.1.3 Crop establishment

It came out of in this work that osmo-primed seeds did not enhance final plant establishment. This finding is in line with the report of Ahmad Afkari, 2010 who reported that total emergence of seedlings from both primed and non-primed seeds decreased with increasing NaCl salinity. It has been reported by Munns (1993) that salt deposit in the root growing medium is the main reason for physiological drought and subsequently reduced cell division and/or enlargement in the root growing region and ultimately reduced root growth. However, this reduction in total emergence was higher for non primed seeds, compared to primed seeds. Percentage of seed germination decreased with rising salinity levels in both primed and un-primed. Basra et al. (2006) reported that delayed and weak

germination in rice seeds subjected to osmo-conditioning for 24 and 48 h in KNO3 was probably due to toxicity. KNO3 toxicity results in injury to cellular organelles and membranes of wheat (Singh and Gill, 1988).

5.1.4 Effect priming methods on the time of germination (MGT) of sorghum and Bambara groundnut

Mean germination time reflects germination speed that cannot be measured by germination percentage. There were minor differences in MGT among priming treatments, although all priming treatments examined in this experiment reduced MGT compared with the control. The MGT is also dependent on the duration of imbibitions and/or internal metabolic activities after imbibitions (the second stage of germination). Priming activates internal metabolism required for furthering the germination process (Basra et al., 2005).

5.2 Seed size effects

5.2.1 Germination and vigour

Seed size affected the germination percentage and index and vigour of Bambara groundnut. Small seeds gave higher germination produced also most vigorous seedling compare to as large seeds. The possible effect of seed size on germination is associated with the length of the structures that form the seedling, but not necessarily with the subsequent biochemical conversion of storage reserves into germinating tissues (Soltani et al., 2002). Small seed size gave greater germination than large seed. Small seeds might be expected to imbibe (take up) water faster than large seeds, so small seeds might germinate faster. However, large seeds have more nutrients stored within the seeds so their plants might be expected to grow

taller than plants from smaller seeds. In pea (Pisum sativum L.) it was showed that cultivars with low 100 seed weight had higher germination percentage than larger seed ones (PekÕen et al., 2004). Several reports showed that spring wheat (Lafond and Baker, 1986), and soybean (Edwards and Hartwig, 1971) emerged faster from small seeds than the large seed size for hybrid. Moreover, many studies indicated that germination percentage of winter wheat (Mian and Nafziger, 1994), seedling emergence of soybean (Johnson and Luedders, 1974; TeKrony et al., 1987) and barley (Demirlicakmak et al., 1963) were not affected by seed size.

5.2.2 Seedling dry weight

Seed size effect on seedling dry weight was statistically different. Differences in the growth of seedlings emerging from seeds of different sizes within a species have been under-studied. Gupta et al. (1983) (studying Leucaena leucocephala) and Negi and Todaria (1997) (studying Acer oblongum, Kydia calyciana, Termina- lia tomentosa, Terminalia bellerica and Terminalia chebula) reported faster growth in seedlings produced from large seeds. Larger seeds have the ability to store greater amounts of carbohydrate in their endosperm or cotyledons than small seeds (Milberg and Lamont, 1997). This may enable early development of an enlarged resource gathering system (root or photosynthetic tissue) to produce a faster growing plant (Hewitt, 1998). It has been reported by Stock et al. (1990) of a positive relationship across species among seed mass and seedling size.

5.3 Interaction among priming methods by variety by seed size.

The three way interaction (seed size by priming methods by variety) on the number of pods per plant was significant in Bambara. Similar results were also obtained by

Basra et al. (2003) in canola and Rashid et al. (2004) in mungbean that primed seed plants produced more grains per pod.

CHAPTER SIX

6.0 Conclusion and recommendations

6.1 Conclusion

From the present investigation it may be concluded that germination and seedling vigor can be enhanced by osmo-priming treatments in sorghum and Bambara groundnut by dormancy breakdown. However, salt priming was more effective that hydro- priming.

In the present study, osmo-priming methods were superior to hydro-priming and the control group in the majority of investigated traits by decreasing the time for a seed to germinate (lower MGT). Priming temperature had an outstanding effect, since on all of the investigated traits; the temperature of 25°C was the best. Between the times intervals which are candidates of a superior treatment, the 72 h can be recommended, because it can save time as well as prevent possible damages, like infection of seeds (because of seeds being in the solution for too long). The concentration of the media also had an outstanding effect, concentration of 3.62 g / l for NaCl cannot be recommended because did not enhanced germination meanwhile 11.15 g / l for Mannitol can be recommended.

The greater spread of germination over time results in greater variation in seedling size. This is particularly important in the production of uniform transplants of vegetable and ornamental species.

Seed size do adequately explain variation in germination characteristic and seedling performance of Bambara groundnut. It may be concluded from this experiment that positive relation was found among size, germination and vigour in Bambara groundnut. The fdinding revealed that large seed produced as well as small seed vigorous seedlings; small seed also obtained higher germination.Therefore, seed size enhanced germination and improved vigour of Bambara groundnut.

6.2 Recommendations

It is recommended that:

The priming period for Bambara groundnut should not exceed three days to avoid damaging seeds.

The study should also be repeated on the field at an early sowing date, to evaluate yield and yield components of the two crops.

Another trial be conducted on Bambara groundnut to confirm the effect of small seed size on germination and seed vigour.

REFERENCES

Afkari, A. B. (2010). The effects of NaCl priming on salt tolerance in sunflower germination and seedling grown under salinity conditions. African Journal of Biotechnology, 9:1764-1770.

Ajouri, A., Haben, A. and Becker, M. (2004). Seed priming enhances germination and seedling growth of barley under conditions of P and Zn deficiency. Journal of Plant Nutrition and Soil Science, 167: 630-636.

Amarteifio, J. O., Karikari, S. K., Modise, J. O. (2002). The proximate and mineral composition of six landraces of Bambara groundnut. Tropical Science 42:188–191.

Amarteifio, J. O., Sawula, G., Gibbons, M. R. D. (1997). Comparison of four landrances of Bambara groundnut.Tropical Science 37:143–145.

Amico, R. U., Zizzo, G. V., Agnello, S., Sciortino, A., Iapichino, G. (1994). Effect of seed storage and seed size on germination, emergence and bulbelt production of Amaryllis belladonnal L. Acta. Hortic, 362: 281-8.

Anchirinah, V. M., Yridoe, E. K., Bennet-Lattey, S. O. (2001). Enhancing sustainable production and genetic resource conservation of Bambara groundnut: a survey of indigenous agricultural knowledge systems. Outlook on Agriculture 30:281–286.

AOSA, (1983). Seed Vigor Testing Handbook. Association of Official Seed Analysts.

AOSA, (1988). Rules for testing seeds. Journal of Seed Technology, Vol 6, No. 2. Pp: 126. Association of Official Seed Analysts.

AOSA, (1990). Rules for testing Seeds. Association of Official Seed Analysts

Journal of Seed Technology, 12 (3):1-112.

AOSA, (2002). Seed Vigor Testing Handbook. Association of Official Seed Analysts

Arunachalam, A., Khan, M. L., Singh, N. D. (2003). Germination, growth and biomass accumulation as influenced by seed size in Mesua ferrea L. Turkish Journal of Botany, 27: 343-8.

Ascherman-Koch, C., Hofmann, P., Steiner, A. M. (1992). Presowing treatment for improving quality in cereals. I. Germination and vigour. Seed Science and Technology, 20: 435-440.

Atokple, I. D. K., Clottey, V. A., Gyasi, O., Manful, J. T., Quaye, W., Kwafo, A., Johnson, P., Bruce, J., Andah, A. and Ayireko, P. (1999). Increasing Sorghum Productivity in Ghana: Study on the production Systems of Sorghum Pp: 62.

Atokple, I. D. K. (2003). Sorghum and Millet breeding in West Africa in Practice. Proceedings of AFRIPRO. European Union Research Framework International workshop on Sorghum and Millet Proteins held on 2- 4 April 2003 at Intundla Game Lodge, South Africa.

Axtell, J. D. (1998). Opening Comments. In 'Proceedings of the West African Hybrid Sorghum and Pearl millet Seed Workshop in September 28–October 2, (1998)'. Palais de Congres, Niamey, Niger Pp: 1–19.

Azam-Ali, S. N., Sesay, A., Karikari, S. K., Massawe, F. J., Anguilar-Marjarrez, J., Bannayan, M., Hampson, K. J. (2001). Assessing the potential of underutized crop – A case study using Bambara groundnut. Experimental Agriculture 37:433–472.

Baalbaki, R. Z., Copeland, L. O. (1997). Seed size, density and protein content effect on field performance of wheat. Seed Science and Technology, 25: 511-21.

Basra, S. M. A., Ehsanullah, E. A. W., Cheema, M. A. and Afzal, I. (2003). Effect of storage on growth and yield of primed canola seeds (Brassica napus). International Journal of Agriculture and Biology, 5:117-120.

Basra, S. M. A., Farooq, M. and Tabassum, R. (2005). Physiological and biochemical aspects of seed vigour enhancement treatments in fine rice (oryza sativa L.). Seed Science and Technology, 33: 623-628.

Basra, S. M. A., Farooq, M., Tabassum, R. and Ahmed, N. (2006). Evaluation of seed vigour enhancement techniques on Physiological and biochemical basis in coarse rice (Oryza sativa L.). Seed Science and Technology, 34: 719-728.

Begemann, F. (1986). Bambara Groundnut: Background Information. International Institute of Tropical Agriculture (IITA), Genetic Resources Unit, Ibadan, Nigeria. Pp: 17.

Begemann, F. (1988). Ecogeographic Differentiation of Bambara Groundnut (Vigna subterranea) in the Collection of the International Institute of Tropical Agriculture (IITA). Wissenschaftlicher Fachverlag Dr Fleck, Niederkleen, Germany. Pp: 153.

Bennett, M., Fritz, V. A. and Callan, N. W. (1992). Impact of seed treatments on crop stand establishment. Horticultural Technology, 2(3):345-349.

Berchie, J. N., Adu- Dapaah, H., Sarkodie-Addo, J., Asare, E., Agyemang, A.,

Addy, S. and Donkoh, J. (2010). Effect of Seed priming on Seedling Emergence and Establishment of Four Bambara Groungnut (Vigna subterrenea L. Verdc.) Landraces. Journal of Agronomy, 9:180-183.

Biasutti, M., and Sobel, A. H. (2009). Delayed Sahel rainfall and global seasonal cycle in a warmer climate. Geophysical Research. Letter, 36, L23707.

Bougne, S., Job, C. and Job, D. (2000). Sugarbeet seed priming: solublization of the baic subunit of 11– S globulin in individual seeds, Seed Science Research, 10: 153 -161.

Bradford, K. J. (1986). Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. Horticultural Science 21:1105-1112.

Bretagnolle, F., Thompson, J. D. and Lumaret, R. (1995). The influence of size variation on seed germination and seedling vigour in diploid and tetraploid Dactylis glomerata L. Annals of Botany, 76: 607-615.

Brink, M. (1997). Rates of progress towards flowering and podding in Bambbara groundnut (Vigna subterrenea) as a function of temperature and photoperiod. Annals of Botany, 80:505-513.

Brough, S. H., Azam-Ali, S. N., Taylor, A. J. (1993). The potential of Bambara groundnut (Vigna subterranea) in vegetable milk production and basic protein functionality systems. Food Chemistry 47: 277–283;

Burgass, R. W. and Powell, A. A. (1984). Evidence for repair processes in the invigouration of seeds by hydration. Annals of Botany, 53:753-757.

Caseiro, R., Bennett, M. A., Marcos- Filho, J. (2004). Comparison of three priming techniques for onion seed lots differing in initial seed quality. Seed Science and

Technology, 32:365-375.

Cayuela, E., Perez-Alfocea, F., Caro, M. and Bolarin, M. C. (1996). Priming of seeds with NaCl induces physiological changes in tomato plants grown under salt stress. Physiologia Plantarum . 96:231-236

Chastin, T. G., Ward, K. J., Wisocki, D. J. (1995). Stand establishment responses of soft white winter wheat to seedbed residue and seed. Crop Science, 35: 213-218

Clark, L. J., Whalley, W. R., Ellis-Jones, J., Dent, K., Rowse, H. R., Finch-Savage, W. E., Gatsai, T., Jasi, L., Kaseke, N. E., Murungu, F. S., Riches, C. R. and Chiduza, C. (2001). On-farm seed priming in maize: a physiological evaluation. Seventh Eastern and Southern Africa Regional Maize Conference, 11th-15th February, 2001. Pp: 268-273.

Coolbear, P., Newell, A. J. and Bryant, J. A. (1987). An evaluation of the potential of low temperature pre-sowing treatments of tomato seeds as a means of improving germination performance. Annals of Applied Biology, 110:185-194.

Collinson, S. T., Sibuga, K. P., Tarimo, A. J. P.and Azam-Ali, S. N. (2000). Influence of sowing date on the growth and yield of Bambara groundnut (Vigna subterranea L.) landraces in Tanzania. Experimental Agriculture, 36: 1–13;

Dakora, F. D., Muofhe, M. L. (1996). Molecular signals involved in nodulation of the African Bambara groundnut. In: Proc Int Bambara groundnut Symp, University of Nottingham, UK, pp 171–179

Dalziel, J. M. (1937). Voandzeia Thou. in The Useful Plants of West Tropical Africa. Crown Agents, London Pp. 269-271.

Damirkaya, M., Okgu, G., Atak, G. Y. and Kolsarici, O. (2006). Seed treatments to overcome salt and drought stress during germination in sunflower (Helianthus annuus L.). European Journal of Agronomy, 24: 291-295.

Davies, J. C. (1982). Pest losses and control of damage on sorghum in the developing countries- The Realities and Myths, ICRISAT sorghum in eighties. Pp: 215-221

Dearman, J., Brocklehurst, P. A. and Drew, R. l. K. (1986). Effects of osmotic priming and ageing on onion seed germination. Annals of Applied Biology, 108: 639-648.

De Wet, J. M. J., Harlan, J. R, and Price, E. G. (1976). Variability in Sorghum bicolor. Pp: 453-464 in Origins of African Plant Domestication. (Harlan, J.R., de Wet, J.M.J., and Stemler, A.B.L., Eds.). The Hague, Netherlands: Mountain Press.

Demir, I. and Van De Venter, H. A. (1999). The effect of priming treatments on the performance of watermelon (Citrullus lanatusThunb.) Matsum. Et Nakai) seeds under temperature and osmotic stress. Seed Science and Technology, 27:871-875.

Demirlicakmak, A., Kaufmann, M. L. and Johnson, L. P. (1963). The influence of seed size and seeding rate on yield and yield components of barley. Canadian Journal of Plant Science, 43: 330-337.

Dendy, D. A. V. (1995). In 'Sorghum and the Millets: Chemistry and Technology'. (D.A.V. Dendy, ed.), American Association of Cereal Chemists, St. Paul, USA Pp. 11-26.

Dingkuhn, M., Singh, B., Clerget, B., Chantereau, J., and Sultan, B. (2006). Past, present and future criteria to breed crops for water-limited environments in West

Africa. Agriculture Water Management, 80(1–3), 241– 261.

Doku, E. V. (1969a). Growth habit and pod production in Bambara groundnut (Voandzeia subterranea). Ghana Journal of Agricultural Science, 2: 91-95.

Du Petit-Thouars, L. M. A. (1806). Genera nova Madagascariensis, Pp. 23. Paris.

Edwards, C. J. Jr. and Hartwig, E. E. (1971). Effect of seed size upon rate of germination in soybeans. Journal of Agronomy, 63: 429-430.

Ehsan, N., Mohammad, B., Ali, G. M. H., Ali, A. (2009). Does Hydro and Osmo-Priming Improve Fennel (Foeniculum vulgare) Seeds Germination and Seedlings Growth? Notulae Botanicae. Horti Agrobotanici Cluj-Nopaca, 37 (2) 2009, 190-194.

Ellis, R. H. and Robert, E. H. (1980). The influence of temperature and moisture on seed viability period in barley (Hordeum distichum). Annals of Botany, 45: 31–37.

Esmaielpour, B., Ghassemi, G. K., Khoei, F., Gregoorian, V. and Toorchi, M. (2006). The effect of NaCl priming on cucumber seedling growth under salinity stress. Journal of Food Agriculture and Environment, 4: 347-349.

FAO, (1982). Legumes in human nutrition. FAO Food and Nutrition Paper No. 20. FAO, Rome. Farrington, J. and S. Biggs. 1990. NGOs, agricultural technology and the rural poor. Food Policy 15(6):479-491.

FAO, (1991). Sorghum and millets in human nutrition, Vol. XVIII. Rome, FAO/WHO. Pp 33

FAO, (2005). The state of food insecurity in the world. Pp 92- 102

Farooq, M., Basra, S. M. A., Hafeez, K. and Ahmad, N. (2005). Thermal

hardening: a new seed vigour enhancement tool in rice. Acta Botanica Sinica, 47:187-193.

Fujikura, Y., Kraakh, L. A., Basra, S., Karssen, C. M. (1993). Hydro-priming, a simple and inexpensive priming method. Seed Science Technology, 21: 411- 415.

Ghiyasi, M., Abbasi, A. S., Tajbakhsh, M., Amirnia, R. and Salehzade, H. (2008). Effect of osmo-priming with poly ethylene glycol 8000 (PEG 8000) on germination and seedling growth of wheat (Triticum aestivum L.) seeds under salt stress. Research Journal of Agriculture and Biological Sciences, 3(10):1249-1251.

Giri, G. S. and Schilinger, W. F. (2003). Seed priming on winter wheat for germination, emergence, and yield. Crop Science, 43:2135-2141.

Glen, D. M., and Wiltshire, C. W. (1988). Distribution of slug species. In IACR Long Ashton Research Station Annual Report, 1987, Pp.28.

Godfery, W. N., Onyango, J. C., Beck, E. (2004). Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. Crop Science, 44: 806-811.

Goli, A. E. and Ng, N. Q. (1988). Bambara groundnut multi-location yield trial. Pp. 11-12 in Annual Report, Genetic Resources Unit, IITA. 1987.

Goli, A. E., Begemann, F. and Ng, N. Q. (1991). Germplasm diversity in Bambara groundnut and prospects for crop improvement. Pp. 195-202 in Crop Genetic Resources of Africa Vol. 2.

Grzesik, M. and Nowak, J. (1998). Effects of matriconditioning and hydro-priming on Helichrysum bracteatum L. seed germination, seedling emergence and stress tolerance. Seed Science and Technology, 26, 363-376.

Gueye, M., James, E. K., Kierans, M., Sprent, J. L. (1998). The development and structure of root nodules on Bambara groundnut ([Voandzeia] Vigna subterranea). World Journal of Microbiology and Biotechnology, 14:177–184

Gupta, S. K., Pathak, P. S. and Roy, R. D. (1983). Seedling growth of Leucaena leucocephala (Lam.) de wit.II. Effect of seed size. Indian Journal of Forestry, 6: 202-204.

Harlan, J. R. and de Wet, J. M. J. (1972). A simplified classification of cultivated sorghum. Crop Science, 12: 172–176.

Harris, D. (1996). The effects of manure, variety, seedlinfs, seed priming, depth and date of sowing on the emergence and early growth of Sorghum bicolor (L.) Moench in semi arid Botswana. Soil and Tillage Research, 40:73-88.

Harris, D., Joshi, A., Khan, P. A., Gothkar, P. and Sodhi, P. S. (1999). On farm seed priming in semi-arid agriculture. Development and evaluation in maize, rice and chickpea in India, using participatory methods. Experimental Agriculture, 35:15-29

Harris, D., Tripathi, R. S. and Joshi, A. (2000). On- farm priming to improve crop establishment and yield in direct- seeded rice in IRRI : `Intenational Workshop on Dry –seeded Rice Technology`. Held in Bangkok, 25 – 28 January 2000. The international Rice Research institute, Manila, The Philippines, 164.

Harris, D., Pathan, A. K., Gothkar, P., Joshi, A., Chivasa, W. and Nyamudeza, P. (2001). On-farm seed priming using participatory methods to revive and refine a key technology. Agricultural Systems, 69:151-164.

Hartman, H. T., Kester, D. E., Davies, F. T. and Geneve, R. L. (2002). Plant

propagation and nursery management, 6th Edition, Prentice-Hall of India, New Dehli.

Heydecker, W. and Coolbear, P. (1977). Seed treatments for improved performance—Survey and attempted prognosis. Seed Science and Technology, 5:353-424.

Heller, J., Begemann and Mushonga, J. (1995). Conservation and Improvement of Bambara groundnut (Vigna subterranea). 14–16 November Harare, Zimbabwe

Hepper, F. N. (1963). The Bambara groundnut (Voandzeia subterranea) and Kersting's groundnut (Kerstingiella geocarpa) wild in West Africa. Kew Bulletin, 16:395-407.

Hewitt, N. (1998). Seed size and shade tolerance: a comparative analysis of North American temperate trees. Oecologia 114: 432- 440.

Hosseein, A., Farahani and Karsa, M. (2011). Effect of hydro-priming on seedling vigour in Basil (Ocimum basilicum L.) under salinity conditions. Advances in environmental biology, 5 (5):828-833.

ISTA, (1993). Hand book for seedling evaluation. International Seed Testing Association. Zurich, Switzerland.

Jacques-Félix, H. (1946). Remarques sur l'origine et la geocarpie du Voandzeia subterranea Thou. Bulletin de la Societe Botanique de France, 93(9):260-362.

Jones, M. J. and Wanbi, A. (1992). Site factor influence on barley response to fertilizer in on farm trials in northern Syria: descriptive and predictive models, Experimental Agriculture, 28:63-87.

John Easton, 2005 personal communication.

Johnson, D. R. and Luedders, V. D. (1974). Effect of planted seed size on emergence and yield of soybeans (Glycine max (L.) Merr.). Journal of Agronomy, 66: 117-118.

Jumsoon, K., Jeuonlai, C., Ywonok, J. (1996). Effect of seed priming on the germinability of tomato (Lycopercicon esculentum Mill.) seeds under water and saline stress. Journal of the Korean Society for Horticultural Science, 37: 516-521

Karssen, C. M., Haigh, A., Van Der Toorn, P. and Wages, R. (1989). Physiological mechanisms involved in seed priming. In: Recent Advances in t he Development and Germination of Seeds (Taylorson, R. B.,Ed.). Proceedings of Third International Workshop on Seeds. 6-12 August, 1986, Williamsburg, VA, USA. Pp. 269-288.

Kaydan, D., Yağmur, M. (2008). Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. African Journal of Botany, 7: 2862-2868.

Khan, A. A., Tao, K-L, Knypl, J. R., Borkowskr, B. and Powell, L. E. 1978. Osmotic conditioning of seeds: physiological and biochemical changes. Acta horticulture, 83: 267-278.

Khan, A. A. (1992). Preplant physiological seed conditioning. Horticultural Review, v.14, p.131-181.

Kiwallo, L. (1991). Inventaire des maladies cryptogamiques du voandzou [Vigna subterranea (L.) Verdc.] au Burkina Faso. Mémoire de fin d'études en agronomie, Institut du Développement Rural, Université de Ouagadougou, Burkina Faso: Pp.54.

Kropff, M. J. and Van laar, H. H. (1993). Modeling crop-weed interactions. CAB international Wallingford, U.K., 272.

Kumaga, F. K., Adiku, S. G. K. and Ofori, K. (2003). Effect of post-flowering Water Stress on dry Matter and yield of three Tropical Grain Legumes. International journal of agriculture and biology, 1560–8530/2003/05–4–405–407.

Lacroix, B., Assoumou, Y., Sangwan, R. S. (2003). Efficient in vitro direct shoot organogenesis of fertile plants from embryo explants of Bambara groundnut [Vigna subterranea (L.) Verdc]. Plant Cell Report, 21: 1153–1158.

Lafond, G. P., and Baker, R. J. (1986). Effect of genotype and seed size on speed of emergence and seedling vigor in nine spring wheat cultivars. Crop Science, 26: 341-346.

Linnemann, A. R. (1987). Bambara groundnut (Vigna subterranea (L.) Verdc.): a review. Abstract On Tropical Agriculture 12 (7).

Linnemann, A. R. (1990). Cultivation of Bambara groundnut (Vigna subterranea (L.) Verdc.) in Western Province, Zambia. Report of a Field Study. Tropical Crops Community No. 16 Wageningen Agricultural University.

Linnemann, A. R. (1992). Bambara groundnut (Vigna subterranea) literature: a revised and updated bibliography. Tropical Crops Communication 7. Department of Tropical Crop Science, Wageningen Agricultural University, Netherlands, Pp.124.

Linnemann, A. R. (1994). Photothermal regulation of phonological development and growth in Bambara groundnut [Vigna subterranea (L.) Verdc.]. PhD Thesis, Wageningen Agricultural University, the Netherlands: 123 pp.

Linnemann, A. R.; Azam-Ali, S. N. (1993). Bambara groundnut [Vigna subterranea (L.) Verdc.]. In: Williams J. T. (ed) Underutilized crops series 2. Vegetables and pulses. Chapman & Hall, London, pp 13–58;

Marcgrav de Liebstad, G. (1948). Natural history of brazil. Book. Jeticulu or root Mechoacan, Mandubi, an anonymous, 1(29):43-44.

Maréchal, R., Mascherpa, J. M. and Stainier, F. (1978). Etude taxonomique d'un groupe complexe d'espèces des genres Phaseolus et Vigna (Papilionaceae) sur la base de données morphologiques et polliniques, traitées par l'analyse informatique. Boissiera, 28:177-178.

Massawe, F. J., Schenkel, W., Basu, S. and Temba, E. M. (2003). Artificial Hybridisation in Bambara Groundnut. In: Proceedings of the International Bambara Groundnut Symposium, Botswana College of Agriculture, Botswana, 8–12 August: 193–210.

Massindeni, D. R. (2006). Evaluation of Bambara groundnut (Vigna subterranea (L.) Verdc.) for yield stability and yield related characteristics. Agriculture Research Council- Grain Crop Institute (ARC- GCI) http://alldissertations.com/ful.php?id = 102622.

Matthews, S., Wagner, M. H., Ratzenboeck, A., Khajeh Hosseini, M., Casarini, E., El-Khadem, R., Yakhlifi, M. and Powell, A. A. (2011b). Early counts of radicle emergence during germination as a repeatable and re-producible vigour test for maize. Seed Testing International, 141, 39–45.

Matthews, S., and Powell, A. 2011. Towards automated single counts of radicle emergence to predict seed and seedling vigour. Seed Testing International, 142, 44-48

Mauromicale, G., Cavallaro, V. (1997). A comparative study of seed germination under suboptimal temperatures. Seed Science and Technology, 25: 399-408.

McDonald, M. B. (2000). Seed priming. Black, M. and Bewley, J. D. (eds). Seed Technology and its Biological Basis. Sheffield Academic Press Ltd., Sheffield, UK, pp. 287-325.

Mian, M. A. R. and Nafziger, E. D. (1994). Seed size and water potential effects on germination and seedling growth of winter wheat. Crop Science, 34: 169-171.

Milberg, P., Lamont, B. B. (1997). Seed/cotyledon size and nutrient content play a major role in early performance of species on nutrient-poor soil. New Phytologist, 137: 665-672.

Mohammadi, G. R. (2009).The Influence of NaCl Priming on Seed Germination and Seedling Growth of Canola (Brassica napus L.) under Salinity Conditions. American-Eurasian Journal of Agricultural & Environmental Science, 5 (5): 696-700.

Moradi, A., Younesi, O. (2009). Effects of Osmo- and Hydro-priming on Seed Parameters of Grain Sorghum (Sorghum bicolor L.). Australian Journal of Basic and Applied Sciences, 3 (3): 1696-1700.

Mukurumbira, L. M. (1985). Effects of the rate of fertilizer nitrogen and previous grain legume crop on maize yields. Zimbabwe Agricultural Journal, 82(6):177-179.

Munns, R. (1993). Physiological processes limiting plant growth in saline soil: Some dogmas and hypotheses. Plant Cell Environment, 16: 1-24.

Murungu, F. S., Chiduza, C., Nyamugafata, P., Clark, L. J., Whalley, W. R., and Finch-Savage, W. E. (2004). Effects of 'on-farm seed priming' on consecutive daily sowing occasions on the emergence and growth of maize in semi-arid Zimbabwe. Field Crops Research, 89:49-57.

Murungu, F. S. (2011). Effects of seed priming and water potential on seed germination and emergence of wheat (Triticum aestivum L.) varieties in laboratory assays and in the field. African Journal of Biotechnology Vol. 10(21), pp. 4365-4371.

Negi, A. K., Todaria, N. P. (1997). Effect of seed size and weight on germination pattern and seedling development of some multi-purpose tree species of Garhwal Himalaya. Indian Forester 123: 32-36.

Ng, N. Q., Osunmakinwa, A. A., Begemann, F. and Goli, A. E. (1985). Germplasm

maintenance/preservation, characterization and documentation. GRU Annual Report International Institute of Tropical Agriculture (IITA), Genetic Resources Unit, Ibadan, Nigeria. 11 pp.

Nishitani, T., Muraki, K. and Inouye, J. (1988). Effects of day length on flowering and fruiting in Bambara groundnut (Vigna subterrenea (L.) Verdc.). Jpn. Journal of Tropical Agricultural, 32:80-4.

Nnadi, L. A., Singh, L. and Balasubramanian, V. (1981). Effect of grain legumes and sorghum on soil nitrogen status and the yield of subsequent maize crops.

Samaru Journal of Agricultural Research, 1:183-90.

Numjun, K., Yeonok, J., Jeoung, L. C. and Song, M. K. (1997). Changes of seed proteins related to low temperature and germinability of primed seed of pepper (Capsicum annuum L.). Journal of the Korean Society for Horticultural Science, 38: 342-346

Nyarko, G., Alderson, P. G. and Craigon, J. (2006). Towards cabbage seed production in the tropics. Ghana Journal of Horticulture, 5, in press.

Obizoba, I. C. (1983). Nutritive value of cowpea-bambara groundnut-rice mixtures in adult rats. Nutrition Reports International, 27:709-12.

Onwueme, I. C. and Sinha, I.T. (1999). Field crop production in tropical Africa CTA publication. ScienceDirect, 93: 264-272.

PekÕen, E., PekÕen, A., Bozolu, H. and Gülümser, A. (2004). Some seed traits and their relationships to seed germination and field emergence in Pisum sativum L. Journal of Agriculture, 3: 243-246.

Perry, D. A. (1978). Report of the Vigour Test Committee, 1974-1977. Seed Science and Technology, 1978, 6:159-181.

Pill, W. G. and Necker, A. D. (2001). The effects of seed treatments on germination and establishment of Kentucky bluegrass (Poa pratensis L.). Seed Science and Technology, 29:65-72.

Rajpar, I., Khanif, Y. M. and Memon, A. A. (2006). Effect of seed priming on growth and yield of wheat (Triticum aestivum L.) under non-saline conditions. International Journal of Agricultural Research, 1:259-264.

Rashid, A., Harris, D., Hollington, P. A. and Rafiq, M., (2004). Improving the yield of mungbean (Vigna radiate L.) in the North West Frontier Province of Pakistan using on-farm seed priming. Center of Arid Zone studies, University of Wales, Wales, UK. 40:233-244.

Raven, P. H., Ray, F. E.and Susan, E. E. (2005). Biology of Plants, 7th Edition. New York: W.H. Freeman and Company Publishers. pp. 504–508.

Rowland, J. R. J. (1993). Bambara groundnut. In: Rowland JRJ (ed) Dryland farming in Africa, Macmillan Ltd., London, pp 278–282.

Rowse, H. R. (1991). Methods of priming seeds. U.K. Patent No. 2192781.

Rowse, H. R. (1992). Methods of priming seeds. U.S. Patent No. 5,119,589.

Ruan, S., Xue, Q. and Tylkowska, K. (2002). The influence of priming on germination of rice (Oryza sativa L.) seeds and seedling emergence and performance in flooded soil. Seed Science and Technology, 30: 61-67.

Salim, M. H. and Todd, G. W. (1968). Seed soaking as a pre-sowing drought hardening treatment in wheat and barley seedling. Agro Food, 60: 179-82.

Salinas, A. R. (1996). Influence of Glycine max (L.) Merrill seed quality on crop establishing and overcoming of ambiental stress. Pesquisa Agropecuaria Brasileira, 31: 379-386.

Scott, S. J., Jones, R. A. and Williams, W. J. (1984). Review of data analysis methods for seed germination. Crop Science, 24:1192-1199

Shravani, B., Sean, M., Michael, D., Jeremy, A. R., Sayed, N. Azam-Ali., Richard, M., Remy, S. P. (2007). Inheritance of 'domestication' traits in Bambara groundnut (Vigna subterranea (L.) Verdc.). Euphytica, 157:59–68

Simon, E.W. (1984). Early events in germination.. In D.R. Murray (ed.) Seed Physiology, Vol. 2, p.77–115 Germination and reserve mobilization. Academic Press, Orlando, FL.

Singh, H. and Gill, H. S. (1988). Effect of seed treatment with salts on germination and yield of wheat. Agricultural Science Digest, 8: 173-175.

Singh, N. D. (2003). Seed size and adventitious (nodal) roots as factors influencing the tolerance of wheat to waterlogging. Australian Journal of Agriculture and Research, 54: 969-977.

Sivakumar, M. V. K. (1988). Predicting rainy seasonpotential from the onset of rains in southern Sahelian andSudanian climatic zones of West Africa. Agricultural andForest Meteorology 42, 295–305.

Sivritepe, N., Sivritepe, H. O. and Eris, A. (2003). The effects of NaCL priming on salt tolerance in melon seedling grown under saline conditions. Scientia Horticulturae, 97:229-237.

Smith, T. M. (2006). Seed Priming and Smoke Water Effects on Germination and Seed Vigour of Selected Low-Vigour Forage Legumes.

Soltani, A., Galeshi, S., Zeinali, E. and Latifi, N. (2002). Germination, seed reserve utilization and seedling growth of chickpea as affected by salinity and seed size. Seed Science and Technology, 30(1): 51-60.

Somasegaran, P., Abaidao, R. C. and Kumaga, F. (1990). Host-Bradyrhizobium relationships and nitrogen fixation in the bambara groundnut (Voandzeia subterranea (L.) Thou.). Tropical Agriculture, 67:137-142.

Spilde, L. A. (1989). Influence of seed size and test weight on several agronomic

traits of barley and hard red spring wheat. Journal of Production Agriculture, 2: 169-172.

Srinivasan, K., Saxena, S., and Singh, B. B. (1999). Osmo- and hyrdo-priming of mustard seeds to improve vigour and some biochemical activities. Seed Science and Technology, 27(2):785-793.

Stock, W. D., Pate, J. S. and Delfs, J. (1990). Influence of seed size and quality on seedling development under low nutrient conditions in five Australian and South African members of Proteaceae. Journal of Ecology, 78: 1005±1020.

Swanevelder, C. J. (1998). Bambara-food for Africa: (Bambara groundnut: Vigna subterranea). National Department of Agriculture,Grain Crops Institute. Pretoria, South Africa.

Taylor, A. G. and Harman, G. E. (1990). Concepts and technologies of selected seed treatments. Annual Review of Phytopathology, 28: 321-329.

Teetes, G. L. (1982). ‘‘Sorghum insect pest management.’’ In L. R. Housse, L. K. Mughogho, and J. M. Peacock (eds.). Sorghum in the Eighties, 1:225-235. ICRISAT, Patancheru, Andhra Pradesh, India.

TeKrony, D. M., Bustamam, T., Egli, D. B. and Pfeiffer, T. W. (1987). Effects of soybean seed size, vigour, and maturity on crop performance in row and hill plots. Crop Science, 27: 1040-1045.

Thill, D. C., Schirman, R. D. and Appleby, A. P. (1979). Osmotic stability of mannitol and polyethylene glycol 20 000 used as a solution media. Journal of Agronomy, 71: 105-108.

Thornton, J. M. and Powell, A. A. (1992). Short term aerated hydration for the

improvement of seed quality in Brassica oleracea L. Seed Science Research, 2, 41-49.

Van Pijlen, J. G. S., Groot, P. C., Kraak, H. L. and Bino, R. J. (1996). Effect of pre-storage hydration treatments on germination performance, moisture content, DNA synthesis and controlled deterioration tolerance of tomato (Lycopersicon esculentum Mill) seeds. Seed Science Research, 6: 57-63.

Verdcourt, B. (1980). The correct name for the Bambara groundnut. Kew Bulletin, 35 (3) : 474.

Vertucci, C.W. (1989). The kinetics of seed imbibition. Crop Science Society of America (Seed moisture), 14: 93-115.

Wambete, J., Mpotokwane, S. (2003). Investrigating opportunities for Bambara groundnut in the development of weaning foods. In: Proceedings of the International Bambara Groundnut Symposium, Botswana College of Agriculture, Botswana.

Warren, J. E. and Bennett, M. A. (1997). Seed hydration using the drum priming system. HortScience, 32 (7): 1220-1221.

APPENDICES

Appendix I: Plant house experiment

Appendix1.1 Analysis of variance of sorghum varieties seeds germination index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	823.51	274.50	2.80	0.054
Variety2	1217.88	608.94	6.21	0.005	
Treatment.Variety	6	641.55	106.93	1.09	0.387

Residual	36	3532.48	98.12	
Total	47	6215.41		

Appendix 1.2 Analysis of variance of sorghum varieties seedlings vigour index

Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
Treatment	3	1376918.	458973.	4.45	0.009
Variety2	279597.	139799.	1.35	0.271	
Treatment.Variety	6	266448.	44408.	0.43	0.854
Residual	36	3716035.	103223.		
Total	47	5638998.			

Appendix 1.3 Analysis of variance of sorghum varieties seedlings dry weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.014792	0.004931	2.94	0.046

Variety2	0.001015	0.000507	0.30	0.741
Treatment.Variety	6	0.004266	0.000711	0.42	0.858
Residual	36	0.060321	0.001676		
Total	47	0.080393			

Appendix 1.4 Analysis of variance of coefficient of velocity of sorghum varieties seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	95.062	31.688	6.47	0.001
Variety2	0.542	0.271	0.06	0.946	
Treatment.Variety	6	8.625	1.438	0.29	0.936
Residual	36	176.250	4.896		
Total	47	280.479			

Appendix 1.5 Analysis of variance of sorghum varieties seeds germination percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	1410.7	470.2	3.81	0.018
Variety2	369.3	184.6	1.50	0.238	

Treatment.Variety	6	1672.2	278.7	2.26	0.060
Residual	36	4443.8	123.4		
Total	47	7896.0			

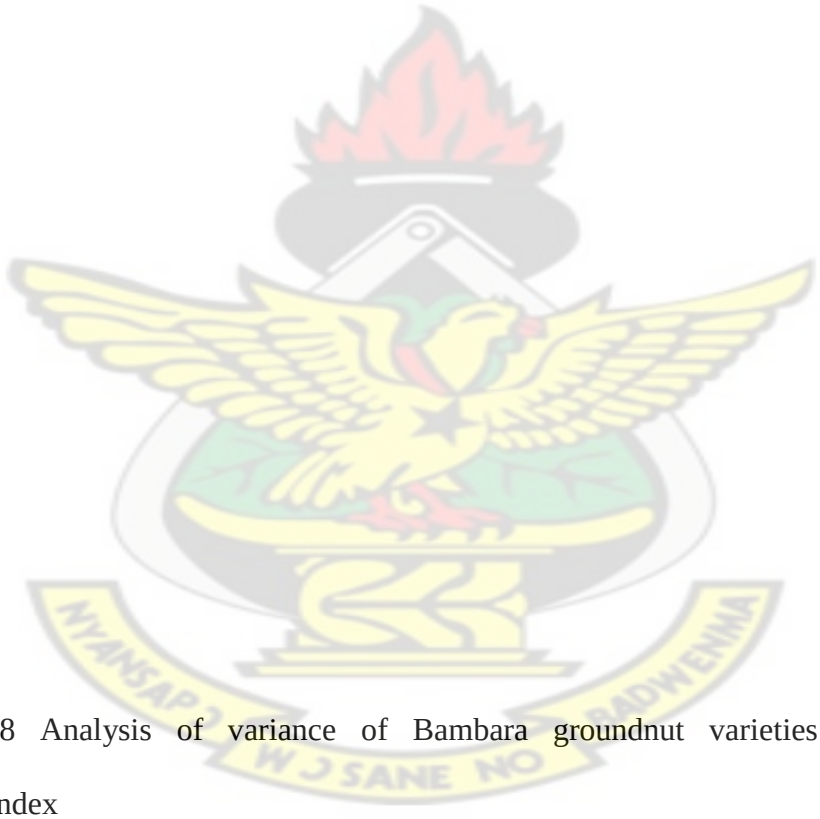
Appendix 1.6 Analysis of variance of seed germination percentage of Bambara groundnut varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Size	1	6778.2	6778.2	11.53	0.001
Treatment	3	5420.8	1806.9	3.07	0.033
Variety2	1458.6	729.3	1.24	0.295	
Size.Treatment	3	874.5	291.5	0.50	0.686
Size.Variety	2	816.9	408.4	0.69	0.503
Treatment.Variety	6	247.9	41.3	0.07	0.999
Size.Treatment.Variety	6	2563.7	427.3	0.73	0.630
Residual	72	42338.9	588.0		
Total	95	60499.5			

Appendix 1.7 Analysis of variance of Bambara groundnut varieties seedling dry weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Size	1	3.2075	3.2075	24.81	<.001
Treatment	3	0.5114	0.1705	1.32	0.275

Variety2	0.1474	0.0737	0.57	0.568
Size.Treatment	3	0.4349	0.1450	1.12	0.346
Size.Variety	2	0.0872	0.0436	0.34	0.715
Treatment.Variety	6	0.5775	0.0962	0.74	0.616
Size.Treatment.Variety	6	0.9805	0.1634	1.26	0.285
Residual	72	9.3067	0.1293		
Total	95	15.2531			



Appendix 1.8 Analysis of variance of Bambara groundnut varieties seed germination index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Size	1	314.33	314.33	9.61	0.003
Treatment	3	729.19	243.06	7.43	<.001

Variety2	62.45	31.22	0.95	0.390	
Size.Treatment	3	4.65	1.55	0.05	0.986
Size.Variety	2	105.21	52.61	1.61	0.207
Treatment.Variety	6	19.77	3.29	0.10	0.996
Size.Treatment.Variety	6	137.49	22.91	0.70	0.650
Residual	72	2355.26	32.71		
Total	95	3728.34			

Appendix 1.9 Analysis of variance of coefficient of velocity of Bambara groundnut varieties seedlings

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r	F pr.
Size	1	25.01	25.01	0.58	0.451	
Treatment	3	668.46	222.82	5.12	0.003	
Variety2	44.19	22.10	0.51	0.604		

Size.Treatment	3	99.85	33.28	0.77	0.517	
Size.Variety	2	5.44	2.72	0.06	0.939	
Treatment.Variety	6	26.49	4.42	0.10	0.996	
Size.Treatment.Variety	6	111.19	18.53	0.43	0.859	
Residual	70	(2) 3044.58	43.49			
Total	93	(2) 3967.24				

Appendix 1.10 Analysis of variance of Bambara groundnut varieties seedlings vigour index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Size	1	3542421.	3542421.	6.92	0.010
Treatment	3	5013110.	1671037.	3.26	0.026
Variety	2	1080297.	540149.	1.05	0.354
Size.Treatment	3	408842.	136281.	0.27	0.850

Size.Variety	2	509795.	254898.	0.50	0.610
Treatment.Variety	6	175186.	29198.	0.06	0.999
Size.Treatment.Variety	6	1377184.	229531.	0.45	0.844
Residual	72	36874706.	512149.		
Total	95	48981542.			

Appendix 1.11 Analysis of variance of Bambara groundnut seed mean germination time

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Replication stratum	3	118.5837	39.5279	110.68	
Replication.*Units* stratum					
Size	1	0.1438	0.1438	0.40	0.528
Treatment	3	29.4881	9.8294	27.52	<.001
Variety	2	6.0590	3.0295	8.48	<.001
Size.Treatment	3	0.1618	0.0539	0.15	0.929
Size.Variety	2	1.6204	0.8102	2.27	0.111
Treatment.Variety	6	0.5250	0.0875	0.25	0.960
Size.Treatment.Variety	6	3.0127	0.5021	1.41	0.225
Residual	69	24.6425	0.3571		
Total	95	184.2371			

Appendix II: field experience

Appendix 2.1 Analysis of variance of Seed germination percentage of Sorghum varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	187.56	93.78	2.93	
Replication.*Units* stratum					
Variety2	780.22	390.11	12.18	<.001	
Treatment	3	186.31	62.10	1.94	0.153
Variety.Treatment	6	181.78	30.30	0.95	0.483
Residual	22	704.44	32.02		
Total		35	2040.31		

Appendix 2.2 Analysis of variance of number of plants per plot of sorghum varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	177.72	88.86	2.90	
Replication.*Units* stratum					
Variety2	555.39	277.69	9.05	0.001	
Treatment	3	325.42	108.47	3.54	0.031
Variety.Treatment	6	248.17	41.36	1.35	0.279
Residual	22	674.94	30.68		
Total	35	1981.64			

Appendix 2.3 Analysis of variance of day to 50 % flowering of sorghum varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	72.12	36.06	3.33	

Replication.*Units* stratum					
Variety2	1054.21	527.11	48.66	<.001	
Treatment	3	77.32	25.77	2.38	0.097
Variety.Treatment	6	73.81	12.30	1.14	0.375
Residual	22	238.31	10.83		
Total	35	1515.77			

Appendix 2.4 Analysis of variance of sorghum plant biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	6532172.	3266086.	8.11	
Replication.*Units* stratum					
Treatment	3	4627403.	1542468.	3.83	0.024
Variety2	6442886.	3221443.	8.00	0.002	
Treatment.Variety	6	1799269.	299878.	0.74	0.620
Residual	22	8863136.	402870.		
Total	35	28264865.			

Appendix 2.5 Analysis of variance of sorghum varieties Mean Germination Time

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.1650	0.0825	0.50	
Replication.*Units* stratum					

Treatment	3	5.1931	1.7310	10.56	<.001
Variety2	0.8507	0.4253	2.59	0.097	
Treatment.Variety	6	0.5615	0.0936	0.57	0.749
Residual	22	3.6078	0.1640		
Total		35	10.3781		

Appendix 2.6 Analysis of variance of Coefficient of velocity of sorghum varieties seedlings

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2.919	1.459	0.35	
Replication.*Units* stratum					
Treatment	3	144.564	48.188	11.58	<.001
Variety2	22.090	11.045	2.65	0.093	
Treatment.Variety	6	15.272	2.545	0.61	0.718
Residual	22	91.533	4.161		
Total	35	276.378			

Appendix 2.7 Analysis of variance of sorghum varieties number of leaves

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.291	0.146	0.06	

Replication.*Units* stratum					
Variety2	162.308	81.154	32.88	<.001	
Treatment	3	6.146	2.049	0.83	0.492
Variety.Treatment	6	61.556	10.259	4.16	0.006
Residual	22	54.296	2.468		
Total	35	284.597			

Appendix 2.8 Analysis of variance of the numbers of plants stands 20 days after sowing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1011.06	505.53	14.28	
Replication.*Units* stratum					
Variety2	2500.22	1250.11	35.31	<.001	
Treatment	3	2410.89	803.63	22.70	<.001
Variety.Treatment	6	1645.11	274.19	7.74	<.001
Residual	22	778.94	35.41		
Total	35	8346.22			

Appendix 2.9 Analysis of variance of days to 50 % flowering of Bambara groundnut varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	20.2575	10.1288	11.86	
Rep.*Units* stratum					
Size	1	0.0356	0.0356	0.04	0.839
Treatment	3	1.2167	0.4056	0.47	0.701
Variety	2	8.5558	4.2779	5.01	0.011
Size.Treatment	3	1.1967	0.3989	0.47	0.707
Size.Variety	2	0.9169	0.4585	0.54	0.588
Treatment.Variety	6	1.7075	0.2846	0.33	0.916
Size.Treatment.Variety	6	5.8175	0.9696	1.14	0.357
Residual	46	39.2758	0.8538		
Total	71	78.9800			

Appendix 2.10 Analysis of variance of Bambara groundnut plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	23.372	11.686	5.20	

Rep.*Units* stratum					
Size	1	4.133	4.133	1.84	0.182
Treatment	3	10.727	3.576	1.59	0.204
Variety2	66.910	33.455	14.89	<.001	
Size.Treatment	3	5.238	1.746	0.78	0.513
Size.Variety	2	2.430	1.215	0.54	0.586
Treatment.Variety	6	7.797	1.300	0.58	0.746
Size.Treatment.Variety	6	12.854	2.142	0.95	0.467
Residual	46	103.367	2.247		
Total	71	236.828			

2.11 Analysis of variance of Bambara groundnut number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3477.1	1738.6	11.45	
Rep.*Units* stratum					

Size	1	0.0	0.0	0.00	0.993	
Treatment	3	251.9	84.0	0.55	0.649	
Variety2	2148.2	1074.1	7.08	0.002		
Size.Treatment	3	536.2	178.7	1.18	0.329	
Size.Variety	2	352.8	176.4	1.16	0.322	
Treatment.Variety	6	1427.9	238.0	1.57	0.178	
Size.Treatment.Variety	6	2302.9	383.8	2.53	0.034	
Residual	46	6981.7	151.8			
Total	71	17478.9				