EFFECT OF PHOSPHORUS FERTILIZER RATES AND PRIMING TREATMENTS ON SEED QUALITY OF BAMBARA GROUNDNUT (*Vigna subterranea* (L.) Verdc.)

BY

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DECLARATION

Declaration by the candidate

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DEDICATION

To my mother Ms. Sidon Atim Okello, and my brothers Mr. Raymond Ocen and Mr. Bonny Okello who have been very supportive during this academic journey.

ABSTRACT

Bambara groundnut is a protein and energy rich legume crop of African origin with potential to contribute to food and nutrition security. Some studies have evaluated its seed quality but limited explanation exists on the relationship between farmers' seed management practices and seed quality as well as the effect of phosphorus fertilizer on seed quality. Seed quality enhancement treatments also needs to be investigated in Bambara groundnut. The objectives of this study therefore were; to document seed management practices and evaluate the quality of farmer saved seed from Uganda; to determine the effect of phosphorus fertilizer rates on seed yield and seed quality of Bambara groundnut; and to determine the effect of hydropriming and halopriming with potassium nitrate on seed germination of Bambara groundnut. Four hundred Bambara groundnut farmers were chosen using purposive sampling and information gathered on their seed management practices. A semi structured questionnaire was used in face-to-face interview. Seed colour and size determination, standard germination and electrical conductivity tests were done on seed samples collected from farmers. Field experiment was set at Zonal Agricultural Research and Development Institute, Ngetta in Uganda using RCBD with a 3x4 factorial treatment structure consisting of 3 Bambara groundnut landraces and 4 phosphorus fertilizer rates. Determination of total seed phosphorus content and a standard germination test were done with seeds harvested from this experiment. Landrace that showed poor germination (AbiBam 001, 18.67% at 0 $KgPha^{-1}$) was selected and stored for 2 months in a deep freezer and subjected to hydropriming and halopriming with potassium nitrate, and a standard germination test done. Results from the survey revealed that farmers obtained seeds mainly from local markets (35.2%), maintained mostly single landraces (52.5%) and recycled their seeds for more than 4 years (39.2%). Seed was sun dried on the ground (81%) and stored mostly in gunny bags on raised platforms (93.5%). Collected Bambara groundnut landraces were identified as Local Bam, AbiBam 001, AbiBam 003, TVSU 688 and TVSU 759. Landraces had varied seed coat colours and significantly differed at $p = 0.05$ in their seed sizes, final germination percentage (FGP), electrical conductivity, germination velocity index (GVI) and seedling vigour index II (SVI-II). Phosphorus fertilizer rates did not significantly affect seed yield ($p = 0.780$) and seed phosphorus content ($p = 0.831$) of landraces but significantly affected FGP ($p = 0.001$), GVI and SVI-II ($p<.001$) of landraces. Hydropriming ($p = 0.279$) and halopriming with potassium nitrate ($p = 0.640$) did not affect FGP of AbiBam 001 landrace. There exists a wide diversity of Bambara groundnut landraces maintained by farmers in Uganda, some of which have good seed quality, alluded to farmers good seed management practices. Among the landraces evaluated, only AbiBam 001 landrace responded positively to phosphorus application with respect to seed yield and seed quality. Seed priming treatments did not improve germination capacity and vigour in AbiBam 001 landrace. Farmers training by the relevant stakeholders in Uganda will help to further improve the quality of their farm-saved seeds. Further studies should be done on the biochemical and physiological properties of the seed coat of Bambara groundnut. Genetic attributes and phosphorus use efficiency of Bambara groundnut landraces should also be investigated to explain their responses to application of phosphorus.

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LIST OF ACRONYMS

EC	Electrical conductivity
FGP	Final germination percentage
GVI	Germination velocity index
SVI-II	Seedling vigour index II
TSW	Thousand seed weight
UBOS	Uganda Bureau of Statistics
ZARDI	Zonal Agricultural Research and Development Institute

DEFINITION OF TERMS

Landrace	A genetically heterogenous crop that has evolved in a certain ecogeographical area and is adapted to the edaphic and climatic conditions and to traditional management and uses

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CHAPTER ONE

INTRODUCTION

1.1 Background

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is one of the neglected and underutilized legumes in Africa (Harouna et al., 2018; Mayes et al., 2011). It is of African origin (FAO, 2017) and is widely cultivated in Sub-Saharan Africa (Baudoin & Mergeai, 2001), especially by women subsistence farmers (Ibrahim et al., 2018; Wasula et al., 2014; Azam-Ali et al., 2001). Bambara groundnut is considered a food security crop (Effa & Uko, 2017; Nyongesa et al., 2013; Abu & Buah, 2011) because it is drought tolerant (Nautiyal et al., 2017; Chai et al., 2016; Berchie et al., 2016) and performs better than other legumes in poor soils (Anchirinah et al., 2001) due to its high nitrogen fixing ability (Yakubu et al., 2010). Bambara groundnut is regarded as the third most important food legume in Africa after cowpea and groundnut (Odongo et al., 2015). Nutritionally, Bambara groundnut seeds contain 63% carbohydrates, 18% proteins and 6.5% fats (Bamishaiye et al., 2011). It has also been utilized for its medicinal values such as curing diarrhoea, mouth diseases and animal wounds (Biodiversity International, 2015).

Bambara groundnut is a dicotyledonous angiosperm belonging to the family Fabaceae and subfamily papilionoideae (APG IV, 2016). Bambara groundnut is an autogamous plant (Gonné et al., 2013), implying that fertilization takes place by fusion of gametes from the same flower. It is an intermediate annual plant with a well sprang up tap root, a creeping stem and grows to a height of approximately 30-35cm (Bamshaiye et al., 2011). Pale yellow flowers develop on the creeping stems which grow into the soil after flower fertilization, carrying developing seed covered in a cushy pod (Bamnetwork, 2014). Dry pods are round

and crinkled, containing one or two smooth and hard seeds (Effa & Uko, 2017). Seed coat colour variegates from black, cream, brown or red and may be streaked with several colours (Jideani & Diedericks, 2014).

Plate 1: Bambara groundnut plants just before anthesis

(Source: Author, 2019)

Plate 2: Round Bambara groundnut pods harvested at physiological maturity

(Source: Author, 2019)

Plate 3: Bambara groundnut seeds collected from Ugandan farmers (A is AbiBam 001 and B is TVSU 688)

(Source: Author, 2019)

Bambara groundnut can be grown as a pure stand or intercropped with other crops such as cassava, maize, millet, sorghum, groundnut, cowpea and yam (Ibrahim et al., 2018; Alhassan & Egbe, 2013; Toure et al., 2012). Bambara groundnut fixes nitrogen in the soil (Sprent et al., 2010), providing a better agronomic and nutritional complement to cereals (Halimi et al., 2019). It performs better than groundnuts (*Arachis hypogaea* L.) on poor soils (Anonymous, 2016; Anchirinah et al., 2001) but phosphorus fertilizer application influences its growth, development and seed yield (Temegne et al., 2019; Temegne et al., 2018), and this is also likely to influence seed quality. Nonetheless, no previous study has documented seed yield and seed quality responses of Ugandan Bambara groundnut landraces to application of different phosphorus fertilizer rates. Seeds are among the sinks for photosynthates, but nutrition of the mother plant which is influenced by deficiency of a nutrient or the addition of a nutrient from an external source affects seed quality (Paneru et al., 2017). A study evaluated wheat seeds obtained from plants grown in phosphorus deficient soil, and reported poor seed germination (Zhu & Smith, 2001).

Early and uniform field emergence and establishment is desirable in farming, but poor field emergence of Bambara groundnut affects its commercialization by farmers (Mabhaudhi & Modi, 2013). Farmers usually cultivate landraces whose seeds are exchanged in the community, but the seed quality of such landraces is either very low, variable or unknown (Mohammed et al., 2016). Poor field emergence of seeds obtained from such landraces could be partly attributed to intrinsic seed properties which calls for quality enhancement. Seed quality enhancement treatments such as hydropriming and halopriming with potassium nitrate solution have been used to improve seed germination and field emergence in many crops (Tizazuet al., 2019; Das & Mohanty, 2018; El-Baki et al., 2018; Anisa et al., 2017),

but nothing has been reported on the response of a Ugandan Bambara groundnut landrace to such seed quality enhancement treatments. This study was therefore geared towards evaluating the quality of farm-saved seeds of Bambara groundnut from North Western, Northern and Eastern Uganda, as well as the response of some of such landraces to different phosphorus fertilizer rates and seed quality enhancement treatments.

1.2 Statement of the problem

Some studies have evaluated the seed quality of Bambara groundnut landraces (Mandizvo & Odindo, 2019; Miya & Modi, 2017; Chibarabada et al., 2014), but none of these studies gave an explanation on seed quality with respect to the practices that farmers undertake. In Uganda, there is scarce information on farmers' seed management practices and the quality of farm-saved seeds of Bambara groundnut, yet seed management affects the quality of farm-saved seeds.

Application of phosphorus fertilizer is reported to improve seed yield of Bambara groundnut landraces in Nigeria (Ikenganyia et al., 2017; Nweke & Emeh, 2013), yet its effect on seed quality has not been clearly explained. Besides, nothing has been reported on the response of Ugandan Bambara groundnut landraces to application of phosphorus fertilizer. Farmers use landraces as their major seed source of Bambara groundnut since certified seeds are unavailable (Ibrahim et al., 2018; Mohammed et al., 2016; Mayes et al., 2008). Seeds obtained from these landraces are maintained and recycled by farmers for longer periods, and are likely to have either unknown, variable or low quality (Mohammed et al., 2016). Poor and delayed field emergence has been reported as one of the limiting factors in Bambara groundnut production (Legwaila et al., 2013; Mabhaudhi & Modi, 2013). There is variation

in field emergence among landraces, ranging from 7 to 21 days after sowing or 35 to 55 days after sowing hence negatively affecting farmers (Mabhaudhi & Modi, 2013; Berchie et al., 2010; Makanda et al., 2009). Seed quality enhancement treatments such as hydropriming and halopriming with potassium nitrate solution have been successful in improving field emergence in many crops and some West African Bambara groundnut landraces. Unfortunately, none of such seed quality enhancement treatments has been done on a Ugandan Bambara groundnut landrace.

1.3 Justification

Bambara groundnut has diverse nutritional compositions (Temegne et al., 2018; Adu-Dapaah & Sangwan, 2004) and is consumed in many forms such as cakes, snacks, paste, fried grain or fresh boil (Jonah et al., 2010). More women are engaged in the production of this crop compared to men (Ibrahim et al., 2018; Wasula et al., 2014), and this enables women to obtain income and food for home consumption thus contributing to household food security. Despite its importance, Bambara groundnut has very poor germination that makes it less attractive to some farmers (Legwaila et al., 2013), hence engaging in other alternative legumes such as cowpea and groundnut. This scenario could result in reduction of Bambara groundnut production and loss of useful germplasm.

Bambara groundnut landraces have an abundance of genetic variations (Massawe et al., 2005). Farmers use their farm-saved seeds which are recycled over time due to lack of improved varieties (Mayes et al., 2008). Seed quality of such recycled seed remains unclear. In Uganda, limited information exists on farmers seed management practices and the seed quality of landraces they maintain. Documentation of Bambara groundnut seed management

practices and quality of farm-saved seeds will be helpful in improving farmers' practices and other aspects related to value addition and marketing. This study will also inform the national research body in Uganda to pursue a breeding programme on Bambara groundnut in a call to address food and nutrition security. Seed producers who may later follow up on improved seed production practices of Bambara groundnut will be interested in selling primed seeds to farmers. This implies that they will need an optimal concentration of the priming agent (potassium nitrate solution) and hydropriming duration for Bambara groundnut. This study gives a good foundation for such seed producers not only on priming agents but also on fertilizer application especially using phosphorus during seed production.

1.4 Objectives

1.4.1 Broad objective

To improve Bambara groundnut seed production through an understanding of farmers' practices, fertilizer use and seed quality enhancement.

1.4.2 Specific objectives

- To document seed management practices and evaluate the quality of farm-saved seeds of Bambara groundnut in Uganda.
- To determine the appropriate rate of phosphorus fertilizer for seed production of Bambara groundnut.
- To determine the effect of hydropriming and halopriming with potassium nitrate solution on seed germination of Bambara groundnut.

1.5 Research questions

1.5.1 Research questions for survey and evaluation of farm-saved seeds

- What are the farmers' seed sources of Bambara groundnut in North Western, Northern and Eastern Uganda?
- What is the seed composition of Bambara groundnut seed samples in North Western, Northern and Eastern Uganda?
- How do farmers in Uganda manage farm-saved seeds of Bambara groundnut?
- What is the quality of farm-saved seeds of Bambara groundnut in North Western, Northern and Eastern Uganda?

1.5.2 Research questions for phosphorus application

- What is the effect of applying different rates of phosphorus fertilizer on seed yield and seed quality of Bambara groundnut?

1.5.3 Research question for seed priming methods

- What is the effect of hydropriming and halopriming with potassium nitrate solution on seed germination of Bambara groundnut?

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and taxonomy of Bambara groundnut

The centre of origin of Bambara groundnut is West Africa (Hillocks et al., 2012), although it was earlier argued that it originated from North Africa and moved to Kwazulu-Natal in South Africa (Swanvelder, 1998). Another recent report confirms that the centre of origin of Bambara groundnut is North Eastern Nigeria and Northern Cameroon in West Africa (FAO, 2017). It is reported that the English name Bambara groundnut is derived from the Bambara tribe who live in Bambara district near Timbuktu, Central Mali (Nwanna et al., 2005). It has also been reported that the wild Bambara groundnut spread from Jos Plateau and Yola in Nigeria to Garoua in Cameroon (Goli, 1997). Bambara groundnut then spread to Eastern and Southern parts of Sudan and was adopted for cultivation throughout tropical Africa (Brink & Belay, 2006). The crop also spread to parts of South America, Asia and Oceania (Baudoin & Mergeai, 2001).

Bambara groundnut belongs to the family Fabaceae. It also belongs to genus *Vigna* consisting of a wild type *Vigna subterranea var. spontanea* (Mohammad, 2014) and cultivated type *Vigna subterranea var. subterranea* which is found in Sub-Saharan Africa (Somta et al., 2011; Shravani et al., 2004). Bambara groundnut has also been given different names by African communities. The names include *Izindlubu* (Zulu, South Africa), *Indlubu* (Xhosa, South Africa), *Kwaruru* (Hausa, Nigeria), *Okpa* (Ibo, Nigeria), *Epa-Roro* (Yoruba, Nigeria), *Nyimo* (Shona, Zimbabwe), *Ntoyoci* (Bemba, Republic of Zambia) (Mahbudhi & Modi, 2013; Bamshaiye et al., 2011).

2.2 Production of Bambara groundnut

Bambara groundnut is a drought tolerant crop (Tsoata et al., 2016). It requires an annual rainfall of about 500mm to 1,200mm during the growing season (Anonymous, 2016). The optimum growth temperature range is 19°C to 30°C, while temperatures below 16 °C and above 38°C are not suitable for its production (FAO, 2007). It also requires a well-drained sandy loam soils, soil PH of between 5.0 and 6.5 and not less than 4.3 or greater than 7.0, and optimum soil depth of 50cm to 100cm (Anonymous, 2016; FAO, 2007).

Bambara groundnut is planted on ridges, heaps or flat seed bed prepared mechanically or manually (Adzawla et al., 2016; Alhassan & Egbe, 2013). The recommended spacing for optimum yield is 50cm x 20cm (Akpalu et al., 2012). Intercropping of Bambara groundnut with crops such as maize, cassava, yam, millet, cowpea and groundnut is a common practice among farmers (Adzawla et al., 2016; Alhassan & Egbe, 2013; Toure et al., 2012). Intercropping has been attributed to heterogeneity of soil types, need for more food at the household, unpredictable climatic conditions and sociocultural factors (Ibeawuchi, 2007). Weeding is commonly done twice but can be once, thrice or more depending on the location (Aviara et al., 2013). Bambara groundnut farmers seldomly use fertilizers (Akpalu et al., 2013). This is because Bambara groundnut has ability to perform better than other legumes in poor soils (Alhassan & Egbe 2013; Akpalu, 2010). However, some farmers in Guinea Savannah of Ghana and Southern Guinea Savannah of Nigeria use fertilizer in Bambara groundnut production (Alhassan & Egbe, 2013; Berchie et al., 2010). Earthing up is also a common practice in Bambara groundnut production, known for improving yield (Ouedraogo et al., 2012). Harvesting of Bambara groundnut is normally done between 4 to 5 months after

sowing, but is dependent on location and landraces sown (Aviara et al., 2013; Hillocks et al., 2012).

Bambara groundnut is attacked by storage pests such as weevils, and field pests such as leaf hoppers, aphids, grasshoppers and root knot nematodes (Ibrahim et al., 2018; Baoua et al., 2014; Kankam & Adomako, 2014). Fungal diseases such as leaf spot, powdery mildew and fusarium wilt also attack Bambara groundnut in the field (Ibrahim et al., 2018; Wakhungu, 2016). However, Bambara groundnut is more tolerant to pests and diseases than cowpea (Adu-Dapaah et al., 2004). Although Bambara groundnut is drought tolerant, water stress negatively affects its seed yield and seed quality (Chibarabada, 2014). A reduction in plant height, leaf number and leaf area index in Bambara groundnut due to water stress has been reported (Mabhaudhi & Modi, 2013; Karunaratne et al., 2011; Mwale et al., 2007). Bambara groundnut is known to have five phenological stages; emergence, vegetative, flowering, pod filling and maturity, but an early onset or delay of a stage in the phenological cycle occurs due to water stress on the plant (Karunaratne et al., 2010). Bambara groundnut is more sensitive to water stress at the flowering stage (Vurayai et al., 2011). Water stress on maternal plant especially at vegetative, flowering and pod filling stages causes yield loss and low dry matter accumulation in Bambara groundnut (Karunaratne et al., 2011; Vurayai et al., 2011; Mwale et al., 2007). Bambara groundnut landraces grown under rainfed conditions flower earlier, for a shorter duration, and mature earlier than when grown under irrigated conditions (Mabhaudhi & Modi, 2013).

The world's annual productivity of Bambara groundnut in 2007 was estimated to be about 0.664t/ha compared to 0.719t/ha in 2016 and 0.715t/ha in 2017 (FAO, 2019). Bukina Faso,

Niger and Cameroon are currently ranked as the world's leading producers (FAO, 2019). Bambara groundnut yield and area under production in Africa in 2019 is estimated at 228,920t and 370,953ha respectively, while the figures stand at 17,182t and 83,750ha yield and production area respectively for Eastern Africa (FAO, 2020). Some studies have reported that the production of Bambara groundnut in Africa is dominated by women subsistence farmers (Ibrahim et al., 2018; Wasula et al., 2014; Hillocks et al., 2012). These farmers are mostly aged below 50 years (Adzawla et al., 2016; Alhassan & Egbe, 2013), with low level of education (Adzawla et al., 2016; Wasula et al., 2014; Berchie et al., 2010) and grow Bambara groundnut in a small area usually about an acre or less (Aviara et al., 2013).

2.3 Utilization of Bambara groundnut

Bambara groundnut is a food security crop, and is produced majorly for human consumption (Ibrahim et al., 2018; Effa & Uko, 2017). It is used as snacks, ingredient in cooking and for making flour (Mazahib et al., 2013). Seed flour of Bambara groundnut has higher oil content, good water absorption and emulsion properties, thus making it a useful substitute in food formulations (Aremu et al., 2008). Fresh seeds of Bambara groundnut can be boiled and eaten as snacks, dried and ground into flour, spiced and made into paste then boiled as "moi-moi or okpa" and the paste can be fried and eaten as "akara" (Jonah et al., 2010). Fresh seeds can also be consumed raw, boiled or grilled and dry seeds can be pulverized to make cakes (Adebowale & Lawal, 2002). Bambara groundnut is also an important source of fibre, calcium, iron and potassium for animal feeding and provides a balanced diet in those localities where animal protein is expensive and the cultivation of other legumes is inconceivable because of unfavourable moisture conditions of the soil (Biodiversity

International, 2015). Bambara groundnut is also important in traditional ceremonies and is a useful gift in some West African communities (Anchirinah et al., 2001).

Bambara groundnut has also been utilized for its medicinal values such as curing diarrhoea, mouth diseases and animal wounds (Biodiversity International, 2015). It is used by several African communities to treat different ailments including venereal diseases by the Ibo of Nigeria (Brink & Belay, 2006). The Luo of Kenya use Bambara groundnut to treat diarrhoea (Mkandawire, 2007). Bambara groundnut is also used to treat amoebic dysentery, sore throat, headaches, stomach pain, joint pain, bone decalcification and is also used as a stimulant for milk production in breast feeding women especially in Cameroon (Temegne, 2018). Bambara groundnut seeds contain kaempferol, an antioxidant polyphenol which abridges the risk of chronic diseases such as cancer (Yao et al., 2015; Jideani & Diedericks, 2014). Raw Bambara groundnut seeds can be chewed and swallowed to treat nausea suffered by most pregnant women (Anonymous, 2011). Leaf preparations of Bambara groundnut are applied to abscesses and the roots are used as aphrodisiac especially in Senegal (Brink & Belay, 2006)

2.4 Seed quality

Seed quality refers to the standard of excellence in certain characters or attributes that determine the performance of seed when sown or stored (Hampton, 2002). Seed quality is a complex character and can also be defined as the viability and vigour attribute of seed that enables emergence and establishment of normal seedlings under a wide range of environments (Khan et al., 2012). However, the practical definition of seed quality differs depending on the end user (Elias, 2018). Farmers consider production of uniform plants with

high yielding capacity under a wide range of field conditions as a measure of quality while for producers of oil seed crop with industrial use such as making cosmetics and soap, seeds with a particular stable fatty acid profile may be used as a measure of quality (Elias, 2018).

However, when seed scientists talk about seed quality, they refer to four quality aspects namely; genetic seed quality, physical seed quality, physiological seed quality and pathological seed quality (Copeland & McDonald, 2012). Genetic seed quality refers to the true to type nature of seeds, that is, plants arising from the seed lot should be uniform with no off types (Hasanuzzaman, 2015). Physiological seed quality is the performance capabilities of seeds in the subsequent generation (Thomas et al., 2016). Physiological seed quality includes seed vigour, seed viability, germination capacity and dormancy (Copeland & McDonald, 2012). Seed vigour is the property of seed that determines its performance (rapid, uniform field emergence and development of normal seedlings) under wide environmental conditions (Marcos-Filho, 2015). Seed viability is the aliveness and capability of seed to produce metabolic enzymes for germination and early seedling growth (Kumar et al., 2013). Seed dormancy is the inability of seed to germinate even under favourable conditions while germination capacity is the ability of seed to develop into normal seedling under suitable conditions (ISTA, 2015). Pathological seed quality refers to the general health status of seeds that is absence or presence of disease pathogens (Hasanuzzaman, 2015). Physical seed quality refers to the proportion of pure seed, insect damaged seed, unwanted materials (chaffs, weeds, stones, sand etc) in a seed lot (Hasanuzzaman, 2015).

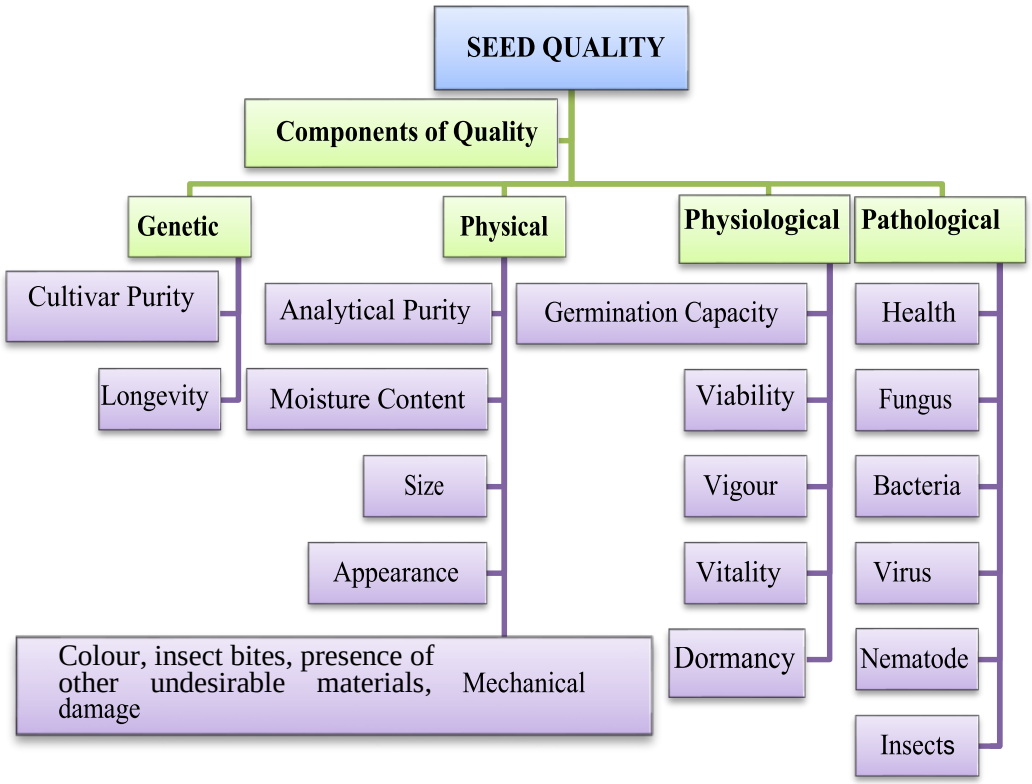


Figure 1: A simplified structural concept of seed quality (Copeland & McDonald, 2012; Huda, 2001)

Seed quality is influenced by a number of factors such as storage conditions, agronomic practices, production environment, maturity stages, packaging materials etc. The type of packaging material used for packaging seeds affects seed moisture content, germination capacity and vigour (Patel et al., 2018). Evaluation of influence of different packing materials such as Jute bag (JB), Polyethylene lined jute bag (JBP), PP woven laminated bag (PPL), HDPE bag with vacuum (HDPEV), Multilayer coextruded plastic bag with vacuum (MCPV), Polyethylene laminated aluminium foil bag with vacuum (ALPEV) and Perdue improve crop storage bag (PICS) on seed quality of chick pea showed that maximum germination of 91.33 % was observed in PPL followed by 89.33 % in JBP while minimum germination of 70.67 % was recorded in JB at the end of 12months storage period (Patel et al., 2018).

Maturity stages of seeds also affect seed quality, as seeds harvested at different maturity stages vary in quality with respect to germination and vigour. The effect of maturity stages on seed quality of two tomato accessions in Bunso, Eastern Ghana was evaluated and the result showed that highest germination capacity of 99.0% was recorded in GH 9207 accession harvested at half ripe stage and lowest germination percentage of 76.5% was recorded in the same accession harvested at initially ripe stage (Tetteh et al., 2018). Seed germination and vigour also improves with agronomic practices such as nutrition of mother plant (Moon et al., 2018; Sawan et al., 2011).

Furthermore, conditions in the production environment also affect seed quality. A suitable environmental temperature and low humidity during seed maturation results in good quality seeds (Copeland & McDonald, 2001). High temperature stress during late stages of seed development and maturation results in poor quality seeds (Egli et al., 2005). This is particularly due to poor seed filling causing shrivelled seeds (Rashid, 2016). Conditions in the production environment especially during seed development and maturation also acts upon the extent of dormancy and viability of suppurate seeds (Bewley & Black, 2012). Seed storage conditions such as relative humidity, temperature, in addition to duration of storage affects seed quality (Alhamdan et al., 2011; Patel et al., 2018). High storage relative humidity and temperature increase the rate of seed deterioration and loss of seed viability whereas most seeds deteriorate slowly and maintain viability for a long time if stored under low relative humidity and low temperature conditions.

2.5 Effect of phosphorus on seed yield and seed quality

Phosphorus is an important primary macro element for plant growth as it plays a critical role in energy storage and transfer as adenosine diphosphate (ADP), adenosine triphosphate (ATP), di-phosphopyridine nucleotide (DPN) and tri-phosphopyridine nucleotide (TPN) (Uchida, 2000). These energy storage and transfer compounds are important in the processes of photosynthesis (Hammond & White, 2008). Phosphorus is required as pyridoxal phosphate particularly in biosynthesis of chlorophyll, hence its application results in high chlorophyll content and photosynthetic activity of the plant (Mairura et al., 2007). The high photosynthetic activity resulting from phosphorus fertilizer application would mean that large amount of photoassimilates is produced and upon translocation and accumulation in the sink, in this case seeds, would improve seed yield and seed quality (Liu et al., 2015; Hossain & Hamid, 2007). Seeds need sufficient amounts of storage compounds to generate energy during germination and this is enhanced by adequate nutrition of the mother plant (Paneru et al., 2017).

Phosphorus is required for the general health, vigour of plants, seed formation and seed development (Moon et al., 2018). Phosphorus plays a role in cell division and development of meristematic tissues (Weil & Brady, 2017). It has been reported that application of 2% diammonium phosphate to cotton plants increased seed yield, seed germination, root length and dry matter production (Sasthri et al., 2001). Evaluation of the effect of nitrogen and phosphorus on seed quality and seed yield of Gaillardia plants revealed that highest germination percentage of 64.67% and seed weight of 0.64g were obtained with a phosphorus rate of 75 $KgPha^{-1}$ (Moon et al., 2018). Accumulation of phosphorus especially in the embryonic region of seed has been shown to have a strong positive correlation with shoot

and root biomass, and seedling length (Mandizvo, 2018). Highest seed yield per plant, seed yield per plot and seed weight of 21.88gplant^{-1}, 1.667gplot^{-1} and 10.29g seed^{-1} respectively, with improved seed vigour and viability were achieved by foliar application of 1728gha^{-1}of phosphorus to cotton plants (Sawan et al., 2011). Similarly, highest grain yield of 3.14t/ha and highest germination percentage of 93.66% were attained by application of 75 KgPha^{-1} in wheat (Paneru et al., 2017).

After translocation of phosphorus from the source (leaves), it accumulates in the sinks including seed during seed filling. Seed phosphorus reserves are metabolized and translocated to the root and shoot tissues during germination to promote early seedling growth (Grant et al., 2001). Higher seed phosphorus content promotes faster seedling establishment (White & Veneklaas, 2012; Zhu & Smith, 2001). Highest hypocotyl length (7.72 cm), radicle length (16.84cm), seedling length (24.56cm), seedling fresh weight (7.11 g 10 seedling $^{-1}$) and seedling dry weight (0.643 g 10 seedling $^{-1}$) were attained with an application rate of 1728gha^{-1} of phosphorus to cotton plants (Sawan et al., 2011).

Some studies have been done with Bambara groundnut in relation to phosphorus fertilizer application. Highest pod weight of 1.62g was achieved by application of 165 KgPha^{-1} to Bambara groundnut (Nweke & Emeh, 2013). A study conducted with different phosphorus fertilizer rates (25, 50 and 75 KgPha^{-1}) reported highest pod number of 19.0 and highest fresh pod weight of 290.76g plant^{-1} with 75 KgPha^{-1} (Ikenganyia et al., 2017). Similarly, another study reported increase in seed yield of Bambara groundnut with application of different rates of phosphorus fertilizer (Temegne et al., 2019). However, it is unknown how Ugandan

Bambara groundnut landraces will respond to varied phosphorus fertilizer rates in relation to seed yield and seed quality.

2.6 Effect of hydropriming on seed germination

Hydropriming is one of the seed priming methods (Kaya et al., 2006). Seed priming is the pre-sowing seed treatment which improves seed germination and emergence under unfavourable conditions or enhance germination of aged and freshly harvested seeds that may not germinate or may have minimal germination capacity (Binang et al., 2012). Hydropriming is done by soaking seeds in distilled water for a given time period and maintaining at a certain temperature, followed by airdrying the seeds to prevent radicle protrusion (Berchie et al., 2010). Hydropriming is reckoned as the cheapest and simplest seed priming method (Ahmad et al., 2014; Jisha et al., 2013).

Hydropriming is very effective in breaking seed dormancy and promoting seed germination because it enhances physiological and biochemical processes in the seed as well as improving antioxidant enzyme systems, and the accumulation of soluble sugars and proteins in the seedling during seed germination and early seedling establishment (Kamithi et al., 2016; Essou et al., 2016; Yan, 2015). Trypsin-like proteolytic enzymes that are important in germination are produced in seeds of some plant species (Yan, 2015; Matsushima & Sakagami, 2012; Ashraf & Foolad, 2005), but their activity is affected by trypsin inhibitors in some seeds, hydropriming antagonizes the inhibitors' functions and promotes protein hydrolysis and cell elongation by trypsin enzymes during seed germination (Ashraf & Foolad, 2005). Hydropriming is very effective in enhancing seed quality in aged seeds provided the deterioration period is short (Kamithi et al., 2016; Yan, 2016; Kibinza et al.,

2011). Hydropriming has been reported to increase germination rate and synchroneity as well as expurgating the lag phase to initiation of germination of *Dodonaea viscosa* seeds thus improving vigour of artificially aged seeds (Essou et al., 2016). Hydropriming increases final germination percentage, germination rate, seedling length, vigour index, total soluble proteins, soluble sugars and enzyme activities of aged groundnut seeds (Ali & Hossein, 2017).

Hydropriming has been shown to enhance seed germination in some crops such as *Phaseolus vulgaris* (Ghassemi et al., 2010), *Oryza sativa* (Matsushima & Sakagami, 2012), chick pea (Ghasemi et al., 2008), sunflower (Kaya et al.,2006), onion (Caseiro et al.,2004), *Aegle marmelos* (Singh, 2017), Bambara groundnut (Berchie et al., 2010), *Solanum lycopersicum* (Camu, 2017). The results of these studies show an increase in germination capacity, germination rate and seedling vigour index. The positive effect of hydropriming on enhancement of seed germination is attributed to solubilization of b-subunit of 11-S globulin storage protein in the seeds (Capron et al., 2000). Effectiveness of hydropriming treatment is influenced by plant species, priming period, seed vigour and incubation temperature (Ahmad & Lee, 2011; Berchie et al., 2010).

Duration of hydropriming affects mean germination time (Ali & Hossein, 2017). Prolonging hydropriming time countenances seed cells to react speedily to an enormously minimal levels of a peculiar environmental stimulus thus speeding up germination rate (Sacala & Demczuk, 2016). Increased time of hydropriming accounted for higher cumulative germination in sunflower (Kaya et al., 2006). The effect of hydropriming on seed germination of Bambara groundnut was studied using some Ghanaian landraces (Berchie et al., 2010). However, the

differences in landraces evaluated in their study and this present study owing to the differences in locations where landraces have adapted is likely to cause different reactions to hydropriming. Besides, they evaluated 24 hours and 48 hours priming period and nothing is reported on what happens if Bambara groundnut seeds are subjected to hydropriming period less than 24 hours.

2.7 Effect of halopriming with potassium nitrate (KNO_3) on seed germination

Seed treatment with potassium nitrate solution is one of the halopriming methods that is used to enhance seed germination (Ashraf & Foolad, 2005). Application of potassium nitrate results in higher germination capacity and better stand establishment in crops (Aml et al., 2011). This can be attributed to the osmotic activity of potassium ions (K^+) that helps in cell water standing, and acting as cofactor for some metabolic enzymes, and nitrate ions which acts as a substrate for amino acid and protein synthesis (Taiz & Zeiger, 2010). Potassium nitrate overcomes seed dormancy through its action on pentose pathway (Carvalho & Nakagawa, 2000) and nitric oxide synthesis (Lara et al., 2014).

Halopriming with potassium nitrate improves seed germination and seedling growth. It was reported that seeds primed with potassium nitrate solution produced vigorous seedlings, accumulated more dry matter and had higher root length than non-primed seeds (Kattimani et al., 1999). An increase in germination percentage by 28.3% and seedling dry weight by 58.1% was observed in seeds treated with potassium nitrate solution compared to non-treated seeds (Mohammadi, 2009). Evaluation of the response of two broad bean cultivars (*Vicia faba*, cv. Nobaria 3 and cv. Sakha 3) to potassium nitrate solution revealed that a significant increase in seed germination especially with Sakha 3 cultivar was observed when they were

treated with potassium nitrate concentration of 3 millimolar (mM) and subjected to salinity levels of 0, 40, 80, 120 and 160mM sodium chloride solution (El-Baki et al., 2018).

Highest germination percentage of 99.1% was observed when Bottle gourd (*Lagenaria siceraria*) seeds stored for 3 months were treated with 150 ppm of potassium nitrate solution (Chakraborty et al., 2017). A study conducted with *Cleome gynandra* L reported that germination capacity of 72% with Pop 16, 23.66% with Nord 14 and 8.0% with Sud 13 varieties were attained at 5 gl^{-1} of potassium nitrate (Essou et al., 2017). Halopriming onion seeds with 1% potassium nitrate solution for a period of 12 hours has also been shown to be very effective in enhancing germination, as germination percentage of 87.5% was achieved in comparison with other treatments of 2% and 3%, which recorded germination percentage of 82.5% and 85.5% respectively, under the same priming period (Nego et al., 2015). It was also demonstrated that 100 mM potassium nitrate solution was effective in enhancing seed germination in *Gerbera jamesonii* and *Zinnia elegans* with the final germination percentage of 74.67% and 93.33% attained in *Gerbera jamesonii* and *Zinnia elegans* respectively (Ahmad et al., 2017).

Halopriming rice seeds with 1% KNO_3 showed higher seed germination of 97.75% compared to 92.95% when primed with 2% KNO_3 (Anisa et al., 2017). Another study reported the highest germination percentage of 88.72%, germination rate of 12.2, root length of 31.62cm, shoot length of 32.12cm and total dry weight of 8.77g by halopriming using 1.5% potassium nitrate solution compared to sodium chloride, control and 0.75% potassium nitrate solution (Esmeili & Heidarzade, 2012). Priming soybean seeds with 1% potassium nitrate solution for 24 hours improved the germination percentage compared to non-primed seed in both field

and laboratory studies (Mohammadi, 2009). Halopriming with 1% potassium nitrate solution was also reported to improve emergence in sorghum as final emergence of 59.87%, 68.63% and 53.30% were recorded for Hegari variety, JS-263 variety and JS-2002 variety respectively in comparison with control which recorded 50.97 % in Hegari, 62.20% in JS-263 and 44.40% in JS-2002 (Shehzad et al., 2012).

Furthermore, it has also been established that halopriming *Solanum lycoperscium* L with 1% potassium nitrate solution improves germination, with the highest germination percentage of 91.75% and 90.25% observed in S-22 variety and Navodya variety respectively (Kumar & Kumar, 2018). However, no much is reported with regard to the response of Bambara groundnut seeds to potassium nitrate treatment. It was thus necessary to study germination behaviour of a Ugandan Bambara groundnut landrace to different concentrations of potassium nitrate solution.

CHAPTER THREE

METHODOLOGY

3.1 Seed management practices and quality of farm-saved seeds of Bambara groundnut in Uganda

3.1.1 Survey

A survey was conducted in North Western, Northern and Eastern Uganda between June and July, 2019. Prior to the survey, a reconnaissance study was done to gather more information on the production of Bambara groundnut in these regions. The survey covered 13 predominant production districts and 26 subcounties across the three regions. Purposive sampling technique targeting Bambara groundnut farmers was used to select respondents for this study. Purposive sampling is a non-probability sampling technique in which a researcher gathers information from a specific category of individuals based on their knowledge and experience on the subject of interest (Cresswell & Plano-Clark, 2011; Bernard, 2002). Purposive sampling is mostly used in qualitative research (Patton, 2002). Bambara groundnut farmers chosen from each subcounty were mobilized in a central location and briefed about the exercise. A semi structured questionnaire (Appendix 1) was then administered to each respondent in a face-to-face interview. A total of 400 Bambara groundnut farmers (28 from North Western, 248 from Northern, and 124 from Eastern region) were interviewed (Table 1).

Table 1: Number of Bambara groundnut farmers interviewed per region

Region	District	Subcounty	Number of farmers
North Western	Nebbi	Kucwiny	17
		Nyaravuru	11
			28
Northern	Gulu	Awach	15
		Paicho	15
	Omoro	Lakwana	15
		Bobi	15
	Agago	Parabongo	18
		Wol	15
	Pader	Pader	15
		Ogom	15
	Lira	Agweng	09
		Aromo	21
	Oyam	Aleka	15
		Otwal	15
	Otuke	Adwari	18
		Okwang	16
	Kole	Bala	15
		Akalo	16
			248
Eastern	Kapelebyong	Acowa	15
		Okungur	12
	Amuria	Willa	15
		Apeduru	16
	Tororo	Peta	18
		Sop-Sop	16
		Nagongera	17
	Kumi	Atutur	15
			124
Total number of respondents			**400**

Bambara groundnut seed samples were also collected from farmers during the survey. These samples were threshed by carefully and gently cracking with a stone, packaged in paper bags, labelled and grouped by region. From these samples, landraces AbiBam 001, Local Bam, AbiBam 003, TVSU 688 and TVSU 759 were identified morphologically using their seed coat colour and grouped according to the region of collection, and used for seed quality

analysis. These landraces were selected for regional representation and availability of their seeds for laboratory analysis.

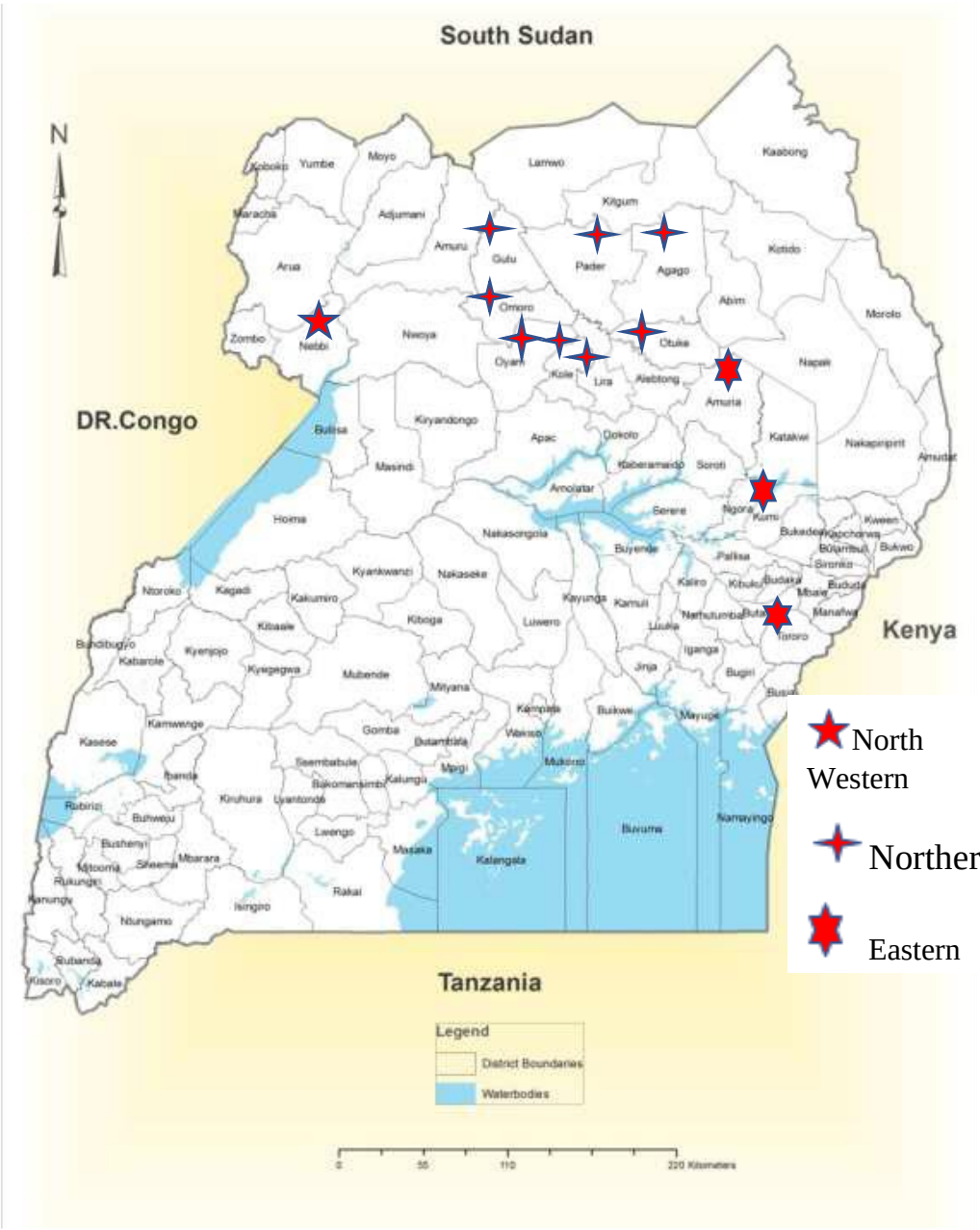


Figure 2: Map of Uganda showing sampled districts

3.1.2 Physical characteristics of farm-saved-seeds

Seed size (length and width) was measured using a Venier calliper. Twenty seeds were randomly picked from each landrace, separated in four groups (replications of 5 seeds each) and their sizes measured at a time by placing the seed between two sleeves of a Venier calliper and recording the corresponding readings in centimetres. Seed colour description for each landrace was done using Royal Horticultural Society colour chart (RHS, 2015) by placing seed in the corresponding colour grouping.

3.1.3 Electrical conductivity test

Electrical conductivity (EC) test was performed on three replicates of 10 seeds each. Seeds were separately weighed and soaked in deionized water for 24 hours and the conductivity of the leachate (MS g^{-1}) measured with an EC meter.

3.1.4 Standard germination test

A standard germination test was performed with 25 seeds in three replications. Seeds were sterilized with 1% sodium hypochlorite solution for 2 minutes and rinsed with distilled water. The sterilized seeds were then placed in germination trays in sterilized sand moistened with distilled water. Seeds were incubated in growth chamber (BJPX-B40011, Biobase Biodustry (Shandong) Co. Ltd) at alternating temperature of 20^{o}C/30^{o}C in 16hrs darkness and 8hrs light for 14 days (Mandizvo & Odindo, 2019; Chibarabada et al., 2014), and germination count recorded daily. Final germination percentage (FGP) was calculated on the 14th day using the formula according to Damalas et al (2019) as

$$\mathrm{FGP} = \frac{\mathrm{Ng}}{\mathrm{Nt}}\ \mathrm{X100} \qquad \textit{Equation 1}$$

Where; Ng is the number of germinated seeds and Nt is the total number of seeds sown.

Germination velocity index (GVI) was calculated according to Maguire (1962) as

$$GVI = {}^{G1}/_{N1} + {}^{G2}/_{N2} + \ldots\ldots + {}^{Gn}/_{Nn} \qquad \textit{Equation 2}$$

Where $G1, G2 \ldots\ldots\ldots Gn$ are number of seeds germinated on 1st, 2nd and last count.

$N1, N2 \ldots\ldots Nn$ are number of days at 1st, 2nd and last count from the sowing day.

Ten normal seedlings (normal seedlings had well-developed root and shoot systems) were oven dried at 65°C for 48 hours and seedling dry weight (SDW) measured using a digital balance (TP-B2000). Seedling Vigour Index II was computed according to Abdul-Baki and Anderson (1973) as

$$Seedling\ Vigour\ Index\ II = FGP\ X\ Seedling\ dry\ weight \qquad \textit{Equation 3}$$

3.1.5 Data collection

Survey data was collected on seed source, seed composition, period of seed recycling, time of seed selection, seed drying method, seed storage and seed processing prior to planting. Laboratory data collected were; seed colour, seed size (length and width), electrical conductivity, final germination percentage, germination velocity index and seedling vigour index II.

3.1.6 Data Analysis

Survey data was analyzed using IBM© SPSS© Version 20. Percentages from SPSS© were extracted and processed in Microsoft Excel 2016 to produce graphs and tables. Analysis of variance was performed in GenStat® 14th Edition and significant means separated using least significant difference (LSD) at 5% significance level. A correlation of seed size and physiological seed quality parameters (FGP, GVI and SVI-II) was done using Microsoft Excel 2016.

3.2 Response of Bambara groundnut landraces to application of phosphorus fertilizer

3.2.1 Site description

Field experiment was conducted at Zonal Agricultural Research and Development Institute (ZARDI) in Ngetta, Northern Uganda. Ngetta was selected because of its ecological conditions that suit Bambara groundnut production. Ngetta ZARDI is located in Northern Agro Ecological Zone in Lira district, few kilometres along Lira - Kitgum road. It lies between 2˚17'N and 32˚55'E with an altitude of 1,100m above sea level. Ngetta ZARDI receives average annual rainfall of about 1,197mm, with temperature range of 15^{o}C to 32.5^{o}C (UBOS, 2009).

3.2.2 Plant materials

Three Bambara groundnut landraces used in this study were obtained from Abi ZARDI located in Arua district, North Western Uganda. These landraces were AbiBam 001, AbiBam 003 and TVSU 759 designated as L_1, L_2 and L_3 respectively in this study. These landraces were chosen because they are commonly grown by farmers in North Western, Northern and Eastern Uganda as observed in the survey.

3.2.3 Soil sampling

Soil sample from Ngetta ZARDI was collected using a simple random sampling procedure. Samples were bulked together to make a composite sample from which a sample was drawn, packaged in a labelled paper bag and taken to Soil Science Laboratory at University of Eldoret for analysis of available phosphorus, PH and organic carbon.

3.2.4 Research design

Field experiment was laid out in a Randomized Complete Block Design (RCBD) with a 3x4 factorial treatment structure, that is 3 Bambara groundnut landraces (AbiBam 001, AbiBam 003 and TVSU 759), and 4 phosphorus rates (0, 50, 75 and 100 $KgPha^{-1}$) in three replications. Each plot was measuring 1m x 1m with a spacing of 1m between blocks and 0.5m between plots and 1m on either side of outside blocks, covering a total area of $140m^2$. Treatments were randomly allocated in the field. Triple supper phosphate (TSP) was used as phosphorus source. Phosphorus rate per plant was calculated and TSP weighed accordingly, that is 1.4g TSP/plant, 2.1g TSP/plant and 2.8g TSP/plant corresponding to 50 $KgPha^{-1}$, 75 $KgPha^{-1}$ and 100 $KgPha^{-1}$ respectively. Respective TSP rate was placed in planting holes for the specified treatment and covered with thin soil layer during sowing. Seeds were sown singly in planting hole at a spacing of 50cm x 20cm (Akpalu et al., 2012), giving plant population of 18 plants per plot.

Table 2: Field Layout at Ngetta

P_1L_2	P_3L_3	P_2L_1	P_0L_3	P_1L_1	P_2L_2	P_3L_1	P_0L_2	P_1L_3	P_3L_2	P_2L_3	P_0L_1
P_1L_3	P_3L_2	P_2L_1	P_0L_2	P_3L_1	P_0L_3	P_1L_1	P_2L_2	P_3L_3	P_0L_1	P_2L_3	P_1L_2
P_0L_1	P_3L_2	P_1L_3	P_2L_2	P_0L_3	P_1L_1	P_3L_3	P_3L_1	P_1L_2	P_2L_1	P_0L_2	P_2L_3

Note; Block 1(Top block), Block 2 (Middle block) & Block 3(Bottom block). P_0, P_1, P_2 and P_3 represents 0, 50,75 and 100 $KgPha^{-1}$ respectively. L_1, L_2 and L_3 represent AbiBam 001, AbiBam 003 and TVSU 759 respectively.

3.2.5 Agronomic and post-harvest handling practices

Land was ploughed twice using a tractor and harrowed once to make a fine seed bed for planting. Planting was done on 16th August, 2019 at the spacing stated in 3.2.4 above. Weeding was manually done by hoeing four times. Earthing up was done just before flowering. No other fertilizer or nutrient source was applied except the experimental phosphorus as stated in section 3.2.4. Harvesting was done on 04th January, 2020 (139 days after sowing) by digging the pods with a hand hoe. Pods were sun dried on gunny bags for five days and later shelled by gently and carefully cracking with a stone. Seeds were packaged in labelled paper bags and taken to University of Eldoret for further analysis.

3.2.6 Determination of seed phosphorus content

Analysis of seed phosphorus content was conducted at soil science laboratory, University of Eldoret, Kenya. Total phosphorus in the seed was determined without adjusting PH in two main procedures, that is sample digestion using Kjeldahl method and colorimetric determination (Okalebo et al., 2002). Ground Bambara groundnut seed sample was digested by treating with hydrogen peroxide, sulphuric acid, selenium powder and salicylic acid. Hydrogen peroxide oxidises the organic matter, selenium powder acts as catalyst for the process, sulphuric acid completes the digestion at elevated temperatures and salicylic acid prevents the loss of nitrates. After this acid digestion of the sample, 2ml of the digest was taken for colorimetric determination using UV spectrophotometer, from which the absorbance of phosphorus standard solution and the sample were measured at wavelength of 880nm. A standard curve of absorbance was plotted against phosphorus standard concentration. Total phosphorus in the sample was calculated using the formula;

$$\text{P in sample (\%)} = \frac{c * v * f}{w} \qquad \textit{Equation 4}$$

where c is the corrected concentration of P in the sample; v = volume of the digest; f = dilution factor; w = weight of the sample (Okalebo et al., 2002).

3.2.7 Standard germination test

Standard germination test was conducted in a completely randomized design using the procedure described in section 3.1.4. Calculation of final germination percentage and germination velocity index was done using equation 1 and equation 2 respectively as in section 3.1.4. Ten normal seedlings were oven dried at 105^{o}C for 24 hours and seedling dry weight measured using a digital balance (PCB 1000-2, KERN & Sohn GmbH, D-72336, Balingen, Germany). Seedling vigour index II was computed from seedling dry weight using the formula in equation 3 (Section 3.1.4).

3.2.8 Data collection

Data was collected on seed yield, thousand seed wight, final germination percentage, germination velocity index, seedling vigour index II and seed phosphorus content.

- **Seed yield**. Seed yield per plot was determined by harvesting all the plants in a plot and weighing seeds with a digital balance (PCB 1000-2, KERN & Sohn GmbH, D-72336, Balingen, Germany) after drying and threshing. Seed yield in tonnes per hectare was then determined from seed yield per plot using the formula;

$$\text{Seed yield (t/ha)} = \frac{\text{Seed yield per plot}(g) * 10{,}000\text{m2}}{\text{plot size(m2)} * 1{,}000{,}000\text{g}} \qquad \textit{Equation 5}$$

- **Thousand seed weight (TSW).** One hundred seeds from each treatment were counted on aluminium foil and weighed with a digital balance (PCB 1000-2, KERN & Sohn

GmbH, D-72336, Balingen, Germany), and the corresponding weight multiplied by 10 to get TSW.

3.2.9 Data analysis

Analysis of variance was performed using GenStat® 14th Edition and significant means separated using least significant difference (LSD) at 5% level of significance.

3.3 Effect of hydropriming and halopriming with potassium nitrate solution on seed germination of Bambara groundnut

3.3.1 Plant material

Landrace that showed low germination capacity from the field experiment (AbiBam 001 at 0 $KgPha^{-1}$, 18.67%) was selected for hydropriming and halopriming with potassium nitrate solution. Seeds were stored at -5◦C in a deep freezer for two months at the seed physiology laboratory, University of Eldoret before subjecting to hydropriming and halopriming with potassium nitrate solution.

3.3.2 Seed hydropriming and halopriming with potassium nitrate solution

Seeds were removed from the deep freezer and left in ambient air for 24 hours before carrying out seed enhancement treatments. Hydropriming was done by soaking 100 seeds in 100ml distilled water followed by incubation at 25ºC for 6, 12, 18 and 24 hours, and air drying for one hour. Seed priming with potassium nitrate was done by soaking 100 seeds in 100ml of 0.5, 1, 2 and 3% potassium nitrate solution for 2 hours, followed by air drying for one hour. Unprimed seeds (not hydroprimed or haloprimed with potassium nitrate solution) were used as control.

3.3.3 Standard germination test

A standard germination test was performed on the primed seeds in a Completely Randomized Design (CRD) using the procedure described in section 3.1.4. Final germination percentage (FGP) and germination velocity index (GVI) were calculated using the formulas in equation 1 and equation 2 respectively as in section 3.1.4. Ten normal seedlings were oven dried at 105^{o}C for 24 hours and seedling dry weight measured using a digital balance (TP-B2000). Seedling vigour index II was computed from seedling dry weight using the formula in equation 3 (Section 3.1.4).

3.3.4 Data collection and analysis

Data was collected on final germination percentage (FGP), germination velocity index (GVI) and seedling vigour index II (SVI-II). Analysis of variance was performed in GenStat® 14th Edition.

CHAPTER FOUR

RESULTS

4.1 Seed management practices and quality of farm-saved seeds of Bambara groundnut in Uganda

4.1.1 Farmers' seed sources of Bambara groundnut

The major seed sources were the local market (35.2%) and farmers' own saved seeds (30.8%). A higher percentage of farmers in North Western (55.2%) and Northern (30.9%) regions used their own saved seeds while 44.0% of those in Eastern region sourced their seeds from local markets (Figure 3).

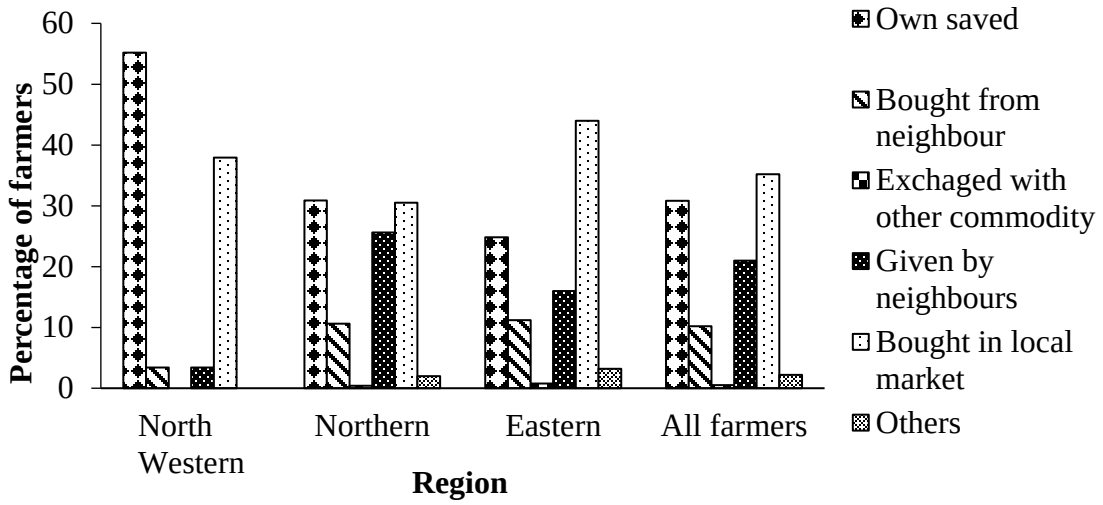


Figure 3: Farmers' seed sources of Bambara groundnut in North Western, Northern and Eastern Uganda

4.1.2 Bambara groundnut seed composition

Farmers used seed coat colours to differentiate landraces. Overall, 52.5% and 33.5% of farmers had single and mixed landraces respectively. More than half (65.5%) of the farmers

in North Western region had mixed landraces while 60.2% and 44.0% of those in Northern and Eastern regions respectively had single landraces (Figure 4).

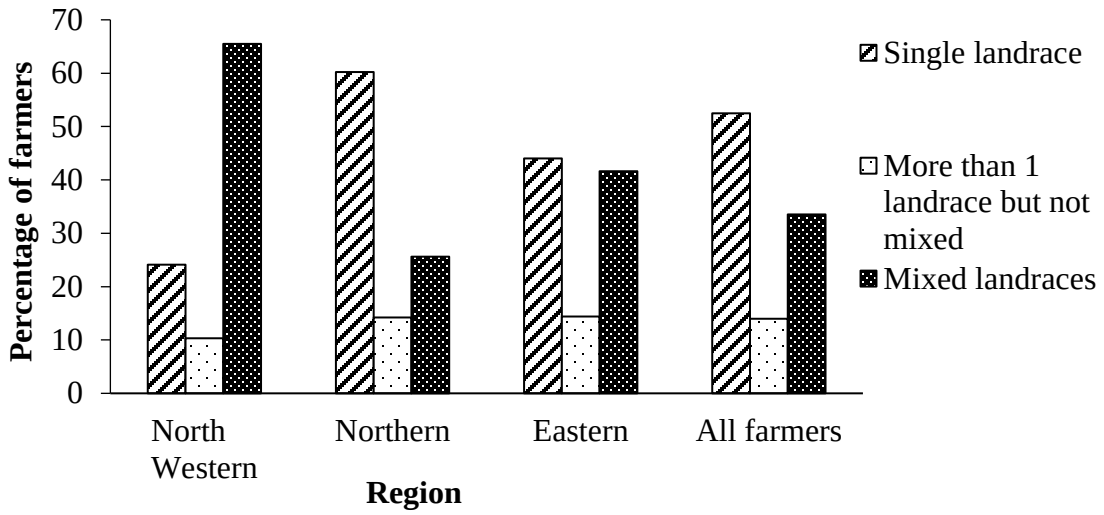


Figure 4: Seed composition of Bambara groundnut in North Western, Northern and Eastern Uganda

4.1.3 Period of Bambara groundnut seed recycling

Generally, farmers recycled the same seed for more than 4 years (39.2%), 2 years (22.8%) and 3 years (21.0%). This was similar across all the three regions, with seed recycling for more than 4 years and 2 years dominating except for North Western region where seed recycling for 3 years was higher than for 2 years (Table 3).

Table 3: Period of seed recycling among Bambara groundnut farmers in North Western, Northern and Eastern Uganda

	Percentage of farmers			
Period (years)	**North Western**	**Northern**	**Eastern**	**All farmers**
1	6.9	9.3	7.2	8.5
2	20.7	22.4	24.0	22.8
3	24.1	19.5	23.2	21.0
4	3.4	7.3	12.0	8.5
>4	44.8	41.5	33.6	39.2

4.1.4 Time of Bambara groundnut seed selection

Seed selection was common during drying (47.8%) and at planting (36.0%). Very few farmers selected seeds before the whole crop was harvested (1.8%). Nonetheless, 20.7% of farmers in North Western region selected seeds during crop harvest (Figure 5). Most farmers (84.3%) did not use any seed selection criterion. However, a few farmers used big sized pods, high yielding plants, and healthy-looking plants and pods as seed selection criteria (Figure 6).

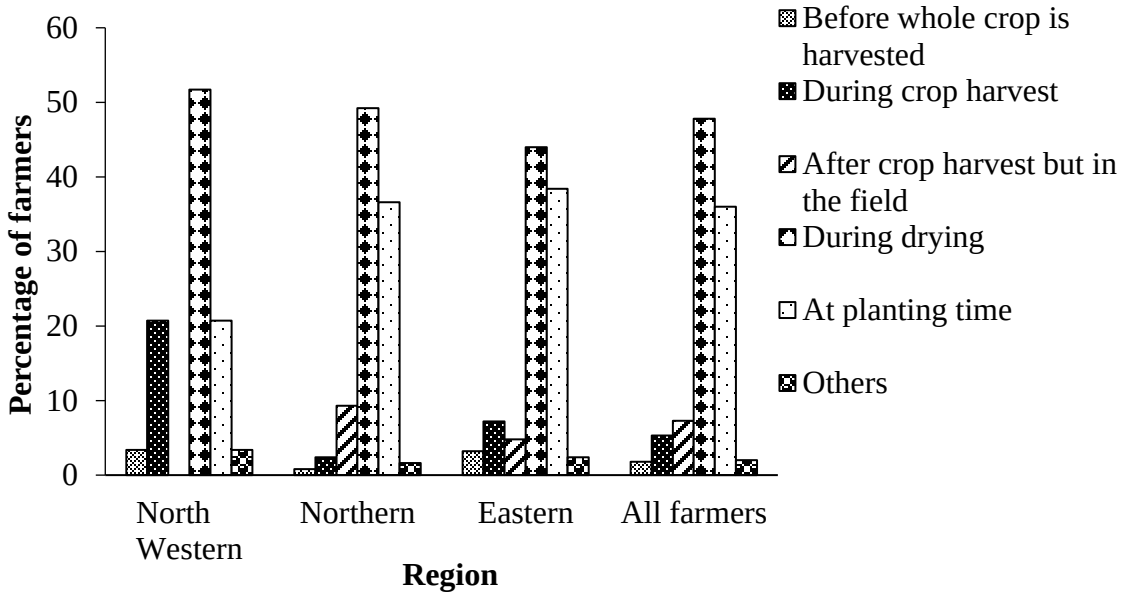


Figure 5: Time of seed selection by Bambara groundnut farmers in North Western, Northern and Eastern Uganda

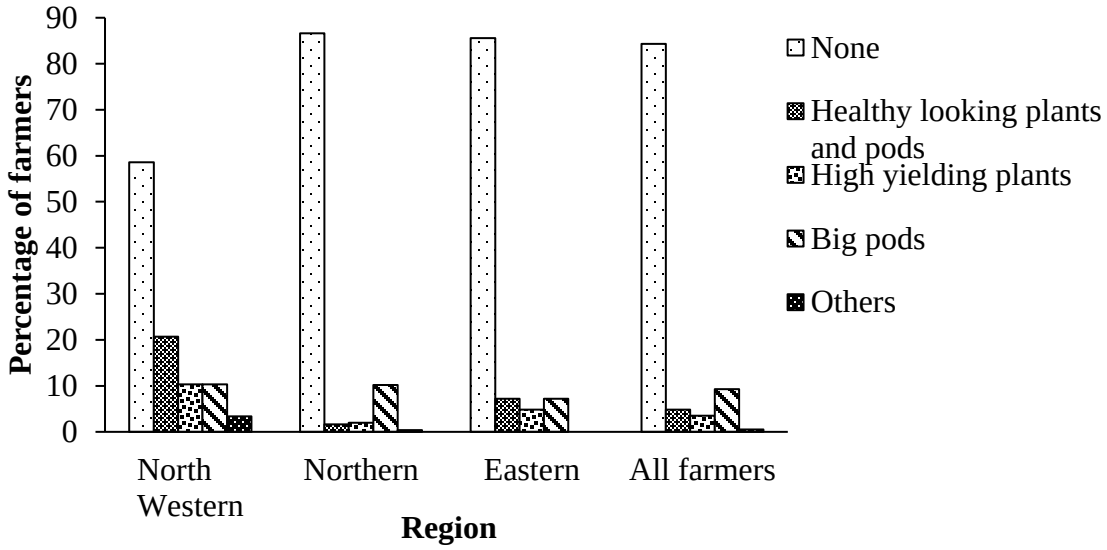


Figure 6: Bambara groundnut seed selection criteria in North Western, Northern and Eastern Uganda

4.1.5 Bambara groundnut seed drying methods

Generally, farmers dried Bambara groundnut directly on the ground (81%) or on tarpaulin (21.3%), a practice similar in all the three regions (Figure 7). Farmers in Eastern region mostly used sound of pods (pods are shaken during drying) (80.0%) and hardness of seed (a pod is broken and seed pressed between thumb and fingers (70.4%) to ascertain that Bambara groundnut was dry enough for storage. This was also similar to their counterparts in Northern region (Table 4).

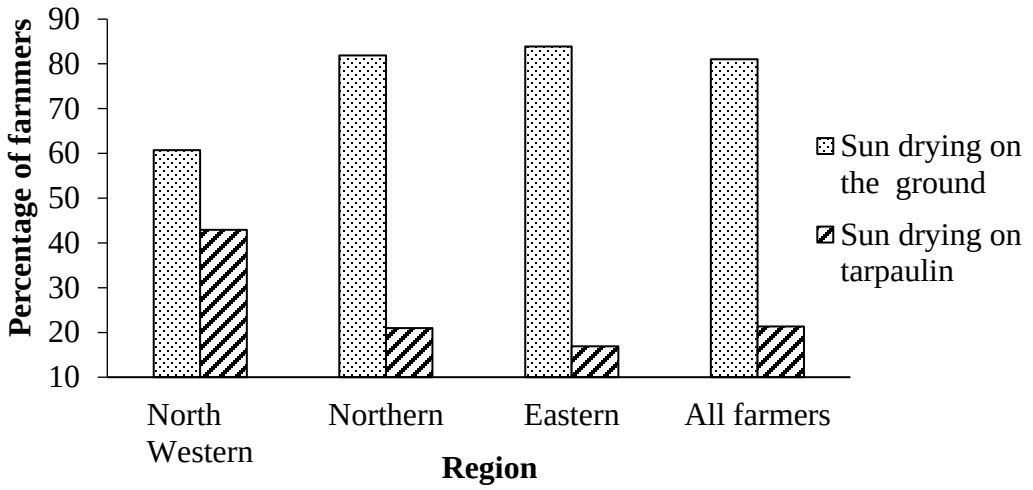


Figure 7: Drying methods of Bambara groundnut seeds in North Western, Northern and Eastern Uganda

Table 4: Indicators of Bambara groundnut seed drying and suitability for storage in Northern and Eastern Uganda

	Percentage of farmers		
Indicators of seed drying	**Northern**	**Eastern**	**All farmers**
Sound of pods	81.1	80.0	80.8
Hardness of seed	57.0	70.4	61.5
Duration of drying	2.0	0.0	1.4
Others	4.9	1.6	3.8

Note: This data was not captured for North Western region

4.1.6 Bambara groundnut seed storage methods

Farmers in all the three regions stored Bambara groundnut while in pods (in shells). The most preferred seed storage method was gunny bags on raised plat form (on stone, top of other produce or timber) (93.5%) and this was common for all the regions. Only a few farmers stored Bambara groundnut in pots and open containers (Figure 8).

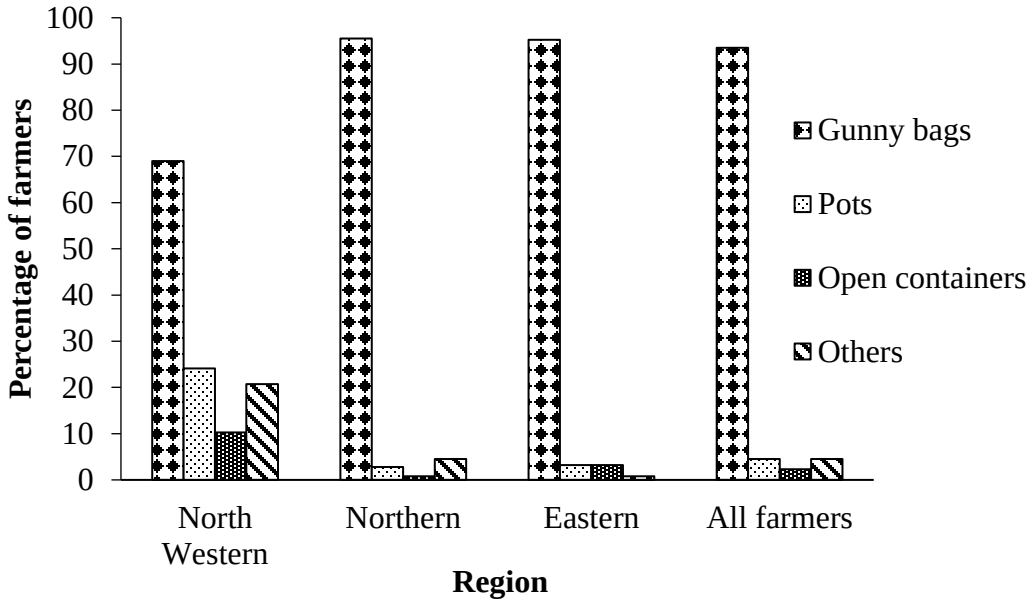


Figure 8: Storage methods of Bambara groundnut seed in North Western, Northern and Eastern Uganda

4.1.7 Bambara groundnut seed processing prior to planting

Farmers used several methods to process seeds before planting, but shelling by hand (52.0%) was the dominant method followed by shelling with mortar (31.2%). Whereas farmers in Northern (37.3%) and Eastern (26.4%) regions used shelling with mortar, none of their counterparts in North Western region used this method (Figure 9). Farmers also sorted their

seeds after shelling to remove all undesirable ones such as discoloured, mechanically damaged and immature seeds.

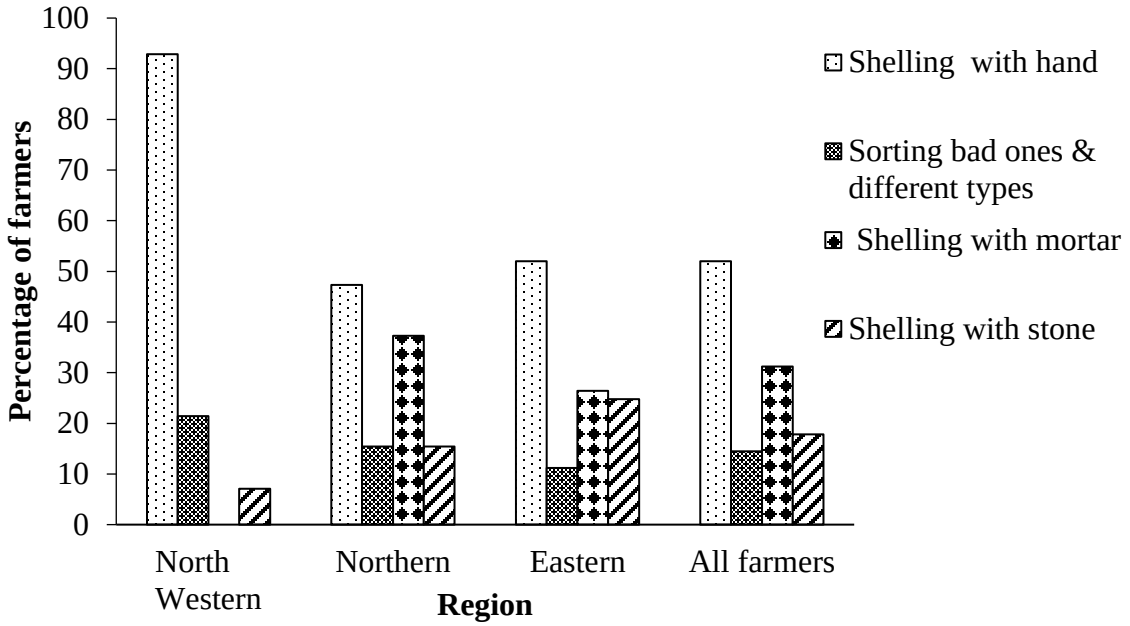


Figure 9: Seed processing methods of Bambara groundnut prior to planting in North Western, Northern and Eastern Uganda

4.1.8 Seed physical characteristics of collected Bambara groundnut landraces

Landraces had varied seed coat colours. Local Bam was brown spotted, TVSU 688 was plain cream, AbiBam 003 was black, AbiBam 001 was mottle, and TVSU 759 was a mixture (Table 5). There was a significant difference among landraces with respect to seed length and width ($p<.001$). The largest seeds were those of Local Bam (1.37 and 1.01cm, length and width respectively) while AbiBam 001 had the smallest seeds (0.89 and 0.74cm, length and width respectively) (Table 6).

Table 5: Seed colour description of collected Bambara groundnut landraces

Landrace	Colour description	Illustration
Local Bam	Brown spotted	
TVSU 688	Plain cream	
AbiBam 003	Black	
AbiBam 001	Mottle	
TVSU 759	Mixture	

Table 6: Comparison of collected Bambara groundnut landraces on the basis of seed size

Landrace	Seed length (cm)	Seed width (cm)
AbiBam 001	0.89±0.04a	0.74±0.04a
AbiBam 003	1.00±0.12bc	0.84±0.03b
Local Bam	1.37±0.13d	1.01±0.06c
TVSU 688	1.07±0.04c	0.83±0.03b
TVSU 759	0.94±0.06ab	0.81±0.06ab
CV (%)	7.1	6.0
LSD	0.113	0.076
F pr.	<.001	<.001

4.1.9 Electrical conductivity (EC)

Landraces showed a significant difference in relation to electrical conductivity (p = 0.008). Local Bam (0.52 MS g^{-1}) and TVSU 688 (0.06 MS g^{-1}) recorded the highest and lowest electrical conductivity respectively (Table 7).

4.1.10 Standard germination test

Landraces significantly differed in their germination capacity (p = 0.007) with TVSU 688 showing the highest germination capacity (96.0%) and AbiBam 001(66.67%) having the lowest germination capacity. Final germination percentage of 93.33%, 84.0% and 68.0% were recorded in AbiBam 003, TVSU 759 and Local Bam landraces respectively. (Figure 10). Similarly, significant differences were observed among landraces with respect to Germination Velocity Index (p = 0.040), being highest in AbiBam 003 (2.91) and lowest in AbiBam 001 (2.03) (Table 7). There was also a significant difference among landraces in relation to Seedling Vigour Index II (p = 0.003), with local Bam (485.3) and AbiBam 001 (213.3) having highest and lowest Seedling Vigour Index II respectively (Table 7).

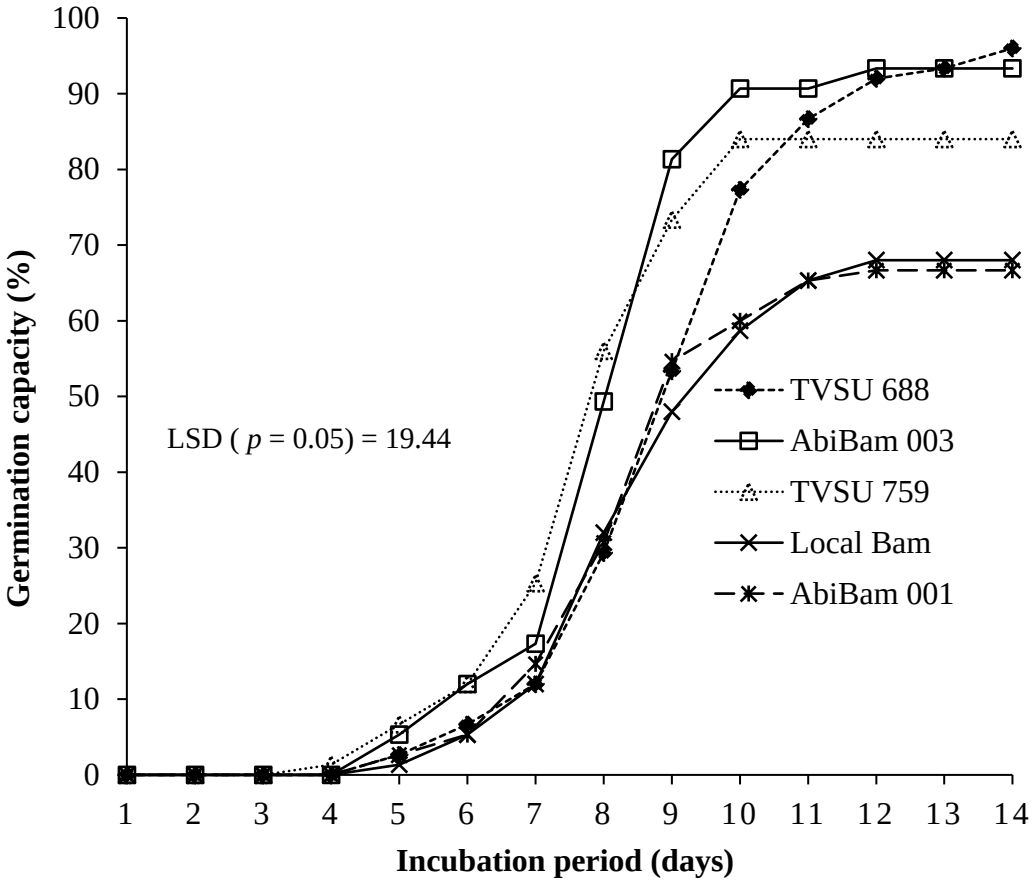


Figure 10: Daily cumulative germination capacity of collected Bambara groundnut landraces

Table 7: Germination Velocity Index (GVI), Electrical conductivity (EC) and Seedling Vigour Index II (SVI-II) of collected Bambara groundnut landraces

Landrace	GVI	EC	SVI-II
AbiBam 001	2.03±0.67a	0.24±0.04b	213.3±43.89a
AbiBam 003	2.91±0.16b	0.15±0.03ab	477.3± 64.45b
Local Bam	2.05±0.36a	0.52± 0.22c	485.3±130.86b
TVSU 688	2.70±0.16ab	0.06± 0.02a	448.5±38.47b
TVSU 759	2.76±0.24b	0.33±0.16bc	283.6a±49.65a
LSD	0.677	0.221	134.1
F pr.	0.040	0.008	0.003

4.1.11 Relationship between seed size and physiological seed quality

Seed size was negatively correlated with final germination percentage (r = -0.24 and -0.19, seed length and width respectively) and Germination Velocity Index (r = -0.36 and -0.23, seed length and width respectively) but positively correlated with Seedling Vigour Index II (r = 0.71 and 0.74, seed length and width respectively) (Table 8).

Table 8: Correlation coefficients of seed size (seed length and width) with final germination percentage (FGP), Germination velocity index (GVI) and Seedling vigour index II (SVI-II) of collected Bambara groundnut landraces

	Seed length	Seed width	FGP	SVI-II	GVI
Seed length	-				
Seed width	0.97*	-			
FGP	-0.24ns	-0.19ns	-		
SVI-II	0.71*	0.74*	0.43ns	-	
GVI	-0.36ns	-0.23ns	0.93*	0.29ns	-

* significant at 5%; ns not significant at 5%

4.2 Response of Bambara groundnut landraces to application of phosphorus fertilizer

4.2.1 Soil chemical properties of study site

The results of soil analysis showed high amount of organic carbon. The soil was slightly acidic with PH of 6.01. Available phosphorus was also high (Table 9).

Table 9: Soil chemical properties of the study site

Organic carbon (%)	Available phosphorus (%)	PH
2.2	1.36	6.01

4.2.2 Seed yield of Bambara groundnut landraces at different phosphorus rates

Landraces did not differ significantly with respect to seed yield (p = 0.332). Application of phosphorus did not also significantly affect seed yield of landraces (p = 0.780). The interaction of landraces and phosphorus rates was not significant (p = 0.323). AbiBam 001 showed an increasing trend in seed yield with increasing phosphorus rate, attaining highest seed yield (2.94t/ha) at 100 $KgPha^{-1}$. AbiBam 003 and TVSU 759 exhibited decreasing trends with increasing phosphorus rate, with exception at 50 and 100 $KgPha^{-1}$ where AbiBam 003 and TVSU 759 respectively showed an increase in seed yield. Accordingly, AbiBam 003 attained highest seed yield (2.41t/ha) at 50 $KgPha^{-1}$ while TVSU 759 attained highest seed yield (2.58t/ha) at 0 $KgPha^{-1}$ (Table 10).

Table 10: Seed yield of Bambara groundnut landraces at different phosphorus rates

Phosphorus rate ($KgPha^{-1}$)	**Landrace**		
	AbiBam 001	AbiBam 003	TVSU 759
0	2.01± 0.73	2.38±0.46	2.58±0.30
50	2.22±0.66	2.41±0.72	1.89±0.04
75	2.46±1.01	1.82±0.24	1.63±0.25
100	2.94±1.65	1.57±0.38	1.87±0.31
MEAN	2.41	2.04	1.99
CV (%)	33.9		
LSD (p≤0.05) Landrace	NS		
LSD (p≤0.05) P rate	NS		
LSD (p≤0.05) Landrace X P rate	NS		

4.2.3 Thousand seed weight (TSW) of Bambara groundnut landraces at different phosphorus rates

Landraces exhibited a significant difference in relation to TSW (p = 0.031). However, TSW of landraces was not affected by phosphorus fertilizer application (p = 0.696). Interaction of landraces and phosphorus rates was not significant (p = 0.772). AbiBam 001 demonstrated an increasing trend in TSW with increase in phosphorus rate, with a decline at 100 $KgPha^{-1}$, recording highest TSW (491.33g) at 75 $KgPha^{-1}$. AbiBam 003 had an initial increasing trend in TSW, followed by a decline and an increase at 75 and 100 $KgPha^{-1}$ respectively, registering highest TSW (511.43g) at 50 $KgPha^{-1}$. TVSU 759 depicted a decreasing trend in TSW, with an exceptional increase at 100 $KgPha^{-1}$, attaining highest TSW (462.23g) at 0 $KgPha^{-1}$ (Table 11).

Table 11: Thousand seed weight of Bambara groundnut landraces at different phosphorus rates

Phosphorus rate ($KgPha^{-1}$)	**Landrace**		
	AbiBam 001	**AbiBam 003**	**TVSU 759**
0	464.63±54.43	500.93±47.23	462.23±10.70
50	470.0±32.90	511.43±84.11	450.93±54.71
75	491.33±40.57	466.67±25.46	403.50±27.17
100	471.0±68.34	489.73±14.17	436.60±19.86
MEAN	474.24	492.19	438.32
LSD(p≤0.05) Landrace	39.802		
LSD(p≤0.05) P rate	NS		
LSD(p≤0.05) Landrace X P rate	NS		
CV (%)	10.0		

4.2.4 Seed phosphorus content of Bambara groundnut landraces at different phosphorus rates

Landraces did not show any significant difference in their seed phosphorus content (p = 0.702). Similarly, application of phosphorus did not significantly affect seed phosphorus content of landraces (p = 0.831). The interaction of landraces and phosphorus rates was not significant (p = 0.888). AbiBam 001 displayed a constant trend in seed phosphorus content, accompanied by a slight increase at 100 $KgPha^{-1}$, registering a maximum seed phosphorus content (0.28%) at 100 $KgPha^{-1}$. AbiBam 003 landrace demonstrated an increasing trend in seed phosphorus content while TVSU 759 landrace had a decreasing trend in its seed phosphorus content with increasing phosphorus rate. AbiBam 003 had highest (0.28%) seed phosphorus content at both 50 and 100 $KgPha^{-1}$, and lowest seed phosphorus content (0.27%) at 0 and 75 $KgPha^{-1}$ respectively. TVSU 759 landrace recorded highest seed phosphorus content (0.3%) at 50 $KgPha^{-1}$ and lowest seed phosphorus content (0.26%) at 100 $KgPha^{-1}$ (Figure 11).

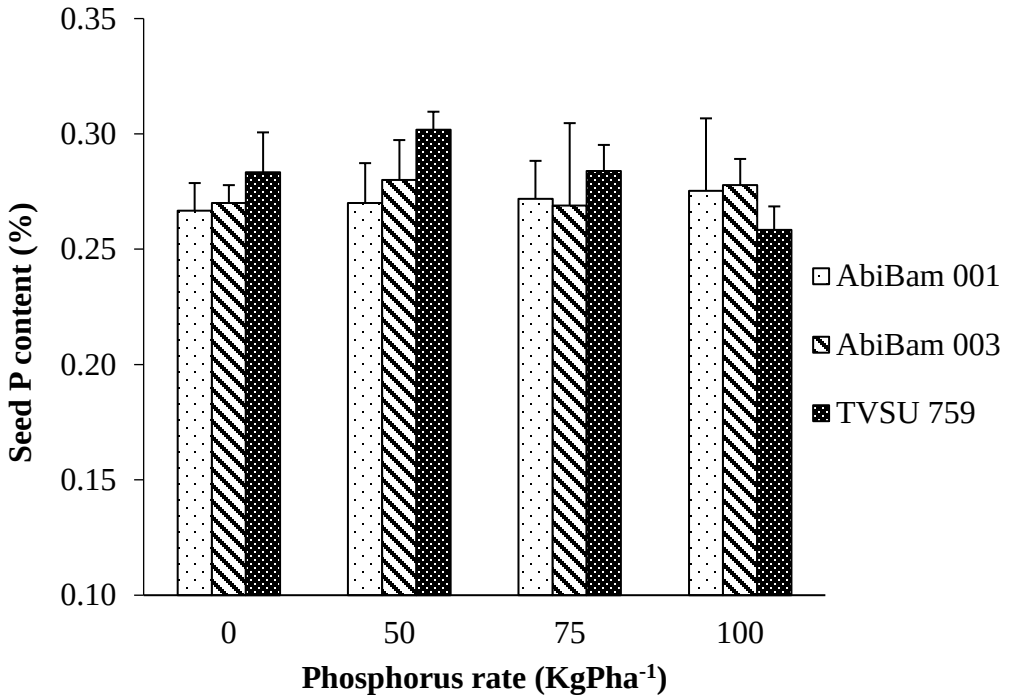


Figure 11: Seed phosphorus content of Bambara groundnut landraces at different phosphorus rates.

4.2.5 Germination capacity of Bambara groundnut landraces at different phosphorus fertilizer rates

Landraces significantly differed in their germination capacity (p<.001). Germination capacity of landraces was also significantly affected by application of phosphorus fertilizer (p = 0.001). The interaction of landraces and phosphorus rates was also significant (p<.001). For AbiBam 001 landrace, germination capacity increased with the increase in phosphorus rate, attaining maximum (61.33%) at 100 KgPha^{-1}. AbiBam 003 landrace exhibited a decreasing trend in germination capacity with increase in phosphorus rate, registering highest germination capacity (90.67%) at 0 KgPha^{-1} and lowest germination capacity (38.67%) at 100 KgPha^{-1}. TVSU 759 landrace had a similar trend in its germination capacity, with only

a slight increase at 50 KgPha^{-1}, recording highest germination capacity (86.67%) at 50 KgPha^{-1} (Figure 12).

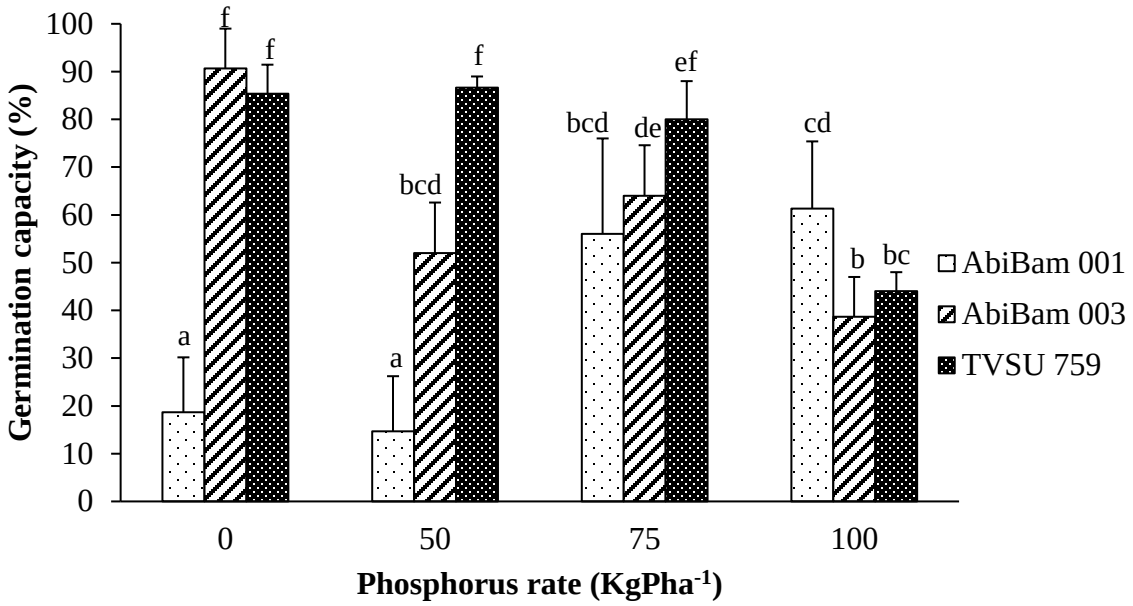


Figure 12: Germination capacity of Bambara groundnut landraces at different phosphorus rates. The bars are standard deviations

4.2.6 Seed vigour of Bambara groundnut landraces at different phosphorus fertilizer rates

Seed vigour was measured using germination velocity index (GVI) and seedling vigour index II (SVI-II). Landraces exhibited a significant difference in their GVI (p<.001), and application of phosphorus significantly affected GVI of landraces (p<.001). The interaction of landraces and phosphorus rates was also significant (p<.001). AbiBam 001 landrace showed an increasing trend in GVI, although with a decrease at 50 KgPha^{-1}, recording highest GVI (2.03) at 100 KgPha^{-1}. Both AbiBam 003 and TVSU 759 landraces demonstrated decreasing trends in GVI with increasing phosphorus rate, with exception at 75 KgPha^{-1}

where both had an increase in GVI. Accordingly, AbiBam 003 attained highest GVI (2.65) at 0 KgPha^{-1} while TVSU 759 registered highest GVI (2.89) at 75 KgPha^{-1} (Figure 13).

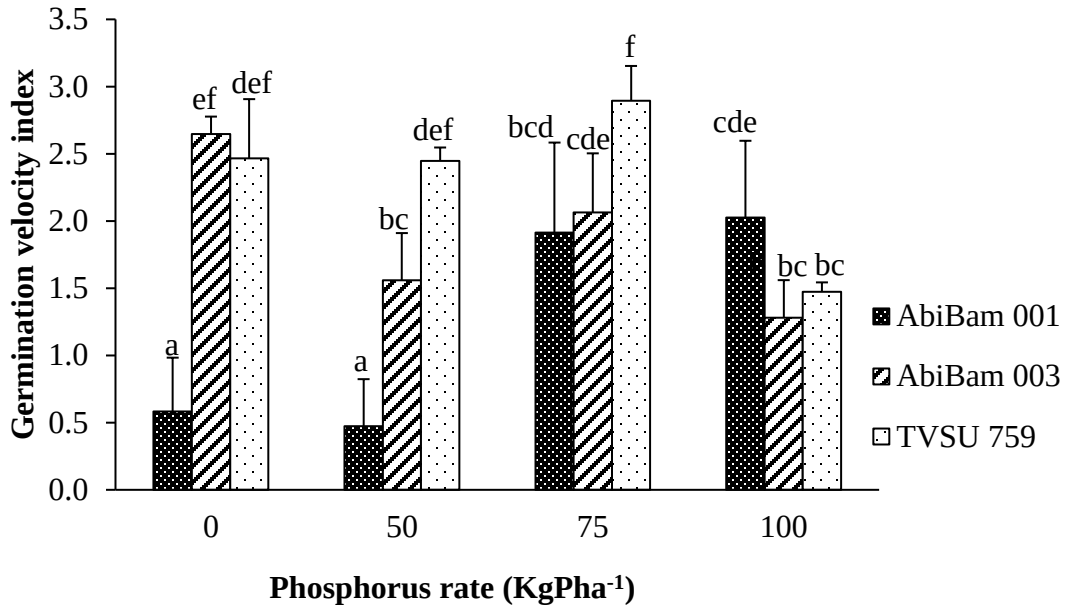


Figure 13: Germination velocity index of Bambara groundnut landraces at different phosphorus rates. The bars are standard deviations

There was a significant difference among landraces with respect to seedling vigour index II (SVI-II) (p<.001). Similarly, application of phosphorus was also shown to significantly affect SVI-II of landraces (p<.001). The interaction of landraces and phosphorus rates was significant (p<.001). Seedling vigour index II of AbiBam 001 landrace followed the same trend as its GVI, being highest at 100 KgPha^{-1} (206.83) and lowest at 50 Kgpha^{-1} (37.55). AbiBam 003 landrace also had a similar trend in its SVI-II as GVI, attaining highest SVI-II (383.11) at 0 KgPha^{-1}. TVSU 759 exhibited a general decreasing trend in its SVI-II albeit with an increase at 50 KgPha^{-1}, recording highest SVI-II (362.51) at 50 KgPha^{-1} (Figure 14).

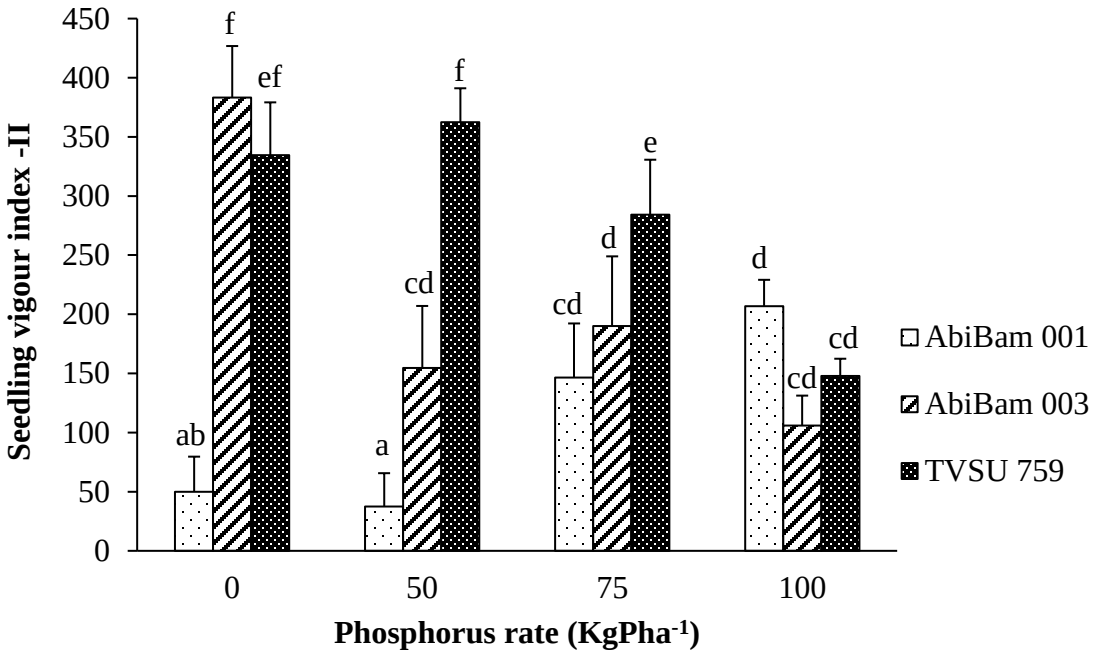


Figure 14: Seedling vigour index II of Bambara groundnut landraces at different phosphorus rates. The bars are standard deviations

Table 12: Summary of seed yield and seed quality responses of Bambara groundnut landraces to application of different phosphorus fertilizer rates

Landrace	**Seed yield**	**1000 seed weight**	**Seed P content**	**FGP**	**GVI**	**SVI-II**
AbiBam 001	Increasing trend with increasing P rate	Increasing trend with increasing P rate	Constant trend with increasing P rate	Increasing trend with increasing P rate	Increasing trend with increasing P rate	Increasing trend with increasing P rate
AbiBam 003	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Increasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate
TVSU 759	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate	Decreasing trend with increasing P rate
Comment	Not significant at $p \leq 0.05$ for both P rate and landrace	Not significant for P rate but significant for landrace at $p \leq 0.05$	Not significant at $p \leq 0.05$ for both landrace and P rate	significant at $p \leq 0.05$ for both landrace and P rate	significant at $p \leq 0.05$ for both landrace and P rate	significant at $p \leq 0.05$ for both landrace and P rate

4.3 Effect of hydropriming and halopriming with potassium nitrate solution on seed germination of Bambara groundnut

4.3.1 Germination capacity and seed vigour of AbiBam 001 Bambara groundnut landrace at different hydropriming durations

Treatments did not show any significant difference in relation to germination capacity ($p = 0.279$). Interestingly, control had the highest germination capacity (90.67%) while seeds primed for 18 hours (80.0%) and 24 hours (80.0%) had the lowest germination capacity at the end of 14 days incubation period. However, germination commenced on the 3rd day for seeds hydroprimed for 18 and 24 hours and on the 4th day for those hydroprimed for 6 and 12 hours, while there was a delay in germination of control treatment up to the 5th incubation day. Control treatment attained maximum germination capacity (90.67%) on the 7th incubation day while 6, 12,18, and 24 hours hydropriming periods attained maximum germination capacity on the 9th (82.67%), 10th (82.67%), 13th (80.0%) and 11th (80.0%) incubation days respectively (Figure 15).

Similarly, there was no significant difference among treatments with respect to germination velocity index ($p = 0.881$) and seedling vigour index II ($p = 0.813$). The highest (4.063) and lowest (3.795) germination velocity index were attained with 12, and 24 hours hydropriming periods respectively (Table 12). On the other hand, seedling vigour index II was highest in 6 hours hydropriming period (358.93) and lowest in 18 hours hydropriming period (320.93) (Table 13).

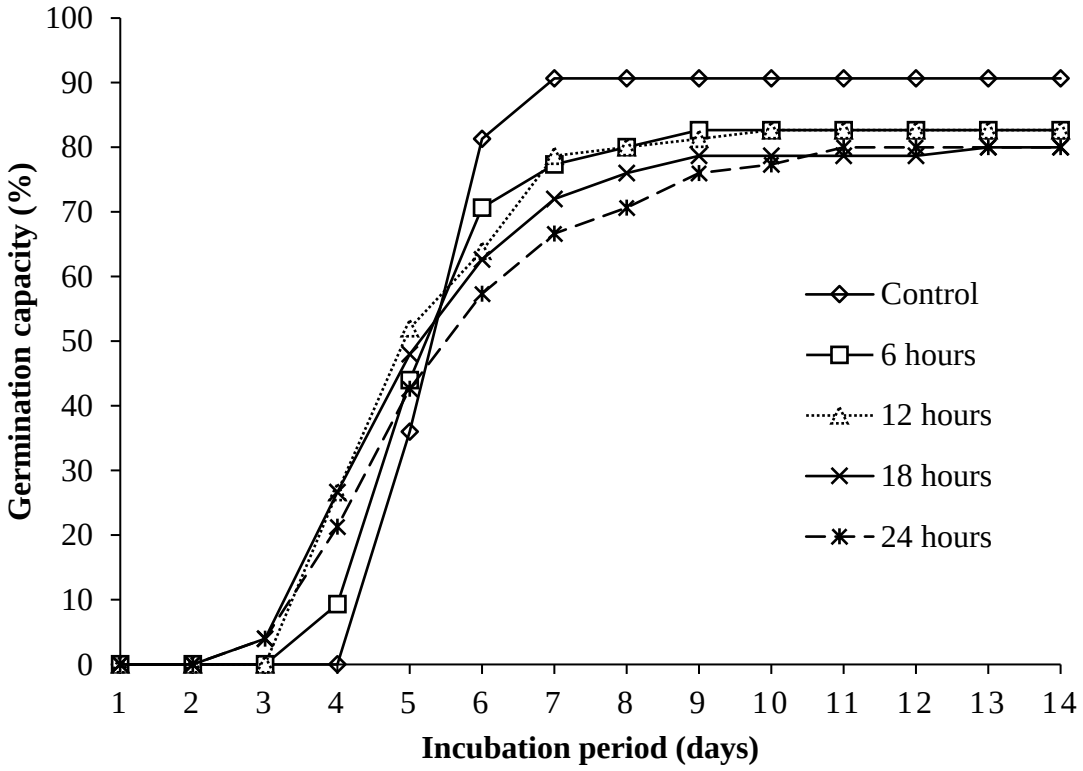


Figure 15: Daily cumulative germination capacity of AbiBam 001 Bambara groundnut landrace at different hydropriming durations

Table 13: Germination velocity index (GVI) and seedling vigour index II (SVI-II) of AbiBam 001 Bambara groundnut landrace at different hydropriming durations

Treatment	GVI	SVI-II
Control	4.022±0.58	328.67±40.02
6 hours	3.829±0.32	358.93±65.83
12 hours	4.063±0.44	351.07±26.23
18 hours	3.986±0.22	320.93±44.23
24 hours	3.795±0.27	333.87±33.57
CV (%)	9.9	13.0
LSD	NS	NS
F pr	0.881	0.813

4.3.2 Germination capacity and seed vigour of AbiBam 001 Bambara groundnut landrace at different potassium nitrate concentrations

There was no significant difference among treatments with respect to germination capacity (p = 0.640). The highest (92.0%) and lowest (82.67%) germination capacity were attained with 3% and 0.5% potassium nitrate concentrations respectively. Germination commenced in all potassium nitrate concentrations on the 4th incubation day and on the 5th incubation day in control. Control treatment attained a maximum germination capacity (90.67%) on the 7th incubation day, 0.5 and 1% potassium nitrate concentrations on the 8th day (82.67% and 84.0% respectively) whereas 2 and 3% potassium nitrate concentrations attained maximum germination capacity on the 9th (86.67%) and 10th (92.0%) incubation days respectively (Figure 16).

Similarly, treatments did not differ in relation to SVI-II (p = 0.346) and GVI (p = 0.988). Control treatment had the highest SVI-II (328.7) while the same parameter was lowest in 3% potassium nitrate concentration (260.1) (Table 13). The lowest (3.86) and highest (4.05) GVI were recorded with 0.5 and 3% potassium nitrate concentrations respectively (Table 14).

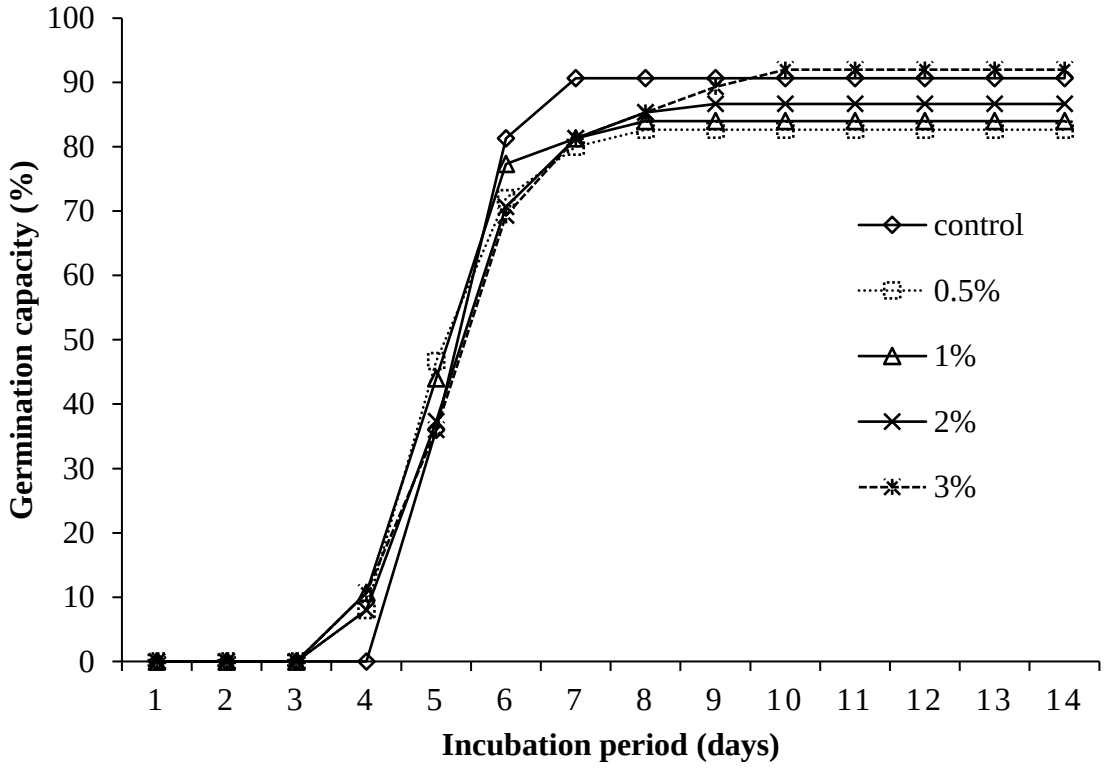


Figure 16: Daily cumulative germination capacity of AbiBam 001 Bambara groundnut landrace at different potassium nitrate concentrations

Table 14: Germination velocity index (GVI) and seedling vigour index II (SVI-II) of AbiBam 001 Bambara groundnut landrace at different potassium nitrate concentrations

Treatment	GVI	SVI-II
Control	4.02±0.58	328.7±40.02
0.5 %	3.8±0.80	280.5±43.45
1 %	3.95±0.52	271.9±37.56
2 %	3.90±0.33	290.4±55.33
3 %	4.05±0.06	260.1±12.27
CV (%)	13.2	14.1
LSD	NS	NS
F pr	0.988	0.346

CHAPTER FIVE

DISCUSSION

5.1 Seed management practices and quality of farm-saved seeds of Bambara groundnut in Uganda

5.1.1 Farmers' seed sources of Bambara groundnut

The major seed sources were farmer's own saved seed and the local market. This is in agreement with Ibrahim et al (2018) who reported the use of farmer's own recycled seed and purchase from local markets as major seed sources for Bambara groundnut in Niger. Nevertheless, this study indicated that seed was basically exchanged among farmers, highlighting a typical characteristic of an informal seed system particularly of a neglected crop like Bambara groundnut. Seed exchange among farmers is attributed to uncertainty about seed preservation (Louwaars, 2007). However, seeds obtained from an informal system may have lower quality compared to those from the formal system, possibly due to the quality control used in the formal system (Biemond, 2013). Seed materials of an informal seed system are often associated with community identity (Perales et al., 2005), thus communities usually have a preference for a particular landrace based on its distinctive characteristics and as a result, landrace types tend to be specific to locations.

5.1.2 Seed composition of Bambara groundnut

The seed composition of farmers' seeds was mostly single or mixed landraces although some reported having "more than one but not mixed" landraces. A similar seed composition among Bambara groundnut farmers in North Eastern Nigeria was reported by Aviara et al (2013). Furthermore, heterogenous mixtures of Bambara groundnut seed has been shown to be

common among farmers in Sub-Saharan Africa (Mohammed et al., 2016). Non improved crops such as Bambara groundnut tend to be mixed yet farmers are not very keen to sort them according to different categories. This implies that even the category "more than one but not mixed" landraces can actually be a mixed type upon threshing and observing the seeds. A mixed landrace may not entirely entail poor seed quality but performance wise, different landraces in the mixture may have different maturity periods, yields and response to environmental factors. A case in point is Bambara groundnut landraces varied reaction to Fusaruim wilt infection (Wakhungu, 2016) and water stress (Chibarabada, 2014). Such diversity could have a negative implication on subsequent yield and seed quality. In addition, sowing of mixed seeds of a crop species ensues in nonuniform field stand establishment, causing heterogeneity in the vigour of plants (Mishra et al., 2010).

5.1.3 Period of Bambara groundnut seed recycling

Farmers frequently recycled seed for more than four years (4 times). This corroborates with Aviara et al (2013) who reported that local communities in North Eastern Nigeria selected and maintained Bambara groundnut landraces for long periods. Increased periods of seed recycling leads to poor seed quality and low yields particularly in hybrids, with minimal effects on open pollinated varieties (Amaza et al., 2010; Warburton et al., 2010; Clayton et al., 2009). However, seed recycling is likely to have a minimal effect on the seed quality of Bambara groundnut which is autogamous (Gonné et al., 2013). It is therefore possible that farmers seed handling practices during recycle periods is a major determinant of seed quality (Gebeyehu et al., 2019). Seed recycling period is also refered to as technical replacement rate (TRR), and varies among crop species. However, there is no recommended TRR for a neglected and underutilized crop such as Bambara groundnut.

5.1.4 Bambara groundnut seed selection time

Seed was largely selected at drying and at planting. Farmers attributed this to ease of selection at those times. However, farmers who select seeds at planting run risk of losing seed as it may be sold or consumed at the household. On the other hand, seed selection at drying ensures that seeds are stored separately and, in most cases, handled differently from the grains, for example re-drying to prevent mould growth. Supply of seeds for crops such as Bambara groundnut are entirely informal, hence seed selection is done either from farmer's own production or other sources (Louwaars, 2007).

5.1.5 Bambara groundnut seed drying methods

Bambara groundnut seeds were typically sun dried on the ground. This was the common practice probably because it is a cheap and convenient method. Farmers normally harvest Bambara groundnut when the pods are already detached from the plant, hence alternative drying methods such as hanging or bunching as with groundnuts is not possible. In addition, access to tarpaulins or construction of a raised drying platform is usually a challenge for most farmers. Sun drying of Bambara groundnut is commonly done by farmers in Dosso region of Western Niger (Ibrahim et al., 2018). Sun drying of seeds directly on the ground for both grain legumes and cereals is practiced by most farmers in Eastern Kenya (Njoroge et al., 2019). This practice is likely to cause infestation by aflatoxin causing fungi *Aspergillus flavus* which would have a negative health impact if seeds are consumed as food (Adithya et al., 2016). However, farmers in this study reported drying Bambara groundnut seeds when in pods, thus it would also be necessary to establish the level of fungal infestation on both the seeds and pods under different drying methods.

5.1.6 Bambara groundnut seed storage methods

Seed was mostly stored in gunny bags and placed on raised platforms (on stone, top of other produce or timber). The non hermetic bags are the most common storage materials used by farmers because they are readily available, affordable and adequately aerated, providing short to medium term storage (Sultana et al., 2016; Jebuni, 2014). Placing the bags on raised platforms keeps seeds free from dampness that could cause mould growth and seed deterioration. Storage of Bambara groundnut in pots and local granaries made of grass materials has been reported, but their use results in high insect pest infestation for seeds in shelled condition (Aviara et al., 2013). Bambara groundnut pods are very hard when dry and insect infestation and damage on seeds stored in pods is likely to be minimal. Farmers of crops such as maize store their seeds in gunny bags and plastic containers especially in Western Kenya (Wambugu et al., 2009). This is also similar to the practices of Bambara groundnut farmers documented in this current study.

5.1.7 Bambara groundnut seed threshing methods

Threshing of pods to obtain seeds prior to planting was mostly done using the hands, pounded in a mortar with a pestle, or cracked with a stone. Information on seed processing indicates that seed shelling by mortar and pestle, stones and treading with feet are commonly practiced among Bambara groundnut farmers in Niger and Nigeria (Ibrahim et al., 2018; Aviara et al., 2013). Other methods include pouring pods into jute or hessian bags and beating with sticks on flat surfaces, and beating jute or hessian bag containing the pods against the wall of a building (Aviara et al., 2013). However, these methods used by farmers involve the application of force to the seeds, which is likely to cause more mechanical damage to the seeds as compared to shelling with hand, although some level of care is taken when

exercising these methods. Mechanical damage on seed tissues has implication on seed quality. Comparison of manual and mechanical threshing of maize at 12% moisture content revealed that mechanical damage on seeds was higher for mechanical threshing, resulting in lower germination capacity and seed vigour as compared with manual threshing (Ri-liang et al., 2019). Determining the extent of mechanical damage of different seed threshing methods on seeds and correlating with physiological seed quality would help in advising Bambara groundnut farmers on appropriate seed threshing methods.

5.1.8 Seed colour and size of collected Bambara groundnut landraces

Landraces showed variability not only in their seed coat colours but also in their sizes, with Local Bam and AbiBam 001 having the largest and smallest seeds respectively. This variability could be explained by production of heterogenous seeds by plants for their survival (Imbert, 2002). Heterogeneity in seeds usually happens due to physiological, environmental and genetic factors (Bhatt et al., 2016) and is exhibited in features such as colour, size and shape (Matilla et al., 2005). Seed heterogeneity is also known to affect seed germination (Smith et al., 2004; Bhatt et al., 2016). Bambara groundnut landraces differing in their seed coat colours have been reported to have varying seed coat thickness, water imbibition and germination capacity (Mandizvo & Odindo, 2019; Chibarabada et al., 2014). Seed colour also affects light and temperature requirement of seeds during germination (Bhatt et al., 2016). In this present study, light coloured landrace, that is TVSU 688 (plain cream) had the highest germination percentage (96%) which is in agreement with the observation by Mandizvo & Odindo (2019) which showed that light coloured Bambara groundnut landrace had the highest germination percentage among landraces of varying seed

coat colours. AbiBam 001 landrace with mottle seed coat recorded the lowest germination percentage among the five landraces evaluated in this current study.

On the other hand, seed size is an important indicator of physiological quality as it affects seed germination and seedling growth particularly under stress conditions (Steiner et al., 2019). Seed size is also known to affect field emergence, plant growth and performance in the field (Adebisi et al., 2013). Generally, larger seeds have higher vigour than smaller seeds of the same maturity stage due to more accumulated reserves in larger seeds (Ambika et al., 2014). The first germination count test of small peanut seeds was higher than that of large seeds of the same crop in both nonstressful and water stressful conditions, indicating a delay in the germination process of large seeds (Steiner et al., 2019). Similarly, the germination speed index of large sized wheat seeds was reportedly lower than that of medium and small sized seeds (Shahi et al., 2015). The high germination rate in small sized seeds is attributed to their larger surface area to volume ratio for water absorption in comparison to large sized seeds (Sadeghi et al., 2011). However, the effect of seed size on seed germination and crop establishment varies between crop species and growth environments (Shahi et al., 2015; Rastegar & Kandi, 2011; Gholami et al., 2009). This present study showed that Local Bam landrace which had the largest seed size, recorded the highest seedling vigour index II among the landraces evaluated whereas AbiBam 001 with the smallest seed size, recorded the lowest seedling vigour index II (Table 6 &7).

5.1. 9 Germination capacity of collected Bambara groundnut landraces

Germination capacity varied among landraces with the highest percentage in TVSU 688 (96.0%) and the lowest in AbiBam 001 (66.67%). Seed harvesting stage is known to affect

germination capacity of seeds as the stage at which the crops are harvested directly relates to the physiological state (development and maturation) of seeds (Tetteh et al., 2018). Evaluation of 3 soybean varieties revealed that germination capacity of 85.25%, 77.25% and 67.33% in Nangbaar, 85.25%, 68.0% and 60.92% in Anidaso, 66.75%, 64.67% and 58.83% in Jeguma varieties were attained when seeds were harvested at physiological maturity, one week after physiological maturity and two weeks after physiological maturity respectively (Isaac et al., 2016). Another study also revealed that germination capacity increased for seeds extracted from fruits that were harvested at initially ripe, half ripe to fully ripe in tomato variety GH 9305 (Tetteh et al., 2018). It is therefore likely that seeds harvested at different times will have different germination capacities exhibited in this study. However, it was not possible to pinpoint the exact maturity stages of seeds used in this study since the seed samples were collected from different farmers. Seed handling practices such as drying (how long and to what moisture content) and storage (storage materials, duration and storage conditions) could also account for such differences observed in germination capacity of landraces.

The germination pattern observed in this study could also be explained by the seed coat colours of landraces. This study revealed that the light coloured (plain cream) landrace (TVSU 688) had the highest germination percentage, which is in agreement with Mandizvo and Odindo (2019) who reported higher germination percentages in light coloured Bambara groundnut landraces.

5.1.10 Seed vigour of collected Bambara groundnut landraces

Local Bam recorded the highest electrical conductivity (0.52 MS g^{-1}) while TVSU 688 (0.06 MS g^{-1}) recorded the lowest among the landraces. Electrical conductivity test measures the concentration of leachates discharged into the solution, which is linked to the integrity of seed coat membrane (Binotti et al., 2008). Differences in electrical conductivity attained in these landraces could be due to differences in their seed coat structure particularly number and size of pores which are likely to influence electrolyte leakage from imbibed seeds. In addition, seed handling practices such as storage (storage period and conditions which influence seed ageing) and seed threshing methods (which may cause mechanical damage in seed coat) influence electrolyte leakage from the seeds (Vishwanath et al., 2019). Mechanical damage on the seed tissues has been reported to be positively correlated with electrical conductivity of seeds (Ri-liang et al., 2019).

Electrical conductivity of a seed lot has been further demonstrated to be influenced by seed age and initial seed moisture content (Ferreira et al., 2017). Still another study suggested that seed coat thickness determines leakages of electrolytes from the seed (Sinefu, 2011), though this was disputed by Chibarabada et al (2014) who found no relationship between electrical conductivity and seed coat thickness. The same study by Chibarabada et al (2014) reported that Bambara groundnut landrace with highest calcium content had lowest electrical conductivity and they attributed it to greater cell wall integrity due to high calcium content. However, the underlying seed coat structure (seed coat thickness, number and size of pores on the seed coat), seed mineralogy and the extent of mechanical damage on the seeds were not determined for the landraces in this study. Besides, it was not possible to trace a specific landrace and pinpoint its exact seed age (duration of storage) and storage conditions (relative

humidity and temperature) by the time of this analysis. Therefore, a more detailed study on seed coat structure, seed mineralogy and age of these landraces would give more light on the electrical conductivity exhibited.

AbiBam 003, a dark coloured (plain black) landrace had the highest germination velocity index among the landraces. This corroborates with Chibarabada et al (2014) who reported the highest germination velocity index in black speckled Bambara groundnut seeds. This is related to the rapid water imbibition in dark coloured seeds which is likely to cause a faster initiation of germination process (Mandizvo & Odindo, 2019). AbiBam 001, a mottle landrace had very low seed vigour. The seed coat of this landrace might have been impregnated with polyphenols particularly condensed tannins which lower water imbibition, resulting in slow germination and low seed vigour. From electrical conductivity, germination velocity index and final germination percentage, Local Bam landrace had lower vigour and germination capacity compared to other landraces. Interestingly however, the same landrace had the highest seedling vigour index II. This suggests that Local Bam seed lot could be less vigorous but the individual seeds that actually germinated had high vigour, which was demonstrated by seedling growth. Local Bam had the largest seeds (Table 6), which is an indication of large food reserves that cause rapid seedling growth upon hydrolysis and translocation to the growing regions. This study also revealed that seed size was positively correlated with seedling vigour index II (Table 8), depicting a higher vigour for those seedlings arising from large seeds. Seeds of different sizes have different levels of food reserves hence determining the initial growth of seedlings (Shahi et al., 2015). Large seeds of peanut produced seedlings with higher dry weight and seedling weight vigour (seedling vigour index II) than small seeds in both stress and non-stressed conditions (Steiner et al.,

2019). Similarly, large sized seeds of soybean were reported to produce plants with the highest shoot dry matter (Limede et al., 2018).

5.2 Response of Bambara groundnut landraces to application of phosphorus fertilizer

5.2.1 Seed yield of Bambara groundnut landraces at different phosphorus fertilizer rates

The effect of phosphorus fertilizer application on seed yield of landraces was not significant. This result is contrary to the studies that reported a significant effect of phosphorus fertilizer application on seed yield of Bambara groundnut (Temegne et al., 2019; Hasan et al., 2019). However, this present study is in agreement with Effa et al (2016) who reported that application of phosphorus fertilizer did not significantly affect seed yield of Bambara groundnut. Seed yield of AbiBam 001 landrace increased with increasing phosphorus rate whereas that of AbiBam 003 and TVSU 759 landraces was opposite to this trend. The result observed in AbiBam 001 landrace affirms with Temegne et al (2019) and Hasan et al (2019) who observed increasing seed yield in Bambara groundnut with increasing phosphorus application rate. However, the trend ascertained in AbiBam 003 and TVSU 759 disagrees with the same studies (Temegne et al., 2019; Hasan et al., 2019), but corroborates with Effa et al (2016) who observed decreasing seed yield in Bambara groundnut with increasing phosphorus application rate. Bambara groundnut landraces with varying seed coat colours, that is white seed coat, light red seed coat and white seed coat with grey eyes were evaluated by Temegne et al (2019) while Hasan et al (2019) used Malaysian landraces. This present study evaluated three landraces, that is AbiBam 001 (mottled), AbiBam 003 (Black) and TVSU 759 (mixture). The different seed types in TVSU 759 landrace could have varied

individual responses to added phosphorus resulting in a negative trend exhibited. The results of soil analysis showed that the soil was slightly acidic with PH of 6.01, and high available phosphorus (Table 9). This soil PH is within the recommended range, that is 5.0 to 6.5 for Bambara groundnut production (FAO, 2007), but the high available soil phosphorus could have caused little or no response by other landraces (AbiBam 003 and TVSU 759) to added phosphorus. However, AbiBam 001 landrace responded positively to application of phosphorus, hence there could be some uniqueness in its genotype and physiology.

The seed yield trends observed in these three Bambara groundnut landraces could probably be due to differences in their phosphorus use efficiency. Crop species exhibit both intra and inter species differences in phosphorus use efficiency (Marcante et al., 2016; Zhou et al., 2016). This is ascribed to differences in both genotypic and root morphological traits (Shanka et al., 2018; Mourice & Tryphone, 2012; Fageria et al., 2010), which influence phosphorus absorption from the soil (Lynch, 1995), and its translocation and use in seed formation (Shen et al., 2011). A study reported that phosphorus efficient common bean cultivars had higher seed yield at all phosphorus levels in comparison to inefficient cultivars (Shanka et al., 2018). However, phosphorus use efficiency was not determined for the landraces evaluated in this present study.

5.2.2 Thousand seed weight of Bambara groundnut landraces at different phosphorus fertilizer rates

Phosphorus fertilizer application did not significantly affect thousand seed weight of landraces. This is inconsistent with the recent studies that reported a significant increase in thousand seed weight of Bambara groundnut landraces (white seed coat, black seed coat and

light red seed coat) with application of different phosphorus fertilizer rates (Wamba et al., 2012). Thousand seed weight of landraces exhibited a similar trend with their seed yield (Table 12). This could be attributed to differences in phosphorus use efficiency of these landraces as mentioned earlier, and also due to genotypic and physiological factors (Deivasigamani & Swaminathan, 2018). Thousand seed weight helps in determining the average seed weight of a seed lot, which is a measure of seed quality, and is related to quantity of stored reserves (Afshari et al., 2011; Cao et al., 2011). Plants raised from heavier seeds are likely to have higher vigour than those raised from lighter seeds of the same maturity stage, possibly due to more stored reserves in heavier seeds (Erdal et al., 2017).

5.2.3 Seed phosphorus content of Bambara groundnut landraces at different phosphorus fertilizer rates

Application of phosphorus did not significantly affect seed phosphorus content of landraces. This result is dissonant to the observation of Temegne et al (2019) which shows that seed phosphorus content of Bambara groundnut significantly increased with application of various phosphorus fertilizer rates. Seed phosphorus content of AbiBam 001 landrace exhibited a constant trend followed by a slight increase, that of AbiBam 003 showed an increasing trend while TVSU 759 had a general decreasing trend in its seed phosphorus content with increasing phosphorus rate (Table 11). The observable pattern in seed phosphorus content of these landraces could be attributed to their phosphorus uptake efficiency from the soil, storage potential and partitioning (Coelho et al., 2002). Phosphorus uptake from the soil is normally attributed to root morphological characteristics and root mycorrhizal association (Farzaneh et al., 2011; Raghothama,1999). Phosphorus partitioning in the seed is influenced

by genotypic and environmental factors (Piergiovanni et al., 2017; Wang et al., 2016; Vandamme et al., 2015).

5.2.4 Germination capacity of Bambara groundnut landraces at different phosphorus rates

Phosphorus fertilizer rates significantly affected germination capacity of Bambara groundnut landraces. Germination capacity of AbiBam 001 landrace had an increasing trend with increase in phosphorus rate, while an opposite trend was observed with AbiBam 003 and TVSU 759 landraces (Table 12). The observation in AbiBam 001 landrace agrees with other studies that reported improved germination capacity in French bean, gaillardia and cotton seeds, with application of phosphorus fertilizer (Moon et al., 2018; Kakon et al., 2015; Sawan et al., 2011). Phosphorus application increases the chlorophyll concentration in plant leaves which improves the photosynthetic capacity of the plants (Sawan et al., 2011). This implies that more assimilates are made available to the plant, which upon translocation and accumulation in the seed during seed filling, would improve germination capacity (Paneru et al., 2017). However, another study revealed that seeds obtained from phosphorus fertilized soybean plants had lower germination capacity than those obtained from plants that did not receive phosphorus fertilizer (Krueger et al., 2013), which is a similar observation in AbiBam 003 landrace. The germination pattern of these landraces could be attributed to their genotypes and embryo maturity at harvesting. Bambara groundnut has an indeterminate growth habit, and flowering and podding continues until maturity of the plant as long as environmental conditions are favourable (Singh & Basu, 2005; Collinson et al., 1996). This flowering behaviour is also influenced by day length especially in photoperiod sensitive landraces (Berchie et al., 2013). This observable flowering pattern in Bambara groundnut

would also suggest that pods and seeds from the same plant can be at different maturity stages even when the plant shows signs of physiological maturity, hence affecting germination capacity.

5.2.5 Seed vigour of Bambara groundnut landraces at different phosphorus fertilizer rates

Application of phosphorus significantly affected seed vigour of Bambara groundnut landraces. The seed vigour of AbiBam 001 landrace showed an increasing trend with increase in phosphorus rate for both GVI and SVI-II. This finding agrees with some studies which have shown that application of phosphorus fertilizer improved seed vigour in both cotton and French bean (Kakon et al., 2015; Sawan et al., 2011). Phosphorus plays a role in metabolism of nucleic acids, proteins and other growth substances in the seed hence improving seed vigour (Welch & Shuman, 1995; Wiatrak et al., 2005). Seed proteins content also improves with application of phosphorus (Kakon et al., 2015). This implies that upon hydrolysis of these proteins, amino acids and other metabolic substances are channelled to the growing points of the seed during germination thus improving seed vigour. AbiBam 003 and TVSU 759 landraces demonstrated decreasing trends in their seed vigour with increase in phosphorus rate. This is consistent with a study which demonstrated that application of phosphorus fertilizer negatively affected seed vigour of soybean (Krueger et al., 2013). The negative trend showed by AbiBam 003 and TVSU 759 landraces could be attributed to their genotypes which influences phosphorus use efficiency, that is absorption and partitioning of phosphorus during seed filling, hence affecting their seed vigour.

5.3 Effect of hydropriming and halopriming with potassium nitrate solution on seed germination and vigour of Bambara groundnut

5.3.1 Germination capacity and seed vigour of AbiBam 001 Bambara groundnut landrace at different hydropriming durations

Hydropriming did not improve seed germination, as all the hydropriming durations recorded lower final germination percentage (FGP) than the control (Figure 15). This finding disagrees with the observation that hydropriming improves percentage emergence in Bambara groundnut (Ogbuehi et al., 2013; Berchie et al., 2010). However, Ochuodho (2005) observed that seed pre-hydration did not improve germination in *Cleome gynandra* seeds, while Mabhaudhi and Modi (2011) reported that hydropriming had a negative effect on final germination of maize seeds. Germination commenced earlier in all hydropriming durations than the control, this agrees with Berchie et al (2010) who reported that Bambara groundnut seeds hydroprimed for 24 and 48 hours emerged earlier than nonprimed seeds under field conditions.

Hydropriming has been shown to improve seed germination in crop species such as groundnut (Das & Mohanty, 2018), sesame (Tizazuet al., 2019), bitter gourd (Tania et al., 2019), *Aegle marmelos* (Singh, 2017), but some studies also reported that germination decreases with increased priming duration (Kumarimanimuthu & Kalaimathi, 2019; Ogbuehi et al., 2013; Dastanpoor et al., 2013). Very low percentage emergence (5.7%) and no emergence at all was observed with 48 hours and 72 hours hydropriming durations respectively in comparison with the control (35.7%) in groundnut seeds (Kumarimanimuthu & Kalaimathi, 2019). Similarly, a low percentage emergence (5.9%) with 36 hours

hydropriming duration and no field emergence at all with 48 hours hydropriming period was also observed in Bambara groundnut (Ogbuehi et al., 2013).

Bambara groundnut landrace (AbiBam 001) used in this study is dark coloured, and it has been reported that dark coloured Bambara groundnut landraces have rapid water imbibition (Mandizvo & Odindo, 2019). Therefore, rapid water imbibition during hydropriming might have caused imbibition injury to the seed cells, hence killing the cells and ensuing in unsuccessful germination of some seeds (Mabhaudhi & Modi, 2011; Finch-Savage et al., 2004). Hydropriming did not improve seed vigour, this disagrees with other studies that reported improved seed vigour in faba beans (Damalas et al., 2019), and Aegle *marmelos* seeds (Sigh, 2017). This observation could be explained by the fact that longer hydropriming periods caused excessive water imbibition by the seed, which might have resulted to membrane damage to seed cells and reduction of oxygen to the seed embryo hence lowering seed vigour (Ogbuehi et al., 2013).

5.3.2 Germination capacity and seed vigour of AbiBam 001 Bambara groundnut landrace at different potassium nitrate concentrations

Halopriming with potassium nitrate solution did not improve germination capacity in this study. This result is contrary to the observation that halopriming with potassium nitrate improves seed germination (Anisa et al., 2017; El-Baki et al., 2018; Essou et al., 2017). Halopriming with potassium nitrate solution has been reported to improve seed germination in other crops such as soybean (Ahmadvand et al., 2012), faba bean (El-Baki et al., 2018), rice (Anisa et al., 2017), sorghum (Shehzad et al., 2012), *Cleome gynandra* (Essou et al., 2017), *Gerbera jamesonii* and *Zinnia elegans* (Ahmad et al., 2017). All these studies primed

seeds with potassium nitrate for more than ten hours, hence the longer priming periods could have caused the difference with this present study which primed seeds with potassium nitrate solution for only two hours.

Potassium nitrate influences seed water imbibition, and time taken to reach phase I and II of imbibition increases with increasing concentration (Anisa et al., 2017). This could possibly explain why the control (non primed seeds) attained maximum germination capacity earlier than all potassium nitrate concentrations (Figure 16), and had higher germination velocity index than most of the potassium nitrate concentrations (Table 13). Although priming with potassium nitrate did not improve final germination of Bambara groundnut, germination showed an increasing trend with increase in the concentration of potassium nitrate from 0.5 to 3%. On the other hand, increasing the concentration of potassium nitrate resulted in a decrease in seedling vigour index II (Table 13). This is in agreement with Nego et al (2015) who had a similar observation when onion seeds were primed with different concentrations of potassium nitrate solution. This decrease could be attributed to the salinity effect of potassium nitrate that could have imposed a negative effect on seedling growth (Nego et al., 2015)

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. There exists among farmers in Uganda, a wide range of Bambara groundnut seed management practices some of which may be harnessed and jointly improved upon by the farmers and seed scientists so as to improve the seed production of this crop.
2. There is a wide diversity of Bambara groundnut landraces maintained by farmers in Uganda. Among the five landraces evaluated in this study, TVSU 688, TVSU 759 and AbiBam 003 showed relatively good seed quality in terms of germination capacity and seed vigour. Despite Local Bam landrace having a relatively low germination capacity and high electrical conductivity that would suggest low quality, it recorded the highest seedling vigour index apparently because of its relatively large seed size.
3. Application of varying phosphorus fertilizer rates did not significantly affect seed yield but significantly affected seed quality of Bambara groundnut landraces used in this study. Only AbiBam 001 landrace showed a positive response both in seed yield and seed quality with increase in phosphorus rates.
4. Seed hydropriming and halopriming with potassium nitrate solution did not improve germination capacity of AbiBam 001 landrace.

6.2 Recommendations

1. Bambara groundnut farmers should be trained on good seed handling techniques so as to further improve on the quality of their seeds since there is no formal seed system for this crop in Uganda.

2. Studies on biochemical and physiological properties of the seed coat of Bambara groundnut landraces used in this study would also help in explaining the observed seed quality.
3. A study on phosphorus use efficiency of Bambara groundnut landraces is recommended to be done at different agro ecological zones where this crop is grown.
4. Genetic and physiological attributes of AbiBam 001 landrace need to be investigated further to get better information for its unique behaviour (positive response) with application of phosphorus.
5. Hydropriming and halopriming with potassium nitrate should also be done with other Bambara groundnut landraces grown by farmers in Uganda so as to evaluate their responses. For halopriming with potassium nitrate solution, a longer priming duration should be investigated.

REFERENCES

Abdul-Baki, A. A., & Anderson, J. D. (1973). Vigor Determination in Soybean Seed by Multiple Criteria. *Crop Science*, 13(6), 630-633.

Abu, H.B., & Buah, S.S.J. (2011). Characterization of Bambara groundnut Landraces and Their Evaluation by Farmers in The Upper West Region of Ghana. *Journal of Developments in Sustainable Agriculture*, 6(1), 64-74.

Adebisi, M. A., Kehinde, T.O., Salau, A.W., Okesola, L.A., Porbeni, J.B.O., Esuruoso, A.O., & Oyekale, K.O. (2013). Influence of Different Seed Size Fractions on Seed Germination, Seedling Emergence and Seed Yield Characters in Tropical Soybean (*Glycine max* L. Merrill). *International Journal of Agricultural Research*, 8(1), 26-33.

Adebowale, K.O., & Lawal, O.S. (2002). Effect of Annealing and Heat Moisture Conditioning on the Physicochemical Characteristics of Bambara groundnut (*Voandzeia subterranean*) Starch and Flour. *Food Chemistry*, 78, 305-311.

Adithya, G., Rajeshwari, B., Keshavulu, K., & Sudini, H. (2016). Effect of *Aspergillus flavus* on Groundnut Seed Quality Under Different Periods of Incubation in Cultivar J11 and JL24. *Progressive Research*,11, 2194-2197.

Adu-Dapaah, H.K., & Sangwan, R.S. (2004). Improving Bambara groundnut Productivity Using Gamma Irradiation and *In vitro* Techniques. *African Journal of Biotechnology*, 3(5), 260-265.

Adu-Dapaah, H.K., Asibuo, J.Y., Danquah, A.O., Owusu-Akyaw, M., Haleegoah, J., & Amoatey, H. (2004). Bambara groundnut Improvement through Mutation Breeding in Ghana. Proceedings of the Final Research Coordination Workshop in Genetic Improvement of Underutilized and Neglected Crops in Low Income Food Deficit Countries through Irradiation and Related Techniques, May 19-23, Pretoria, South Africa. pp. 37-48.

Adzawla, W., Donkoh, S.A., Nyarko, G., O'Reilly, P., & Mayes, S. (2016). Use Patterns and Perceptions About the Attributes of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Northern Ghana. *Ghana Journal of Science, Technology and Development*, 4 (2), 56-71.

Afshari, H., Eftekhari, M., Faraji, M., Ebadi, A.G., & Ghanbarimalidareh, A. (2011). Studying the Effect of 1000 grain weight on the Sprouting of Different Species of *Salvia* L. Grown in Iran. *Journal of Medicinal Plants Research*, 5(16), 3991-3993.

Ahmad, G., & Lee, H. C. (2011). Response of Sesame (*Sesamum indicum*) Cultivars to Hydropriming of Seeds. *Australian Journal of Basic and Applied Science*, 1(12), 638-642.

Ahmad, I., Saleem, A.M., Mustafa, G., Ziaf, K., Afzal, I., & Qasim, M. (2017). Seed Halopriming Enhances Germination Performance and Seedling Vigor of G*erbera jamesonii* and *Zinnia elegans*. *Sarhad Journal of Agriculture*, 33(2), 199-205.

Ahmad, K.U., Rahman, M. M., & Ali, M. R. (2014). Effect of Hydropriming Method on Maize (*Zea mays*) Seedling Emergence. *Bangladesh Journal of Agriculture Research*, 39 (1), 143-150.

Ahmadvand, G., Soleimani, F., Saadatian, B., & Pouya, M. (2012). Effect of Seed Priming with Potassium Nitrate on Germination and Emergence Traits of Two Soybean Cultivars under Salinity Stress Conditions. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 12 (6), 769-774.

Akpalu, M. M., Sarkodie-Addo, J., & Akpalu, S. E. (2012). Effect of Spacing on Growth and Yield of Five Bambara groundnut (*Vigna subterranea* (L) Verdc.) Landraces. *Journal of Science and Technology*, 32 (2), 9-19.

Akpalu, M.M. (2010). Growth, Yield and Nutritional Quality of Five Bambara groundnut (*Vigna subterranean* (L.) Verdc.) Landraces to Different Plant Population Densities. MSc. Thesis. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Akpalu, M.M., Atubilla, I.A., & Oppong-Sekyere, D. (2013). Assessing the Level of Cultivation and Utilization of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in The Sumbrungu Community of Bolgatanga, Upper East Region, Ghana. *International Journal of Plant, Animal and Environmental Sciences*, 3(3), 68-75.

Alhamdan, A.M., Alsadon, A.A., Khalil, S.O., Wahb-Allah, M.A., Nagar, M.E., & Ibrahim, A.A. (2011). Influence of Storage Conditions on Seed Quality and Longevity of four Vegetable Crops. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 11, 353-359.

Alhassan, G. A., & Egbe, M. O. (2013). Participatory Rural Appraisal of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Production in Southern Guinea Savanna of Nigeria. *Journal of Agricultural Science*,1(2), 18-31.

Ali, S., & Hossein, R. R. (2017). Effect of Hydropriming on Morphological and Physiological Performance of Aged groundnut (*Arachis hypogaea* L.) Seeds. *Iranian Journal of Field Crop Science*, 48, 43-53.

Amaza, P., Udoh, E., Abdoulaye, T., & Kamara, A. (2010). Analysis of Technical Efficiency among Community-based Seed Producers in The Savannas of Borno State, Nigeria. *Journal of Food, Agriculture and Environment*, 8, 1073-1079.

Ambika, S., Manonmani, V., & Somasundaram, G. (2014). Review on Effect of Seed Size on Seedling Vigour and Seed Yield. *Research Journal of Seed Science*, 7(2), 31-38.

Aml, E. A. E., Farouk, S., & Abd, E. H. M. (2011). Evaluation of Different Seed Priming on Seedling Growth, Yield and Quality Components in Two Sunflower (*Helianthus annus L.*) Cultivars. *Trends in Applied Sciences Research*, 6(9), 977-991.

Anchirinah, V.M., Yiridoe, E.K., & Benneh-Lartey, S.O. (2001). Enhancing Sustainable Production and Genetic Resources Conservation of Bambara groundnut: A survey of Indigenous Agricultural Knowledge System. *Outlook on Agriculture*, 30(4), 281-288.

Anisa, R., Wanchai, C., Pitipong, T., & Damrongvudhi, O. (2017). Effect of Seed Priming with Different Concentrations of Potassium Nitrate on the Pattern of Seed Imbibition and Germination of Rice (*Oryza sativa* L.). *Journal of Integrative Agriculture*, 16(3), 605-613.

Anonymous. (2011). Production Guideline for Bambara Groundnuts. www.nda.agric.za/docs/Brochures/ProdguideBambara.pdf

Anonymous. (2016). Bambara groundnuts. Department of Agriculture, Forestry and Fisheries, Pretoria. pp. 20.

APG IV. (2016). Angiosperm Phylogeny Group. "An Update of The Angiosperm Phylogeny Group Classification for The Orders and Families of Flowering Plants: APG IV" (PDF). *Botanical Journal of the Linnean Society*, 181, 1-20.

Aremu, M.O., Olaofe, O., Akintayo, E.T., & Adeyeye, E.I. (2008). Foaming, Water Absorption and Gelation Properties of Kersting's groundnut (*Kerstingiella geocarpa*)

and Bambara groundnut (*Vigna subterranean*) Flours as Influenced by Neutral Salts and Their Concentration. *Pakistan Journal of Nutrition*, 7(1), 194-201.

Ashraf, M., & Foolad, M. R. (2005). Pre-sowing Seed Treatment A Shotgun Approach to Improve Germination, Plant Growth, and Crop Yield Under Saline and Non-saline Conditions. *Advances in Agronomy*, 88, 223-271.

Aviara, N.A., Lawal, A.A., Atiku, A.A., & Haque, M.A. (2013). Bambara groundnut Processing, Storage and Utilization in Northeastern Nigeria. *Continental Journal* of *Engineering Sciences*, 8(1), 28-36.

Azam-Ali, S.N., Aguilar-Manjarrez, J., & Bannayan-Avval, M. (2001). A Global Mapping System for Bambara groundnut Production of the Food and Agriculture Organization of the United Nations. FAO Agricultural Information Management Series No.1, ISBN 00-0-000000-0.

Bamnetwork. (2014). Bambara Groundnut. WWW.Bambaragroundnut.org

Bamshaiye, O.M., Adegbola, J.A., & Bamshaiye, E.I. (2011). Bambara groundnut: An Under-utilized Nut in Africa. *Advances in agricultural Biotechnology*, 1, 60-72.

Baoua, I.B., Amadou, L., Baributsa, D., & Murdock, L.L. (2014). Triple Bag Hermetic Technology for Postharvest Preservation of Bambara groundnut (Vigna subterranea (L.) Verdc.). *Journal of Stored Product Research*, 58,48-52.

Baudoin, J.P., & Mergeai, G. (2001). Grain Legumes. In: Raemaeker, R. (Ed.). Crop Production in Tropical Africa. Directorate General for International Cooperation, Brussels. pp. 313-317.

Berchie, J. N., Amelie, G., McClymont, S., Raizada, M., Adu-Dapaah, H., & Sarkodie-Addo, J. (2013). Performance of 13 Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Landraces Under 12h and 14h Photoperiod. *Journal of Agronomy*, 12 (1), 20-28.

Berchie, J.N, Dapaah, H.A., Agyemang, A., Sarkodie, A.J., Addo, J.K., Addy, S., & Blankson, E. (2016). Performance of Five Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Landraces in The Transition Agroecology of Ghana Under Different Sowing Dates. *Agricultural and Food Science Journal of Ghana*, 9(1), 718-729.

Berchie, J.N., Adu-Dapaah, H., Sarkodie-Addo, J., Asare, E., Agyemang, A., Addy, S., & Donkoh, J. (2010). Effect of Seed Priming on Seedling Emergence and Establishment

of Four Bambara Groundnut (Vigna *subterranea* (L.) Verdc.) Landraces. *Journal of Agronomy*, 9(4),180-183.

Berchie, J.N., Adu-Dapaah, H.K., Dankyi, A.A., Plahar, W.A., Nelson-Quartey, F., Haleegoah, J., Asafu-Agyei, J.N., & Addo, J.K. (2010). Practices and Constraints in Bambara Groundnut Production, Marketing and Consumption in the Brong Ahafo and Upper-East Regions of Ghana. *Journal of Agronomy*, 9(3), 111-118.

Bewley, J.D., & Black, M. (2012). Physiology and Biochemistry of Seeds in Relation to Germination. Vol 2: Viability, Dormancy and Environmental Control. Springer

Bhatt, A., Gairola, S., & El-Keblawy, A.A. (2016). Seed Colour Affects Light and Temperature Requirements during Germination in Two *Lotus* Species (Fabaceae) of the Arabian Subtropical Deserts. *International Journal of Tropical Biology*, 64 (2), 483-492.

Bernard, H. R. (2002). Research Methods in Anthropology: Qualitative and Quantitative Approaches (3rd ed.). Walnut Creek, CA: Alta Mira Press.

Biemond, P.C. (2013). Seed Quality in Informal Seed Systems. PhD Thesis. Wageningen University, The Netherlands.

Binang, W.B., Shiyam, J.Q., & Ntia, J.D. (2012). Effect of Seed Priming Method on Agronomic Performances and Cost Effectiveness of Rain Fed Dry-Seeded NERICA rice. *Research Journal of Seed Science*, 5(4), 136-143.

Binotti, F.F.S., Haga, K.I., Cardoso, E.D., Alves, C.Z., Sá, M.E., & Arf, O. (2008). Effect of the Accelerated Aging Period in the Electrical Conductivity Test and in the Physiological Quality of Bean Seeds. *Acta Scientiarum Agronomy*, 30(2), 247-254.

Biodiversity International. (2015). Nutritious Underutilized Species. www.bioversityinternational.org/uploads/tx_news/Nutritious_underutilized_species_Bambara groundnut 168301.pdf

Brink, M., & Belay, G. (2006). Plant Resources of Tropical Africa. Cereals and Pulses. PROTA Foundation Wageningen, Netherlands/ Backhuys Publishers, Leiden, Netherlands /CTA.

Camu, I. V. M. (2017). Understanding the Mechanism(s) of Hydro-Priming to Improve Seed Vigour and Seedling Establishment of *Solanum lycopersicum.* PhD Thesis. University of Exeter, UK.

Cao, H.W., Zhang, H., Chen, Z.B., Wu, Z.J., & Cui, Y.D. (2011). Chinese Traditional Medicine Matrine: A Review of its Antitumor Activities. *Journal of Medicinal Plants Research*, 5(10), 1806-1811.

Capron, I., Corbineau, F., Dacher, F., Job, C., Come, D., & Job, D. (2000). Sugar beet Seed Priming: Effects of Priming Conditions on Germination, Solubilization of 11-S Globulin and Accumulation of LEA Proteins. *Seed Science Research*, 10(3), 243-254

Carvalho, N.M., & Nakagawa, J. (2000). Seeds: Science, Technology and Production. Jaboticabal-SP: FUNEP 2000. pp. 588.

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(2), 365-375.

Chai, H.H., Massawe, F., & Mayes, S. (2016). Effects of Mild Drought Stress on The Morpho-physiological Characteristics of a Bambara groundnut Segregating Population. *Euphytica*, 208(2), 225-236.

Chakraborty, S., Aher, B.M., Kalyanrao, R., Anil, R., & Sasidharan, N. (2017). Effect of Potassium Nitrate on Seed Quality Enhancement in Different Aged Seeds of Bottle gourd [*Lagenaria siceraria* (Molina) Standl]. *Journal of Experimental Biology and Agricultural Sciences*, 5(5), 656-661.

Chibarabada, T.P. (2014). Seed Quality and Water Use Characteristics of a Bambara groundnut (*Vigna subterranea* L.) Landrace Differing in Seed Coat Colour. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Chibarabada, T.P., Modi, A.T., & Mabhaudhi, T. (2014). Seed Quality Characteristics of a Bambara groundnut (*Vigna subterranea* L.) Landrace Differing in Seed Coat Colour. *South African Journal of Plant and Soil*, 31(4), 219-226.

Clayton, G.W., Brandt, S., Johnson, E.N., O'Donovan, J.T., Harker, K.N., Blackshaw, R.E., Smith, E.G., Kutcher, H.R., Vera, C., & Harman, M. (2009). Comparison of Certified and Farm Saved Seed on Yield and Quality Characteristics of Canola. *Agronomy Journal*, 101, 1581-1588.

Coelho, C.M.M., Pires, S.J.C., Tsai, S.M., & Vitorello, V.A. (2002). Seed Phytate Content and Phosphorous Uptake and Distribution in Dry Bean Genotypes. *Brazilian Journal of Plant Physiology*,14, 51-58.

Collinson, S. T., Azam-Ali, S. N., Chavula, K.M., & Hodson, D. A. (1996). Growth, Development and Yield of Bambara groundnut (*Vigna subterranea)* in Response to Soil Moisture. *Journal of Agricultural Science*, (126), 307-318.

Copeland, L. O., & McDonald, M. F. (2012). Principles of Seed Science and Technology. Springer Science and Business Media.

Copeland, L.O., & McDonald, M.F. (2001). Seed Germination. Principles of Seed Science and Technology. Springer. pp. 72-123.

Cresswell, J. W., & Plano-Clark, V. L. (2011). Designing and Conducting Mixed Method Research (2nd ed.). Thousand Oaks, CA: Sage.

Damalas, C.A., Koutroubas, S.D., & Fotiadis, S. (2019). Hydro-Priming Effects on Seed Germination and Field Performance of Faba Bean in Spring Sowing. *Agriculture*, 9 (201), 1-11.

Das, S., & Mohanty, S. (2018). Seed Priming for Improving Quality and Performance of Partially-Deteriorated Groundnut seeds. *Journal of Pharmacognosy and Phytochemistry*, 7(5), 3083-3088.

Dastanpoor, N., Fahimi, H., Shariati, M., Davazdahemami, S., & Hashemi, S.M.M. (2013). Effects of Hydropriming on Seed germination and Seedling Growth in Sage (*Salvia officinalis* L.). *African Journal of Biotechnology*,12(11), 1223-1228.

Deivasigamani, S., & Swaminathan, C. (2018). Evaluation of Seed Test Weight on Major Field Crops. *International Journal of Research Studies in Agricultural Sciences*, 4(1) 8-11.

Effa, E.B., & Uko, A.E. (2017). Food Security Potentials of Bambara groundnut (Vigna subterranea (L.) Verdc.). *International Journal of Development and Sustainability*, 6 (12), 1919-1930.

Effa, E.B., Nwagwu, F.A., Osai, E.O., & Shiyam, J.O. (2016). Growth and Yield Response of Bambara groundnut (*Vigna subterranea* (L.) Verdc) to Varying Densities and Phosphate Fertilizer Rates in Calabar, South Eastern Nigeria. *Journal of Biology, Agriculture and Healthcare*, 6 (16),14-20.

Egli, D. B., TeKrony, D.M., Heitholt, J.J., Rupe, J. (2005). Air Temperature During Seed Filling and Soybean Seed Germination and Vigor Contribution No. 03-06129 from the

Kentucky Agricultural Experimental Station, University of Kentucky, Lexington, KY 40546-0312. *Crop Science*, 45, 1329-1335.

El-Baki, A. G. K., Shaddad, M.A.K., Mostafa, D., & Al-Shimaa, R. (2018). The Effect of Seed Presoaking with KNO_3 on Seed Germination, Proline, Protein Pattern, ß-Amylase and Mineral Composition of Two Faba Bean Cultivars Treated with NaCl. *Egyptian Journal of Bot*any, 58 (3), 445-461.

Elias, S.G. (2018). The Importance of Using High Quality Seeds in Agriculture Systems. *Agricultural research and technology*, 15(4), 1-2.

Erdal, I., Küçükyumuk, Z., Kurt, S.S., & Değirmenci, M. (2017). Effects of Seed Weights on Plant Growth and Mineral Nutrition of Wheat and Bean Plants, *Süleyman Demirel University Journal of Natural and Applied Sciences*, 21, 749-755.

Esmeili, M.A., & Heidarzade, A. (2012). Investigation of Different Osmopriming Techniques on Seed and Seedling Properties of Rice (*Oryza sativa*) Genotypes. *International Research Journal of Applied and Basic Sciences*, 3, 242-246.

Essou, J.I.L., Ahissou, S.Z., Aristide, C.A., & Gbèwonmèdéa, H.D. (2017). Effects of Diverse Pretreatments on Seed Germination in *Cleome gynandra* L. (Capparidaceae) - A Threatened Species, Collected from Different Agro-Ecological Zones in Benin. *International Journal of Current Research in Biosciences and Plant Biology*, 4(7), 47-59.

Fageria, N. K., Baligar, V. C., Moreira, A., & Portes. T.A. (2010). Dry Bean Genotypes Evaluation for Growth, Yield Components and Phosphorus Use Efficiency. *Journal of Plant Nutrition*, 33 (14), 2167-2181.

FAO. (2007). Data Sheet *Vigna subterranea.* Ecocrop. FAO

FAO. (2017). www.fao.org/traditional-crops/bambaragroundnut/en/

FAO. (2019). FAOSTAT. Production/Yield Quantities of Bambara Beans in Africa 1994 - 2017. www.fao.org/faostat/en/#data/QC/visualize

FAO. (2020). Production/Yield quantities of Bambara beans in Africa 1994 - 2019 www.fao.org/faostat/en/#data/QC/visualize

Farzaneh, M., Vierheilig, H., Lössl, A., & Kaul, H. P. (2011). Arbuscular Mycorrhiza Enhances Nutrient Uptake in Chickpea. *Plant Soil Environment*, 57 (10), 465-470.

Ferreira, L.B.S., Fernandes, N.A., Costa, L. A., Rodrigo, A.S., Nascimento, W.M., & Leão-Araújo, E.F. (2017). Temperature and Seed Moisture Content Affect Electrical Conductivity Test in Pea Seeds. *Journal of Seed Science*, 39 (4), 410-416.

Finch-Savage, W.E., Dent, K.C., & Clark, L.J. (2004). Soak Conditions and Temperature Following Sowing Influence the Response of Maize (*Zea mays* L.) Seeds to On-farm Priming (Pre-sowing Seed Soak). *Field Crops Research*, 90, 361-374.

Gebeyehu, S., Kangile, J., & Mwakatobe, E. (2019). Assessment of Seed Quality along The Rice Seed Value Chain in Tanzania. *Development in Practice*, 29(7), 854-866.

Ghasemi, G. K., Chadordooz, J.A., Nasrollahzade, S., & Moghaddam, M. (2010). Effects of Hydro-priming Duration on Seedling Vigour and Grain Yield of Pinto bean (*Phaseolus vulgaris* L.) Cultivars. *Notulae Botanicae Horti Agrobotanici*, 38(1), 109-113.

Gholami, A., Sharafi, S., Sharafi, A., & Ghasemi, S. (2009). Germination of Different Seed Size of Pinto Bean Cultivars as Affected by Salinity and Drought Stress. *Journal of Food, Agriculture and Environment*, 7(2), 555-558.

Goli, A.E (1997). Bambara groundnut (*Vigna subterranea* (L) Verdc.). In: Heller, J., Begemann, F., & Mushonda, J (Eds.). Promoting the Conservation and Use of Underutilized and Neglected Crops, vol 9. International Plant Genetic Resources Institute, Rome. pp. 167.

Gonné, S., Félix-Alain, W., & Benoît, K.B. (2013). Assessment of Twenty Bambara groundnut (*Vigna subterranea* (L.) Verdcourt) Landraces using Quantitative Morphological Traits. *International Journal of Plant Research*, 3(3), 39-45.

Grant, C.A., Flaten, D.N., Tomasiewicz, D.J., & Sheppard, S.C. (2001). The Importance of Early Season Phosphorus Nutrition. *Canadian Journal of Plant Science*, 81, 211-224.

Halimi, A.R., Mayes, S., Barkla, B., & King, G. (2019). The Potential of The Underutilized Pulse Bambara groundnut (*Vigna subterranea* (L.) Verdc) for Nutritional Food Security. *Journal of Food Composition and Analysis*, 77, 47-59.

Hammond, J.P., & White, P.J. (2008). Sucrose Transport in the Phloem: Integrating Root Responses to Phosphorus Starvation. *Journal of Experimental Botany*, 59, 93-109.

Hampton, J.G. (2002). What is Seed Quality? *Seed Science and Technology*, 30(1), 1-10.

Harouna, D.V., Kawe, P.C., & Mohammed, E.M.I. (2018). Under-Utilized Legumes as Potential Poultry Feed Ingredients: A Mini- Review. *Archives of Animal and Poultry Sciences*, 1(1), 1-3.

Hasan, M., Uddin, M.K., Mohammed, M.T.M., Zuan, A.T.K., & Motmainna. (2019). Impact of Nitrogen and Phosphorus Fertilizer on Growth and Yield of Bambara groundnut. *Plant Archives*,19 (1), 501-504.

Hasanuzzaman, M. (2015). Seed Quality. www.hasanuzzaman.webs.com

Hillocks, R.J., Bennett, C., & Mponda, O.M. (2012). Bambara groundnut: A Review of Utilization, Market Potential and Crop Improvement. *African Crop Science Journal*, 20 (1), 1-6.

Hossain, M.A., & Hamid, A. (2007). Influence of N and P Fertilizer Application on Root Growth, Leaf Photosynthesis and Yield Performance of Groundnut. *Bangladesh Journal of Agricultural Research*, 32(3), 369-374.

Huda, M.N. (2001). Why Quality Seed? Reality & Vision Bangladesh Context. Evergreen Printing & Packaging, Dhaka-1000. pp.9-156.

Ibeawuchi, I. I. (2007). Intercropping - A food Production Strategy for Resource Poor Farmers. *Nature and Science*, 5(1), 46-59.

Ibrahim, A.R., Dansi, A., Salifou, M., Ousmane, A., Alzouma, A., & Alou, W. (2018). Farmers' Practices, Utilization, Conservation and Marketing of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Dosso Region, Western Niger. *Genetic Resources and Crop Evolution*, 65(7), 1907-1914.

Ikenganyia, E.E., Anikwe, M.A.N., & Ngwu, O.E. (2017). Responses of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] to Phosphate Fertilizer Rates and Plant Spacing and Effects on Soil Nutrient Status in a Degraded Tropical Ultisol Agbani Enugu South East Nigeria. *International Journal of Plant & Soil Science*, 17(4), 1-17

Imbert, E. (2002). Ecological Consequences and Ontogeny of Seed Heteromorphism Perspect. *Plant Ecology, Evolution and Systematics*, 5, 13-36.

Isaac, O.T., Banful, B.K., Amoah, S., Apuri, S., & Seweh, E.A. (2016). Effect of Harvesting Stages on Seed Quality Characteristics of Three Soybean (*Glycine max* (L) Merrill) Varieties. *Journal of Scientific and Engineering Research*, 3(4), 326-333.

ISTA. (2015). ISTA Rules Full Issue. International Rules for Seed Testing 2015, 1-276.

Jebuni, S.N. (2014). Evaluation of Farmers Storage Structures and Their Effects on The Quality of Sorghum Grain in Wa West District in the Upper West Region of Ghana. MSc. Thesis. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Jideani, V.A., & Diedericks, C.F. (2014). Nutritional, Therapeutic, and Prophylactic Properties of *Vigna subterranea* and *Moringa oleifera*. In: Oguntibe, O. (Ed.). Antioxidant- antidiabetic Agents and Human Health. Janeza Trdine, 9, 51000. Rijeka, Croatia, 187-201.

Jisha, K.C., Vijayakumari, K., & Puthur, J. T. (2013). Seed Priming for Abiotic Stress Tolerance: An Overview. *Acta Physiologiae Plantarum*, 35, 1381-1396.

Jonah, P.M., Adeniji, O.T., & Wammand, D.T. (2010). Variability and Genetic Correlations for Yield and Yield Characters in Some Bambara groundnut (*Vigna subterranea*) Cultivars. *International Journal of Agriculture and Biology*, *12*(2), 303-307.

Kakon, S.S., Bhuiyan, M.S.U., & Hossain, S.M.A. (2015). Influence of Nitrogen and Phosphorus on Yield and Seed Quality of French Bean. *Bangladesh Agronomy Journal*, 18 (2), 1-8.

Kamithi, K.D., Wachira, F., & Kibe, A.M. (2016). Effects of Different Priming Methods and Priming Durations on Enzyme Activities in Germinating Chickpea (*Cicer arietinum* L.). *American Journal of Natural and Applied Sciences*, 1(1), 1-9.

Kankam, F., & Adomako, J. (2014). Efficacy of Neem Seed Powder on Root Knot Nematodes (*Meloidogyne* spp.) Infecting Bambara Groundnut (*Vigna subterranea*). *Asian Journal of Agriculture and Food Science*, 2(2), 166-170

Karunaratne, A.S., Azam-Ali, S.N., Al Shareef, I., Sesay, A., Jorgensen, S.T., & Grout, N.M.J. (2010). Modelling the Canopy Development of Bambara groundnut. *Agricultural and Forest Meteorology*,150, 1007-1015.

Karunaratne, A.S., Azam-Ali, S.N., Izzi, G., & Steduto, P. (2011). Calibration and Validation of FAO- Aqua Crop Model for Irrigated and Water Deficient Bambara groundnut. *Experimental Agriculture*, 47, 509-527.

Kattimani, K.N., Reddy, Y.N., & Rajeswar. B.R. (1999). Effect of pre-sowing seed treatment on germination, seedling emergence, seedling vigour and root yield of Ashwagandha (*Withania somnifera* Daunal.). *Seed Science Technology*, 27, 483-488.

Kaya, M.D., Okcu, G., Atak, M., Cikili, Y., & Kolsarici, O. (2006). Seed Treatments to Overcome Salt and Drought Stress During Germination in Sunflower (*Helianthus annuus L*.). *European Journal of Agronomy*, 24(4), 291-295.

Khan, N., Kazmi, R.H., Willems, L.A., Heusden, V. A.W., Ligterink, W., & Hilhorst, H.W. (2012). Exploring the Natural Variation for Seedling Traits and Their Link with Seed Dimensions in Tomato. *PLoS One,*7(8), 1-14.

Kibinza, S., Vinel, D., Côme, D., Bailly, C., & Corbineau, F. (2006). Sunflower Seed Deterioration as Related to Moisture Content During Ageing, Energy Metabolism and Active Oxygen Species Scavenging. *Physiologica Plantarum,*128, 496-506.

Krueger, K., Goggi, A.S., Mallarino, A.P., & Mullen, R.E. (2013). Phosphorus and Potassium Fertilization Effects on Soybean Seed Quality and Composition. *Crop Science,* 53, 602-610

Kumar, H., Radhamani, J., & Sarbhoy, R. (2013). Viability Assessment Through TZ Test of Seeds Collected from Different Agro Climatic Zones of India. *Indian Journal of Life Science,* 3(1),133-135.

Kumar, Y.P., & Kumar, P.R. (2018). Effect of Seed Priming on Seed Quality of Tomato (*Solanum lycoperscium* L.). *The Pharma Innovation Journal*, 7(2), 264-267

Kumarimanimuthu, V.D., & Kalaimathi, P. (2019). Influence of Hydropriming of Seeds on Growth Parameters of Groundnut (*Arachis hypogaea* L.). *International Journal of Life Science*, 7(2), 359-361.

Lara, T.S., Lira, J.M.S., Rodrigues, A.C., Rokocevic, M., & Alvarenga, A.A. (2014). Potassium Nitrate Priming Affects the Activity of Nitrate Reductase and Antioxidant Enzymes in Tomato Germination. *Journal of Agricultural Science*, 6, 72-80.

Legwaila, G.M., Karikari, S.K., Mogamisi, K., & Mathowa, T. (2013). Response of Three Bambara groundnut landraces to presowing hydration in Botswana. *Agriculture and Biology Journal of North America,* 4(4), 430-434.

Limede, A.C., Oliveira, C.E.S., Zoz, A., Zuffo, A.M., Steiner, F., & Zoz, T. (2018). Effects of Seed Size and Sowing Depth in the Emergence and Morphophysiological Development of Soybean Cultivated in Sandy Texture Soil. *Australian Journal of Crop Science,* 12(1), 93-98.

Liu, C., Wang, Y., Pan, K., Jin, Y., Li, W., & Zhang, L. (2015). Effects of Phosphorus Application on Photosynthetic Carbon and Nitrogen Metabolism, Water Use Efficiency and Growth of Dwarf Bamboo (*Fargesia rufa*) Subjected to Water Deficit. *Plant Physiology and Biochemistry*, 96, 20-28.

Louwaars, N. (2007). Seeds of Confusion: The Impact of Policies on Seed Systems. PhD Dissertation. Wageningen, The Netherlands.

Lynch, J. (1995). Root Architecture and Plant Productivity. *Plant Physiology*, 1 (109),7-13.

Mabhaudhi, T., & Modi, A.T. (2011). Can Hydro-Priming Improve Germination Speed, Vigour and Emergence of Maize Landraces under Water Stress? *Journal of Agricultural Science and Technology B*, 1, 20-28.

Mabhaudhi, T., & Modi, A.T. (2013). Growth, Phenological and Yield Responses of a Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Landrace to Imposed Water Stress under Field Conditions. *South African Journal of Plant and Soil*, 30(2), 69-79.

Maguire, J.D. (1962). Speed of Germination-Aid in Selection and Evaluation for Seedling Emergence and Vigor. *Crop Science*, 2,176-177.

Mairura, F.S., Mugendi, D.N., Mwanje, J.I., Ramisch, J.J., Mbugua, P.K., & Chianu, J.N. (2007). Integrating Scientific and Farmers Evaluation of Soil Quality Indicators in Central Kenya, *Geoderma* ,139, 134-143.

Makanda, I., Tongoona, P., Madamba, R., Icishahayo, D., & Derera, J. (2009). Evaluation of Bambara groundnut Varieties for off season Production in Zimbabwe. *African Crop Science Journal*,16, 175-183.

Mandizvo, T. (2018). Association between Seed Coat Colour, Physiological and Biochemical Processes in Relation to Seed Quality and Performance of Bambara groundnut Landraces. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Mandizvo, T., & Odindo, A.O. (2019). Seed Mineral Reserves and Vigour of Bambara groundnut (*Vigna subterranea* L.) Landraces Differing in Seed Coat Colour, *Heliyon*, 5 (e01635), 1-11.

Mandizvo, T., & Odindo., A.O. (2019). Seed Coat Structural and Imbibitional Characteristics of Dark and Light-Coloured Bambara groundnut (*Vigna subterranea* L.) Landraces. *Heliyon*, 5 (e01249), 1-21.

Marcante, N. C., Muraoka, T., Bruno, I.P., & Camacho. M. A. (2016). Phosphorus Uptake and Use Efficiency of Different Cotton Cultivars in Savannah Soil (Acrisol). *Acta Scientiarum Agronomy*, 38 (2), 239-247.

Marcos-Filho, J. (2015). Seed Vigour Testing: An Overview of the Past, Present and Future Perspective. *Scientia Agricola*, 72,363-374.

Massawe, F.J., Mwale, S.S., Azam-Ali, S.N., & Roberts, J.A. (2005). Breeding in Bambara groundnut (Vigna subterranea (L.) Verdc.): Strategic Considerations. *African Journal of Biotechnology*, 4(6), 463-471.

Matilla, A., Gallardo, M., & Puga-Hermida, M.I. (2005). Structural, Physiological and Molecular Aspects of Heterogeneity in Seeds: A Review. *Seed Science Research*, 15, 63-76.

Matsushima, K., & Sakagami, J. (2012). Effects of Seed Hydropriming on Germination and Seedling Vigor During Emergence of Rice Under Different Soil Moisture Conditions. *American Journal of Plant Science*, 4(8), 1584-1593.

Mayes, S., Basu, S., Murchie, E., Roberts, J., Azam-Ali, S.N., Stadler, F., Mohler, V., Wenzel, G., Massawe, F., & Kilian, A. (2008). BAMLINK-A Cross Disciplinary Programme to Enhance the Role of Bambara Groundnut (*Vigna subterranea* [L.] Verdc.) for Food Security in Africa and India. International Symposium on Underutilized Plants for Food Security, Nutrition, Income and Sustainable Development, *Acta Horticulturae* 806 International Society for Horticultural Science, 2009, 137-150

Mayes, S., Massawe, F.J., Alderson, P.G., Roberts, J.A., Azam-Ali, S.N., & Herman, M. (2011). The Potential for Underutilized Crops to Improve Security of Food. *Journal of Experimental Botany*, 63(3), 1075-1079.

Mazahib, A. M., Nuha, M. O., Salawa I. S., & Babiker, E. E. (2013). Some Nutritional Attributes of Bambara groundnut as Influenced by Domestic Processing. *International Food Research Journal*, 20(3), 1165-1171.

Mishra, A., Swamy, S.L., Bargali, S.S., & Singh, A.K. (2010). Tree Growth, Biomass and Productivity of Wheat Under Five Promising Clones of *Populus deltoides* in Agrisilviculture System. *International Journal of Ecology and Environmental Sciences*, 36, 167-174.

Miya, S.P., & Modi, A.T. (2017). Overcoming the Physical Seed Dormancy in Bambara Groundnut (*Vigna subterranea* L.) by Scarification: A Seed Quality Study. *Journal of Agricultural Science and Technology B*, 7,13-24.

Mkandawire, C.H. (2007). Review of Bambara groundnut Production in Sub-Saharan Africa. *Agricultural Journal*, 2, 464- 470.

Mohammadi, G.R. (2009). The Effect of Seed Priming on Plant Traits of Late-spring Seeded Soybean (*Glycine max* L.). *American-Eurasian Journal of Agriculture & Environmental Science*, 5(3), 322-326.

Mohammed, M.S., Shimelis, H.A., & Laing, M.D. (2016). Preliminary Investigation on Some Agronomic and Morphological Variations of Within and Between Bambara groundnut Landraces. *Journal of Agricultural Science and Technology*, 18, 1909-1920.

Moon, S.S., Bhande, M.H., & Gajbhiye, R. P. (2018). Effect of Nitrogen and Phosphorus on Seed Quality and Seed Yield of Gaillardia. *International Journal of Current Microbiology and Applied Sciences*, 6, 1279-1283.

Mourice, S.K., & Tryphone. G.M. (2012). Evaluation of Common bean (*Phaseolus vulgaris* L.) Genotypes for Adaptation to Low Phosphorus. *International Scholarly Research Network Agronomy*, 2012, 1-9.

Muhammad, Y.Y. (2014). Exploring the Potential of Bambara groundnut, An Underutilized African Legume Species, Towards Food Security in Africa. *African Journal of Agricultural Science and Technology*, 2, (11), 201-204.

Mwale, S.S., Azam-Ali, S.N., & Massawe, F.J. (2007). Growth and Development of Bambara groundnut (*Vigna subterranea*) in Response to Soil Moisture: 1. Dry Matter and Yield. *European Journal of Agronomy*, 26(4), 345-353.

Nautiyal, P.C., Kulkarni, G., Singh, A.L., & Basu, M.S. (2017). Evaluation of Water-deficit Stress Tolerance in Bambara groundnut Landraces for Cultivation in Sub-tropical Environments in India. *Indian Journal of Plant Physiology*, 22(2),190-196.

Nego, J., Dechassa, N., & Dessalegne, L. (2015). Effect of Seed Priming with Potassium Nitrate on Bulb Yield and Seed Quality of Onion (*Allium Cepa* L.), under Rift Valley Conditions, Central Ethiopia. *International Journal of Crop Science and Technology*, 1(2), 1-12.

Njoroge, A.W., Baoua, I., & Baributsa, D. (2019). Postharvest Management Practices of Grains in the Eastern Region of Kenya. *Journal of Agricultural Science*,11(3), 33-42.

Nwanna, L.C., Enujiugha, V.N., Oseni, A.O., & Nwanna, E.E. (2005). Possible Effects of Fungal Fermentation on Bambara groundnuts (*Vigna subterranean* (L.) Verde) as A Feed Stuff Resource. *Journal of Food Technology*, 3(4), 572-57

Nweke, I.A., & Emeh, H.O. (2013). The Response of Bambara Groundnut (Vigna Subterranea (L.) Verdc) To Phosphate Fertilizer Levels in Igbariam South East Nigeria. *Journal of Agriculture and Veterinary Science*,2(1) 28-34.

Nyongesa, B.O., Were, B.A., Gudu, S., Dangasuk, O.G., & Onkware, A.O. (2013). Genetic Diversity in Cultivated Sesame (*Sesamum indicum* L.) and Related Wild Species in East Africa. *Journal of Crop Science and Biotechnology*, 16(1), 9-15.

Ochuodho, J.O. (2005). Physiological Basis of Seed Germination in *Cleome gynandra* (L.). PhD Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Odongo, F.O., Oyo, M.E., Wasike, V., Owuoche, J.O., Karanja, L., & Korir, P. (2015). Genetic Diversity of Bambara groundnut (*Vigna subterranea* (L) Verdc.) Landraces in Kenya Using Microsatellite Markers. *African Journal of Biotechnology*, 14(4), 283-291.

Ogbuehi, H. C., Madukwe, D.K., & Ashilonu, P. (2013). Assessment of Hydro Priming of Seeds on Performance of Morphological Indices of Bambara Groundnut (*Vigna subterrenea* Linn.) Landrace. *Global Journal of Biology, Agriculture and Health Sciences*, 2 (2), 17-22.

Okalebo, J.R., Gathua, K.W., & Woomer, P.L (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual; 2nd edition. Sacred African Publishers, Nairobi.

Ouedraogo, M., Zagre, B.M., Thorndal, S.J., & Liu, F. (2012). Effect of Earthing up Times on Yield of Bambara groundnut Landraces in Sahel-Burkina Faso. *African Journal of Agricultural Research*, 7, 4505-4511.

Paneru, P., Bhattachan, B.K., Amgain, L.P., Dhakal, S., Yadav, B.P., & Gyawaly, P. (2017). Effect of Mother Plant Nutrition on Seed Quality of Wheat (*Triticum aestivum.* L) in Central Terai Region of Nepal. *International Journal of Applied Sciences and Biotechnology*, 5(4), 542-547

Patel, J.V., Antala, D.K., & Dalsaniya, A.N. (2018). Influence of Different Packaging Materials on the Seed Quality Parameters of Chickpea. *International Journal of Current Microbiology and Applied Sciences*, 7(12), 2458-2467.

Patton, M. Q. (2002). Qualitative Research and Evaluation Methods (3rd ed.). Thousand Oaks, CA: Sage.

Perales, H.R., Benz, B.F., & Brush, S.B. (2005). Maize Diversity and Ethnolinguistic Diversity in Chiapas, Mexico. Proceedings of the National Academy of Sciences of the United States of America, 102 (3), 949-954.

Piergiovanni, A.R., Lioi, L., Montesano, V., & Sa, G. (2017). Comparative Evaluation of Phosphorus Accumulation and Partitioning in Seeds of Common Bean (*Phaseolus vulgaris* L.). *Italian Journal of Agronomy*, 12(849),144-150.

Raghothama, K.G. (1999). Phosphate Acquisition. *Annual Review of Plant Physiology and Plant Molecular Biology*, 50, 665-693.

Rashid, M. (2016). Effect of Environment during Seed Development on Brassica Seed Quality. PhD Thesis. Lincoln University.

Rastegar, Z., & Kandi, M.A.S. (2011). The Effect of Salinity and Seed Size on Reserve Utilization and Seedling growth of Soybean (*Glycine max*). *International Journal of Agronomy and Plant production*, 2, 1-4.

Ri-liang, G., Ran, H., Guang-yao, J., Zhi-peng, Y., Li-sha, R., Li, L., & Jian-hua, W. (2019). Effect of Mechanical Threshing on Damage and Vigor of Maize Seed Threshed at Different Moisture Contents. *Journal of Integrative Agriculture*,18(7), 1571-1578.

Sacala, E., & Demczuk, A. (2016). Effect of Laser and Hydropriming of Seeds on Some Physiological Parameters in Sugar beet. *Journal of Elementology*, 21(2), 527-538.

Sadeghi, H., Khazaei, F., Sheidaei, S., & Yari, L. (2011). Effect of Seed Size on Seed Germination Behavior of Safflower (*Carthamus tinctorius* L.). ARPN *Journal of Agricultural and Biological Sciences*, 6, 5-8.

Sasthri, G., Thiagarajan, C.P., Srimathi, P., Malarkodi, K., & Venkatasalam, E.P. (2001). Foliar Application of Nutrient on the Seed Yield and Quality Characters of Non-aged and Aged Seeds of Cotton cv. MCU5. *Madras Agricultural Journal*, 87, 202-206.

Sawan, Z.M., Fahmy, A.H., & Yousef, S.E. (2011). Effect of Potassium, Zinc and Phosphorus on Seed Yield, Seed Viability and Seedling Vigor of Cotton (*Gossypium barbadense* L.). *Archives of Agronomy and Soil Science*, 57(1), 75-90.

Shahi, C., Vibhuti., Bargali, K., & Bargali., S. S. (2015). How Seed Size and Water Stress Effect the Seed Germination and Seedling Growth in Wheat Varieties? *Current Agriculture Research Journal*, 3(1), 60-68

Shanka, D., Dechassa, N., Gebeyehu, S., & Elias, E. (2018). Phosphorus Use Efficiency of Common Bean Cultivars in Ethiopia. *Communications in Soil Science and Plant Analysis*, 49 (11), 1302-1313.

Shehzad, M., Ayub, M., Ahmad, A.U.H., & Yaseen, M. (2012). Influence of Priming Techniques on Emergence and Seedling Growth of Forage Sorghum (*Sorghum bicolor* L.). *The Journal of Animal and Plant Sciences*, 22, 154-158.

Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., & Zhang, F. (2011). Phosphorus Dynamics: From Soil to Plant. *Plant Physiology*, 156, 997-1005.

Shravani, B., Jeremy, R., Richard, M., Sayed, A., & Remy, P. (2004). The Genetics of Bambara groundnut and the Construction of Genetic Linkage map. www.crop science.org

Sinefu, F. (2011). Bambara groundnut Response to Controlled Environment and Planting Date Associated Water Stress. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Singh, A.L., & Basu, M.S. (2005). Bambara Groundnut: Its Physiology and Introduction in India. In: Advances in Plant Physiology (Ed. Trivedi, P.C.). pp.235-249. I.K. International Publishing House Pvt. Ltd. New Delhi, India.

Singh, R. (2017). Effects of Hydropriming on Seed Germination and Vigour of *Aegle marmelos. Journal of Pharmacognosy and Phytochemistry*, 6(5), 446-449.

Smith, S.M., Jenkinson, M., Woolrich, M.W., Beckmann, C.F., Behrens, T.E., Johansen-Berg, H., Bannister, P.R., De-Luca, M., Drobnjak, I., Flitney, D.E.,Niazy, R.K., Saunders, J., Vickers, J., Zhang, Y., De Stefano, N., Brady, J.M., & Matthews, P.M., (2004). Advances in Functional and Structural MR Image Analysis and Implementation as FSL. Neuroimage 23 (Suppl 1), S208-S219.

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

Sprent, J.I., Odee, D.W., & Dakora, F.D. (2010). African Legumes: A Vital but Under-utilized Resource. *Journal of Experimental Botany*, 61(5),1257-1265.

Steiner, F., Zuffo, A.M., Busch, A., Sousa, T.O., & Zoz, T. (2019). Does Seed Size Affect the Germination Rate and Seedling Growth of Peanut under Salinity and Water Stress? *Pesquisa Agropecuaria Tropical*, 49, 1-9.

Sultana, N., Ali, Y., Jahan, S., &Yasmin, S. (2016). Effect of Storage Duration and Storage Devices on Seed Quality of Boro Rice Variety BRRI dhan47. *Journal of Plant Pathology and Microbiology*, 8(1),1-6.

Swanevelder, C.J. (1998). Bambara - Food for Africa. www.daff.gov.za

Taiz, L., & Zeiger, E. (2010). "Plant Physiology" 5th edition. Sinauer Associates Inc Publishers, Sunderland, MA, USA.

Tania, S.S., Hossain, M.M., & Hossain, M.A. (2019). Effects of Hydropriming on Seed Germination, Seedling Growth and Yield of Bitter gourd. *Journal of Bangladesh Agricultural University*, 17(3), 281-287.

Temegne, N. C., Taffouo, V. D., Tadoh, T. C., Gouertoumbo, W. F., Wakem, G. A., Nkou, F. T. D., Nuemsi, P. P. K., & Youmbi, E. (2019). Effect of Phosphate Fertilization on Growth, Yield and Seed Phosphorus Content of Bambara Pea (*Vigna subterranea*) Landraces. *Journal of Animal and Plant Science*, 29(3), 1-11.

Temegne, N.C. (2018). Improvement in the Performances of Voandzou (*Vigna subterranea* (L.) Verdc.) in Response to Phosphate Deficiency through Chemical and Biological Fertilization. PhD Thesis. University of Yaounde I, Cameroon.

Temegne, N.C., Nkou-Foh, T.D., Taffouo, V.D., Wakem, G.A., & Youmbi, E. (2018). Effect of Mycorrhization and Soluble Phosphate on Growth and Phosphorus Supply of Voandzou (*Vigna subterranea* (L.) Verdc.). *Legume Research*, 41(6), 879-884.

Tetteh, R., Aboagy, L.M. E., Darko, R., & Osafo, E.A. (2018). Effect of Maturity Stages on Seed Quality of Two Tomato Accessions. *African Crop Science Journal*, 26(2), 237-244.

Thomas, B., Murphy, D.J., & Murray, B.G. (2016). Encyclopedia of Applied Plant Science 2nd edition. Imprint Academic Press.

Tizazu, Y., Dereje. A. D., Germew, T, G., & Assefa, F. (2019). Evaluation of Seed Priming and Coating on Germination and Early Seedling Growth of Sesame (*Sesamum indicum* L.) under Laboratory Condition at Gondar, Ethiopia. *Cogent Food and Agriculture*, 5,1-9.

Toure, Y., Kone, M., Tanoh, H.K., & Kone, D. (2012). Agro-morphological and Phenological Variability of 10 Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Landraces Cultivated in the Ivory Coast. *Tropicultural*, 30, 216-221.

Tsoata, E., Temegne, N.C., & Youmbi, E. (2016). Analysis of Early Physiological Criteria to Screen Four *Fabaceae* Plants for Their Tolerance to Water Stress. *International Journal of Recent Scientific Research*,7(11),14334-14338.

UBOS. (2009). Statistical Abstract 2009.

Uchida, R. (2000). Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms. *Plant nutrient management in Hawaii's soils*, 4, 31-55.

Vandamme, E., Rose, T.J., Saito, K., Jeong, K., & Wissuwa, M. (2015). Integration of P Acquisition Efficiency, P Utilization Efficiency and Low Grain P Concentrations into P-efficient Rice Genotypes for Specific Target Environments. *Nutrient Cycling in Agroecosystems*, 104(3), 413-427.

Vishwanath, R.H., Gurumurthy, R., & Manjunatha, M.V. (2019). Influence of Seed Processing and Storage on Seed Quality of Soybean Var. DSb-21. *International Journal of Current Microbiology and Applied Sciences*, 8(1), 1684-1694.

Vurayai, R., Emongor, V., & Moseki, B. (2011). Effect of Water Stress Imposed at Different Growth and Developmental Stages on Morphological Traits and Yield of Bambara groundnuts (*Vigna subterranea* L. Verdc). *American Journal of Plant Physiology*, 6, 17-27.

Wakhungu, C.N. (2016). Screening of Selected Bambara Nut (*Vigna subterranea* (L.) Verdc) Landraces for Tolerance to *Fusarium* Wilt and its Management Using Farmyard Manure in Busia County, Western Kenya. MSc. Thesis. Egerton University, Kenya.

Wamba, O.F., Taffouo, V.D., Youmbi, E., Ngwene, A., & Amougou, A. (2012). Effects of Organic and Inorganic Nutrient Sources on the Growth, Total Chlorophyll and Yield

of Three Bambara Groundnut Landraces in the Coastal Region of Cameroon. *Journal of Agronomy*, 11, 31-42.

Wambugu, P.W., Mathenge, P.W., Auma, E.O., & Van Rheenen, H.A. (2009). Efficacy of Traditional Maize (*Zea mays* L.) Seed Storage Methods in Western Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, 9(4), 1110-1128.

Wang, F., Rose, T., Jeong, K., Kretzschmar, T., & Wissuwa, M. (2016). The Knowns and Unknowns of Phosphorus Loading into Grains, and Implications for Phosphorus Efficiency in Cropping Systems. *Journal of Experimental Botany*, 67(5),1221-1229.

Warburton, M.L., Setimela, P., Franco, J., Cordova, H., Pixley, K., Bänziger, M., Dreisigacker, S., Bedoya, C., & MacRobert, J. (2010). Toward A Cost-effective Fingerprinting Methodology to Distinguish Maize Open-pollinated Varieties. *Crop Science*, 50, 467-477.

Wasula, S.L., Wakhungu, J., & Palapala, V. (2014). Farmers' perceptions and adoption of Bambara nut production as a food security crop in Kakamega County, Kenya. *International Journal of Disaster Management and Risk Reduction*, 6(1), 50-62.

Weil, R.R., & Brady, N.C. (2017). Phosphorus and Potassium. The Nature and Properties of Soils, 15th ed. Pearson, Columbus, OH, USA.

Welch, R.M., & Shuman, L. (1995). Micronutrient Nutrition of Plants. *Critical Reviews in Plant Sciences*, 14 (1), 49-82.

White, P.J., & Veneklaas, E.J. (2012). Nature and Nurture: The Importance of Seed Phosphorus Content. *Plant Soil*, 35,1-8.

Wiatrak, P.J., Wright, D.L., Marois, J.J., Koziara, W., & Pudelko, J.A. (2005). Tillage and Nitrogen Application on Cotton Following Wheat. *Agronomy Journal*, 97, 288-293.

Yakubu, H., Kwari, J.D., & Sandabe, M.K. (2010). Effect of Phosphorus Fertilizer on Nitrogen Fixation by Some Grain Legume Varieties in Sudano -Sahelian Zone of North Eastern Nigeria. *Nigerian Journal of Basic and Applied Science*,18(1), 19-26.

Yan, M. (2015). Hydropriming Promotes Germination of Aged Napa Cabbage Seeds. *Seed Science and Technology*, 43(2), 303-307.

Yan, M. (2016). Hydropriming Increases Seed Germination and Early Seedling Growth in two Cultivars of Napa Cabbage (*Brassica rapa* subsp. *pekinensis*) Grown Under Salt Stress. *Journal of Horticultural Science & Biotechnology*, 91(4), 1-6.

Yao, D.N., Kouassi, K.N., Erba, D., Scazzina, F., & Pellegrini, N. (2015). Nutritive Evaluation of the Bambara groundnut Ci12 Landrace [*Vigna subterranea* (L.) Verdc. (Fabaceae)] Produced in Côte d'Ivoire. *International Journal of Molecular Science*, 16(9), 21428-21441.

Zhou, T., Du, Y., Ahmed, S., Liu, T., Ren, M., Liu, W., & Yang, W. (2016). Genotypic Differences in Phosphorus Efficiency and the Performance of Physiological Characteristics in Response to Low Phosphorus Stress of Soybean in Southwest of China. *Plant Science*, 24,1-13.

Zhu, Y.G., & Smith, S.E. (2001). Seed phosphorus (P) Content Affects Growth and P Uptake of Wheat Plants and Their Association with Arbuscular Mycorrhizal (AM) Fungi. *Plant Soil*, 231, 105-112.

APPENDICES

Appendix I: Questionnaire

UNIVERSITY OF ELDORET

SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY

P.O. BOX 1125-30100, ELDORET, KENYA

Household questionnaire for Bambara nut production and utilization in Uganda, June 2019

1. Consent statement

- "My name is…… from The University of Eldoret, Kenya. We are here to study Bambara nut production and utilization across the country. Your household was selected to be part of this survey.
- "The researchers will keep your responses confidential. Your full name will never be used anywhere to ensure confidentiality."
- "You are not obliged to answer questions if you do not want to and you are free to stop the interview at any time."
- "You may ask questions about this study at any time".
- "We hope that the research will benefit Uganda by assisting us to better understand the production trends, utilization and ways of improving Bambara nut in Uganda."
- "You will not receive any direct benefit if you join this study, your participation is voluntary."
- "The survey will take approximately half an hour. Are you willing to participate?"

2. General Information

2.1 Date:/……/…… (dd/mm/yy) 2.2 Interviewer (Optional)……

2.3 Location

2.3.1 Region	2.3.2 District:	
1. West Nile 2. Northern 3. Eastern 4. Central 5. Western	2.3.3 Sub county:	2.3.4 Village:
	2.3.5 GPS: Easting: Northing: Elevation (m):	

3. Demographics

3.1 Respondent (name)……Sex: 1=Female2=Male.

3.1.1 Age (years)	3.1.2 Marital status	3.1.3 Ethnicity	3.1.4 Household size	3.1.5 Education level attained
1. 11-20 2. 21-30 3. 31-40 4. 41-50	1. Married 2. Single 3. Widowed 4. Separated	1. Acholi 2. Langi 3. Alur/Jonam 4. Madi 5. Teso 6. Jopadhola	Adults…… Children……. Female…… Male…….	1. No formal education 2. Primary 3. Secondary

5. 51-60 6. Over 60		7. Basamia 8. Bakonjo 9. Banyankole 10. Baruli 11. Others (specify……)	Total……....	4. Tertiary (College, Vocational, etc.) 5. University

3.2 What is your most important source of income? (Circle all applicable)
1.Food crop farming
2.Cash crop farming
3.Livestock rearing
4.Salaried employment
5.Business
6.Causal labor
7.Others (specify)…….

4 Land tenure and agriculture

4.1 Land ownership

4.1.1 Do you own land?
1. Yes 2. No

4.1.2 Kindly describe the plots as below

Plot	Size (acres)	Distance from home (Km)	Ownership type	How acquired	If rented, how did you pay for it?	Are land rights of this plot sometimes contested? (Y/N)	Land type	Land use
1.								
2.								
3.								
4.								
5.								

Ownership type	How acquired	How paid for	Land type	Land use
1. Personal/family plot with deed 2. Personal/family plot without deed 3. Rented/leased land 4. Squatter agreement 5. Community land 6. Other (specify……)	1. Bought 2. Rented 3. Inherited 4. Family land 5. In temporary use 6. Gifted 7. Others (Specify……)	1.In cash 2. In kind 3. In labor	1. Upland 2.Swampland 3. Flatland	1.Cultivated by household 2.Shared 3.Leased out 4. In use by an association 5.Grazing land 6. Trees 7.Barren 8. Others (Specify……..)

4.2 Bambara nut production

4. 2.1 Did you grow Bambara nut in the last three years? If No, proceed to 4.2.9

1. Yes [(2017.Y/N); (2018.Y/N); (2019…Y/N)]
2. No

4.2.2 On what proportion of land in 2019?
1. 1 acre
2. Half an acre
3. Quarter of an acre
4. Less than a quarter acre (Estimated size…….m^2)
5. Other (specify……)

4.2.3 How much did you harvest from that plot? (Estimated Kgs…….)

4.2.4 Kindly identify the plot you used for Bambara nut cultivation from above

4.2.5 What was (is) the purpose of your Bambara nut production?
1. Home consumption
2. Sale of seeds/grains
3. Sale of processed products e.g. flour
4. Seed maintenance
5. Other (specify……)

4.2.6 What proportions of farmers in this village engage in Bambara nut production?
1. Very few: <15%
2. Few: 15-<35%
3. Moderate: 35-50%
4. Many: >50%

4.2.7 Reasons for crop popularity (circle all applicable)
1. Drought tolerance
2. Pest and disease tolerance
3. Long storage
4. Palatability
5. Nutrition
6. Food security
7. Cultural
8. Other (specify……..)

4.2.8 Reasons for non-popularity (circle all applicable)
1. Takes long to germinate and establish
2. Hard to cook
3. Long maturity period
4. Difficulty in accessing seed
5. Difficulty in crop management
6. Lack of market
7. Lack of information (production, processing, etc)
8. Pests and diseases
9. Limited uses
10. Better competing alternative legumes
11. Other (specify……)

4.2.9 Have you heard of or seen Bambara nut before?
1. Heard of it and seen it
2. Never heard of it and never seen it
3. Heard of it, not seen it

4.2.10 Do you think you will be interested in growing it if seeds were available?
1. Yes
2. No
3. Not sure

Why?

Yes	No
1. Drought tolerance 2. Pest and disease tolerance 3. Long storage 4. Food security 5. Palatability 6. Nutrition 7. Cultural 8. Other (specify……)	1. Takes long to germinate and establish 2. Hard to cook 3. Long maturity period 4. Difficulty in accessing seed 5. Lack of market 6. Lack of information (production, processing, etc) 7. Pests and diseases 8. Limited uses 9. Better competing alternative legumes 10. Other (specify……)

4.2.11 Cultural practices

1. Sowing date ……./……(mm/yyyy)
2. First harvest date ……./……(mm/yyyy)
3. Last harvest date ……../……(mm/yyyy)

4.2.12 Cropping system

1. Pure stand (on flat field)
2. Pure stand (on ridges)
3. Intercropped

4.2.13 If intercropped, with which crops?

1. Millet
2. Sorghum
3. Cassava
4. Maize
5. Other (specify……)

4.2.14 And in what pattern?

1. Mixed cropping
2. Boundary cropping
3. Row cropping
4. Strip cropping
5. Other (specify……)

4.2.15 How many times do you weed Bambara nut?

1. Once
2. Twice
3. Thrice

4.2.16 What other crops do you normally cultivate on your land?

1. Millet
2. Sorghum
3. Cassava
4. Maize
5. Sweet potato
6. Other (specify……)

4.2.17 Use of integrated crop management practices (ICM)

ICM Code	ICM Options	Access to ICM (Y/N)	Use (Y/N)	Source of ICM
1.	Improved crop varieties			
2.	Crop rotation			
3.	Inter/mixed cropping			
4.	Organic pesticides			
5.	Inorganic pesticides and herbicides			
6.	Manure (GM/FYM)			
7.	Inorganic fertilizer			
8.	Mulching			
9.	Earthing up			
10.	Use of raised seed beds			

4.2.18 Source of ICM
1. Research
2. Fellow farmer
3. Local market
4. Own saved seed
5. NGO
6. OWC/NAADS
7. Other (specify……)

4.2.19 Which of the above ICM practices have you ever applied to Bambara nut? (Circle all applicable)
1. Crop rotation
2. Inter/mixed cropping
3. Organic pesticides
4. Inorganic pesticides and herbicides
5. Earthing up
6. Raised seed bed
7. Manure
8. Other (specify……)

4.2.20 Have you been trained in any ICM?
1. Yes
2. No

By which Organisation?
(Name……)

5.Seed management practices

5.1 Where do you obtain your seed?
1. Own saved from previous harvest
2. Obtained from neighbor (specify if bought, exchanged or given)
3. Bought in local market
4. Other (specify……)

5.2 What is the composition of your seed (How pure is your seed)?
1. Single landrace
2. More than 1 landrace, not mixed
3. Mixed landraces

(Request for samples if available and label appropriately)

5.3 For how long have you been planting this same seed?
1. 1 year (first planting)
2. 2 years
3. 3 years
4. 4 years
5. More than 4 years

5.4 When do you select seed?
1. Before whole crop is harvested
2. During crop harvest
3. After crop harvest, but in the field
4. During drying
5. At planting time (stored together as whole harvest)
6. Other (specify……)

5.5 What seed selection criteria do you deploy in the field? (Circle all applicable)
1. None
2. Healthy looking plants and pods
3. High yielding plant
4. Big pods
5. Other (specify……)

5.6 What are the seed quality assurance activities you carry out in the field? (Circle all applicable)
1. None
2. Weeding
3. Removing diseased or off types
4. Planting separately
5. Other (specify……)

5.7 How do you harvest seeds?
1. Hand hoe
2. Pointed stick
3. Other (specify……)

5.8 How do you dry the seeds? (circle all applicable)
1. Sun drying on the ground
2. Sun drying on tarpaulin (or other similar material)
3. Sun drying on raised platform
4. Shade drying on the ground
5. Shade drying on tarpaulin (or other similar material)
6. Other (specify……)

5.9 How and where do you store your seed? (Circle all applicable)
1. Gunny bags
2. Pots (specify if sealed/covered or not)
3. Open containers (saucepans/plastics/drums)
4. On the ground
5. Other (specify……)

5.10 Do you sometimes notice seed spoilage in storage?
1. Yes
2. No

In what way?
1. Pest damage
2. White mold
3. Black mold
4. Rotting (bad smell)

5. Other (specify……)

5.11 How do you process Bambara nut seed before planting?
1. Thresh with hand
2. Sorting (bad ones, different types)
3. Other (specify……)

5.12 Do you carry out any seed treatment prior to planting?
1. None
2. Soaking
3. Hot water treatment
4. Other (specify……)

5.13 Are the seed handling methods the same as grain handling?
1. Yes
2. No

If NO, what are the differences?
1. Seed purity assurance (sorting)
2. Seed selection (in field or at home)
3. Harvesting stage and method
4. Drying
5. Storage
6. Threshing
7. Pre-sowing treatment

6.Utilization of Bambara nut

6.1 What is the local vernacular name of Bambara nut and this landrace(s)

Translation of the local name into English
……..

6.2 Does the Bambara nut name have a meaning?
1. Yes
2. No

If yes, briefly describe ……....

6.3 Which parts of the plant do you utilize? (Circle all applicable)
1. Seed
2. Leaf
3. Flower/inflorescence
4. Root
5. Shell (pod)
6. Other (specify……)

6.4 How do you utilize them? (Circle all applicable)
1. Food
2. Medicine
3. Animal feed
4. Forage
5. Ornamental
6. Ceremonial
7. Other (specify……)

6.5 What are some of the special uses of Bambara nut? (Circle all applicable)
1. Children
2. Older people
3. Feasts
4. Religious purpose

5. Chiefs
6. Other (specify……)

6.6 How frequently do you make use of the plant?
1. Daily
2. Weekly
3. Occasional
4. Other (specify……)

6.7 What are the main cooking methods you use?
1. Boiling
2. Baking
3. Roasting
4. Local specialties
5. Other (specify……)

6.8 What are the preparatory methods towards cooking?
1. None
2. Soaking
3. Cracking
4. Removal of seed coat
5. Other (specify……)

6.9 What are some of the processing methods you use for Bambara nut?
1. None
2. Fermentation
3. Puddings
4. Chips
5. Canning
6. Other (specify……)

6.10 What stage of the crop do you use for processing?
1. Immature green stage (soft dough stage)
2. Mature green stage (hard dough)
3. Dried bean
4. Other (specify……)

6.11 What is the palatability of the landrace(s) according to local preference (rank if more than 1)
1. Poor
2. Acceptable
3. Good

1st 2nd 3rd 4th

6.12 General popularity of landraces (ranked)
1st ……
2nd ……
3rd ……
4th ……
5th ……

6.13 Are there any myths associated with Bambara nut in your culture (e.g. taboos, stories, superstitions)?

1. Yes
2. No

If yes, briefly describe ……

6.14 How much Bambara nut did you sell from the last harvest?
1. Estimated Kgs and price per (Kg.....; price/kg.....UGX)
2. Did not sell

7.Constraints to Bambara nut production and utilization

	Practice	Constraints (ranked)	Mitigation/Coping mechanisms
1.	Seed access	1	
		2	
		3	
2.	Production	1	
		2	
		3	
3.	Post-harvest handling	1	
		2	
		3	
4.	Storage	1	
		2	
		3	
5.	Utilisation	1	
		2	
		3	
6.	Marketing	1	
		2	
		3	

8.Gender in Bambara nut production and utilization

8.1 Who is responsible for the following activities in Bambara nut? (Write number beside)
1. Woman 2. Man 3. Both woman and man 4. Children 5. All
A. Seed sourcing/selection
B. Site selection
C. Land preparation
D. Sowing
E. Weeding
F. Harvesting
G. Shelling
H. Processing (pounding/grinding, fermenting, etc.)
I. Marketing
J. Cooking
K. Other (specify……)

9.Group membership

9.1 Do you belong to a group?
1. Yes (Name……)
2. No

9.2 How many members are in the group?

Male……Female……. Total.....

9.3 What was your reason for joining the group? (Circle all applicable)
1. Seed production
2. Savings and credit
3. Input support
4. Commodity marketing
5. Social support
6. Other (specify……)

Thank you very much for your participation in this study!

Appendix II: ANOVA seed length of farm-saved seeds

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	0.564700	0.141175	25.19	<.001
Residual	15	0.084075	0.005605		
Total	19	0.648775			

Appendix III: ANOVA seed width of farm-saved seeds

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	0.156970	0.039243	15.44	<.001
Residual	15	0.038125	0.002542		
Total	19	0.195095			

Appendix IV: ANOVA EC of farm-saved seed

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	0.37204	0.09301	6.30	0.008
Residual	10	0.14753	0.01475		
Total	14	0.51957			

Appendix V: ANOVA FGP of farm-saved seed

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	0.85950	0.21488	6.77	0.007
Residual	10	0.31719	0.03172		
Total	14	1.17669			

Appendix VI: ANOVA GVI of farm-saved seed

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	2.0931	0.5233	3.77	0.040
Residual	10	1.3865	0.1387		
Total	14	3.4797			

Appendix VII: ANOVA SVI-II of farm-saved seed

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Landrace	4	186970.	46742.	8.61	0.003
Residual	10	54300.	5430.		
Total	14	241270.			

Appendix VIII: ANOVA Seed yield of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	0.5770	0.1923	0.36	0.780
Landrace	2	1.2294	0.6147	1.16	0.332
Phosphorus level. Landrace	6	3.9461	0.6577	1.24	0.323
Replication stratum	2	0.1518	0.0759	0.14	
Residual	22	11.6448	0.5293		
Total	35	17.5492			

Appendix IX: ANOVA TSW seed weight of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	3220	1073	0.49	0.696
Landrace	2	18061	9031	4.09	0.031
Phosphorus level. Landrace	6	7171	1195	0.54	0.772
Replication stratum	2	891	446	0.20	
Residual	22	48619	2210		
Total	35	77963			

Appendix X: ANOVA Seed phosphorus content of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	9.108E-08	3.036E-08	0.29	0.831
Landrace	2	7.536E-08	3.768E-08	0.36	0.70
Phosphorus level. Landrace	6	2.344E-07	3.906E-08	0.38	0.887
Residual	24	2.498E-06	1.041E-07		
Total	35	2.899E-06			

Appendix XI: ANOVA FGP of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	0.53868	0.17956	7.13	0.001
Landrace	2	1.34520	0.67260	26.70	<.001
Phosphorus level. Landrace	6	1.96731	0.32788	13.02	<.001
Residual	24	0.60451	0.02519		
Total	35	4.45570			

Appendix XII: ANOVA GVI of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	3.4669	1.1556	7.98	<.001
Landrace	2	6.9648	3.4824	24.06	<.001
Phosphorus level. Landrace	6	9.3058	1.5510	10.71	<.001
Residual	24	3.4743	0.1448		
Total	35	23.2118			

Appendix XIII: ANOVA SVI-II of landraces at different phosphorus levels

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Phosphorus level	3	49959	16653	10.97	<.001
Landrace	2	178942	89471	58.93	<.001
Phosphorus level. Landrace	6	223136	37189	24.50	<.001
Residual	24	36436	1518		
Total	35	488474			

Appendix XIV: ANOVA FGP of AbiBam 001 at different hydropriming durations

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	0.17873	0.04468	1.48	0.279
Residual	10	0.30182	0.03018		
Total	14	0.48055			

Appendix XV: ANOVA GVI of AbiBam 001 at different hydropriming durations

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	0.1721	0.0430	0.29	0.881
Residual	10	1.5098	0.1510		
Total	14	1.6820			

Appendix XVI: ANOVA SVI-II of AbiBam 001 at different hydropriming durations

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	3006	752	0.39	0.813
Residual	10	19410	1941		
Total	14	22416			

Appendix XVII: ANOVA FGP of AbiBam 001 at different concentrations of potassium nitrate solution

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	0.15637	0.03909	0.65	0.640
Residual	10	0.60202	0.06020		
Total	14	0.75840			

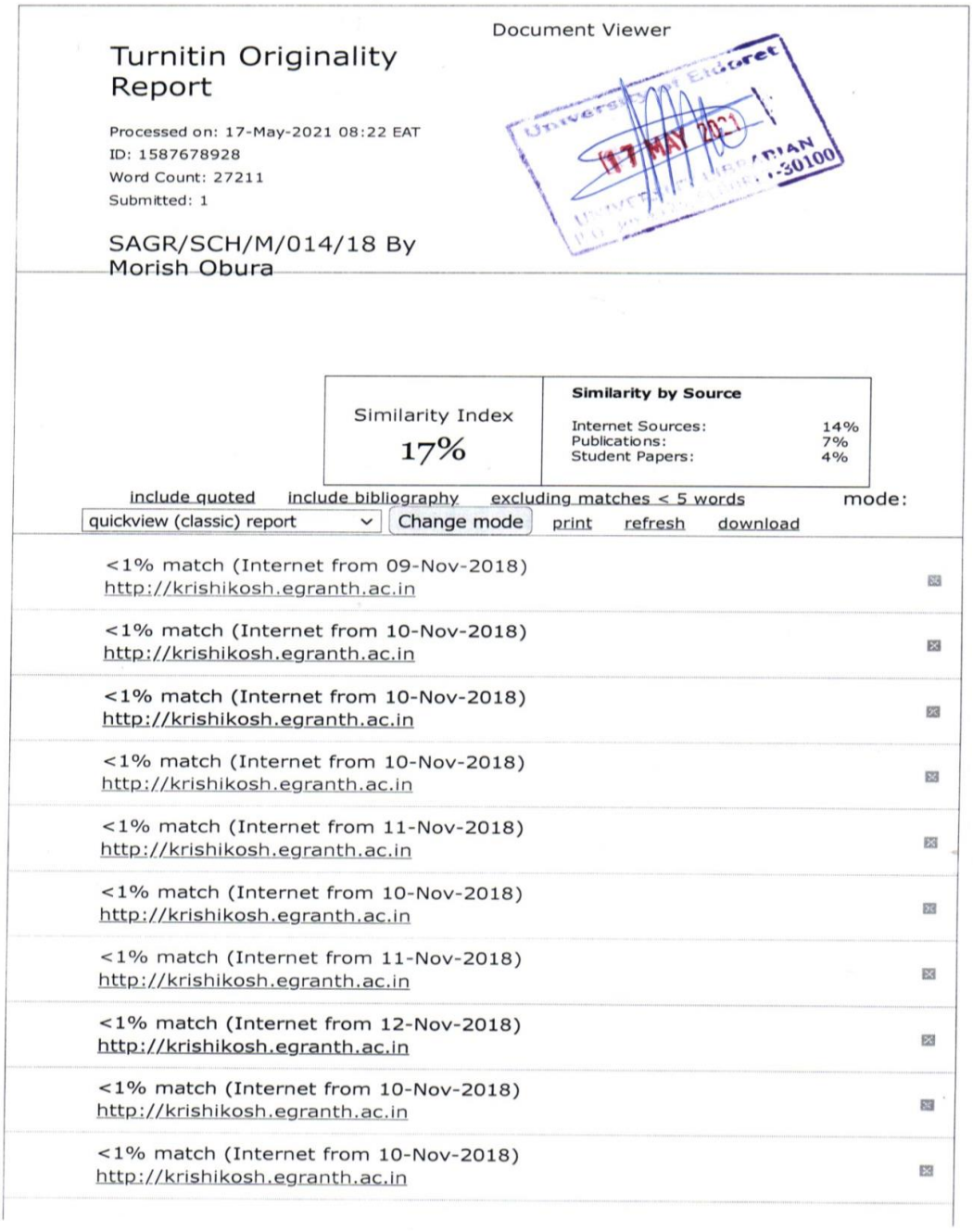
Appendix XVIII: ANOVA GVI of AbiBam 001 at different concentrations of potassium nitrate solution

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	0.0806	0.0202	0.07	0.988
Residual	10	2.7207	0.2721		
Total	14	2.8014			

Appendix XIX: ANOVA SVI-II of AbiBam 001 at different concentrations of potassium nitrate solution

Source of variation	d.f.	s. s.	m.s.	v.r.	F pr.
Treatment	4	8214	2054	1.27	0.346
Residual	10	16222	1622		
Total	14	24436			

Appendix XX: Similarity Report



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