

**EFFECTS OF THRESHING METHODS, MOISTURE CONTENT AND
ENDOSPERM TYPES ON THRESHABILITY AND SELECTED SORGHUM
(*Sorghum bicolor* L. Moench) SEED QUALITY PARAMETERS**

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of Master of Science in Seed Technology and Business Management**

College of Agriculture and Veterinary Sciences

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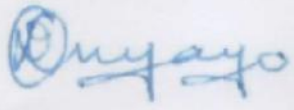
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DEDICATION

I dedicate this work to Almighty God for giving me strength and courage to complete my studies and breaking the long covenant chains that were holding back my life. Also to my lovely husband Wambura Messo Mattuh for the encouragement throughout my studies, and to my Lovely daughter Elizabeth Wambura and my sister Theresia Peter Langa who prayed all the time for God to give me courage, strength and to bless the work of my hand.

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is among the most important cereal crop in the world. Sorghum is a food security crop in most African and Asian countries especially in arid and semi-arid areas where drought is persistent. However, sorghum yields are low in most parts of Africa. One of the reasons for low production is lack of quality seeds due to inappropriate technology including postharvest handling and processing of sorghum seeds. The aims of this study were to evaluate the effects of endosperm type, seed moisture content levels and threshing methods on threshability and quality parameters of the seeds. Two varieties of sorghum were grown in two diverse locations, Kiboko and Katumani. One variety Kari-mtama 1 has hard (vitreous) endosperm type while another variety Seredo has soft (non-vitreous) endosperm type. After harvesting, sorghum panicles were dried in the sun and oven. The panicles were threshed separately for each drying method at two seed moisture levels namely 18-20% and 13-14% moisture contents (M.C). The three threshing methods used included beating by wooden stick in tied sack, using wooden mortar and pestle as well as threshing machine. Mechanical damage was evaluated by using tetrazolium test while the germination percent, germination time and seedling vigour were evaluated using paper towel method in the laboratory following ISTA rules.

The results showed that vitreous endosperm variety had significantly high percentage threshability and significantly low mechanical damage than non-vitreous endosperm variety under both drying methods. Also, threshing machine had significantly lower threshability and mechanical damage compared to the other two methods. There was significant increase in threshability and decrease in mechanical damage when the seeds were threshed at 13%-14% moisture content. In both drying methods, the seeds that were threshed at low moisture content (13%-14%) had significantly high germination percentage, seedlings vigour and took

significantly short time to germinate compared to those which were threshed at high moisture content (18%-20%). Similarly, seeds from panicles that were threshed using machine had significantly higher germination percentage and seedlings vigour followed by those from panicles that were threshed by beating with wooden stick and mortar and pestle, respectively. Also, the seeds from panicles that were threshed using machine took significantly short time to germinate compared to the other two threshing methods.

The results confirmed that, vitreous endosperm sorghum varieties are better for threshability and pose breakage resistance compared to non-vitreous sorghum. However, under both endosperm types threshing machine is the best method for threshing sorghum panicles to obtain high quality seeds followed by beating with wooden stick. Similarly, the results indicate that threshing should be done at low moisture content (13%-14%) for high threshability and quality seed. There was no significant genotype by environment interaction, implying that the results are applicable for varieties planted in different environments.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Sorghum (*Sorghum bicolor* L. Moench) is a coarse tropical grass which belongs to the family Gramineae and its height varies from 0.5 to 5.0 meters. The number of leaves on the main stem varies from 16 to 27 although early maturing varieties have fewer leaves. Sorghum is a self-pollinating crop which is drought-resistant and thus it is suited to areas with low rainfall and water stress conditions. The inflorescence may be a loose to dense panicle with many primary branches (Meru, 2010; PARC, 2011). Sorghum has C₄ photosynthetic pathway and is characterized by a long root system which maximizes water uptake (Meru, 2010; Kange *et al.*, 2014).

Sorghum is native in African tropical areas. The cultivated sorghum is grouped into four categories depending on uses i.e sweet, grain, grass and broom sorghum. Grain sorghum is used mainly for food, seed and rarely is used as raw material in alcoholic beverages. Grass and sweet sorghum are used to make green feed and sweetener syrup while broom sorghum is for making brooms (Mwadalu and Mwangi, 2013). Sorghum is globally cultivated and it is ranked as the fifth most important cereal after maize, wheat, rice and barley (Dharmaputra *et al.*, 2012). In Africa, Sorghum is the second most important cereal after maize where about 20 million tonnes per annum are produced. In the year 2013, the average area cultivated in Africa was about 26 million (M) hectares (ha) with a production of about 25 million tonnes with an average yield of about 0.9 tonnes per ha (FAOSTAT, 2015). The largest producers of sorghum in Sub-Saharan Africa include Nigeria, Sudan, Ethiopia, Burkina Faso and Tanzania. These countries produce about 75% of the total production in the whole region (ASARECA, 2011).

America is the leading continent in sorghum production followed by Africa (Figure 1).

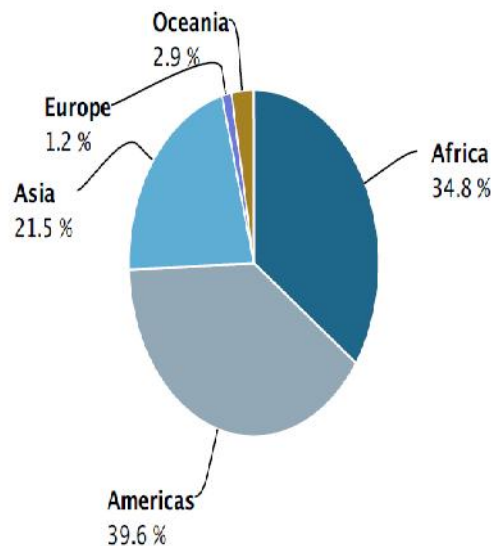


Figure 1: Sorghum production share in the world from 1990-2013: Source// (FAOSTAT, 2015)

Sorghum is commonly grown under rain fed conditions by small scale farmers. They lack resources for inputs such as fertilizers, pesticides, certified seeds and irrigation. Although, the demand for sorghum is high, its production is challenged by lack of inputs, non-availability of quality seeds and susceptibility to pests and diseases. These constraints have led to low yield by small scale farmers (Kange *et al.*, 2014). The successful crop establishment is determined by the quality of seeds. It has been reported that, seed of high quality germinate rapidly and its seedling emerge easily with vigorous root and shoot systems (Abuelgasim and Dessougi, 2011). According to Muui *et al.* (2013), most small scale framers in Africa use farm saved seeds whose quality is usually poor and as a result production is affected.

Low production in sorghum may also be attributed to damage or eating by birds and poor postharvest handling including threshing, drying and storage practices. Threshing is one of the critical aspects in post-harvest handling of the seeds in maintenance of quality (Olaoye *et al.*, 2009). Similarly, threshability of sorghum seeds is of economic importance due to its

impact on seed quality and hence market value. Free threshed varieties save time and energy during processing, and also produce clean and quality seed (Adeyanju *et al.*, 2015). In developing countries, most farmers thresh their seeds by traditional methods and by the use of threshing machine. These traditional methods include pounding using mortar and pestle, beating with sticks or rubbing panicles on hard surfaces and treading under the feet of man or hooves of animals (Kange *et al.*, 2014; Dibaba and Tesfaye, 2015). These methods may cause mechanical damage on seeds which is even worse when the seeds are threshed at unsuitable moisture content.

The recommended threshing moisture of grain seeds is around 14% to 16% (WFP, 2012). Farmers commonly thresh their seeds immediately after harvesting with moisture content around 18%-22% although this is the ideal for harvesting (McNeil and Montross, 2003; Murphy Brown's sorghum Programme, 2012). At this seed moisture content, the grains are soft and much more prone to mechanical damage during threshing and may result to poor threshability of the seeds (Sumner, 2012). According to Afrakhteh *et al.* (2013) high moisture may cause bruising of the seed during processing which reduces germination capacity of the seeds and results into low yield.

Poor storage conditions can result into high deterioration of seed quality. During storage, sorghum could be infested with pests like rats and affected by pathogens (Dharmaputra *et al.*, 2012). Seed moisture content can be considered as the most important factor to the quality of the stored seed. Before storage, drying is necessary to bring down seed moisture content to the appropriate moisture level for storage which is about 13%-14%. The seeds which are under dried loose viability during storage due to mould activities which are facilitated by high seed moisture content (Afrakhteh *et al.*, 2013). According to Alencar and Faroni (2011) the

seed with high moisture content greater than 13%, deteriorates easily during storage due to loss in dry matter caused by continuing respiration process, they also get attacked by fungi easily causing reduction in germination.

1.2 Problem Statement

The climatic change in many areas of Africa region has led to persistently unstable and declining agricultural productivity due to successive drought conditions. This has given rise to the need to find alternative crops such as sorghum that are drought tolerant and thus more suitable for this region. Although the demand for sorghum is increasing, yields are generally low and can vary considerably from year to year. One of the critical factors for the poor yield in sorghum is non availability of quality seeds. In many African countries, the sorghum seed industry is not well developed hence farmers use informal seed sources. Most save their own seeds which they plant during the next generation or obtain seeds from neighbours (Ahmed and Alama, 2010; Muui *et al.*, 2013).

The quality of informal seeds produced by farmers is generally poor. One of the important factors causing low quality of the seeds produced by farmers is insufficient knowledge of postharvest handling and processing practices such as threshing, drying and storage (Dharmaputra *et al.*, 2012). Sorghum seed processing activities practiced by farmers are not carried out appropriately resulting to deterioration in quality (Dharmaputra *et al.*, 2010). It has been reported that, in developing countries, most farmers thresh their seeds by traditional methods and by the use of threshing machines (Dibaba and Tesfaye, 2015). These methods may cause seed loss because of mechanical damage to the grain kernels which is much worse when the seeds are threshed at unsuitable seed moisture content (Olaoye *et al.*, 2010; Kavak *et al.*, 2012). Seeds are generally harvested at high moisture content between 18%-22% and

hence need to dry to appropriate moisture content (13%) before storage (Alencar and Faroni, 2011; McNeil and Montross, 2013). The common methods used by farmers to dry seed include sun although this has been reported to be harmful and it affect seed quality (Babiker *et al.*, 2010; Thai, 2015). There is inadequate knowledge about threshing of sorghum and few studies have been conducted on threshability without focus on quality aspect of threshed seed grains (Saedirad *et al.*, 2013); Adeyanju *et al.*, 2015).

1.3 Justification

Sorghum is one of the most high value crop grown in arid and semi arid areas of Africa due to its adaptability to drought conditions. Farmers are the major source of seeds in sorghum production. However, they have limited knowledge on factors affecting seed quality include growing conditions, variety and postharvest handling of seed. According to Hodges (2012), postharvest losses of sorghum were 11.3% in various East and Southern African countries and this is due to improper harvesting, drying and threshing practices by small scale farmers.

Threshing is the most critical aspects in post harvest handling of grain seeds especially with maintenance of quality (Olaoye *et al* 2009). Farmers commonly thresh their seeds immediately after harvesting with moisture content around 18%-22% although the recommended moisture for threshing is 14%-16% (McNeil and Montross, 2003; MurphyBrown's sorghum programme, 2012; WFP, 2012). At this seed moisture content, the grains are too soft and much more prone to mechanical damage during threshing. According to Dibaba and Tesfaye (2015), most farmers in developing countries thresh their seeds by traditional methods such as pounding in mortar and pestle, beating with sticks or rubbing panicles on hard surfaces, treading under the feet of man or hooves of animals and by the use of threshing machine. This research therefore, aims at addressing some of the gaps in

knowledge of selected threshing practices of sorghum seeds at appropriate seed moisture contents to maintain the quality. Also, providing recommendations to farmers and seed companies on the most appropriate moisture content of the seeds to be threshed and identifying those threshing methods to be used in sorghum to maintain good quality of seeds.

1.4 Objectives

General Objective

To reduce postharvest losses that are associated with sorghum by studying the factors those influence these losses.

Specific objectives

1. To determine the influence of threshing methods, seed moisture content levels and endosperm types, on threshability and seed mechanical damage of sorghum when panicles are dried in the sun and oven
2. To determine the effect of threshing methods, seed moisture content levels and endosperm types, on germination percent, mean germination time and seedling vigour of sorghum when panicles are dried in the sun and oven

1.5 Hypothesis

1. Threshing methods, endosperm types and seed moisture levels have no influence on threshability and mechanical damage of sorghum seed
2. Threshing methods, endosperm types and seed moisture levels have no effect on sorghum germination percent, germination time and seedling vigour.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany of Sorghum

Sorghum (*Sorghum bicolor* L. Moench) is native to the tropical areas of Africa. The oldest cultivation records date back to 3000 B.C. in Egypt. Sorghum is produced throughout the tropical, semi-tropical and arid regions of the world (Mwadalu and Mwangi, 2013). Sorghum is a monocotyledon self-pollinating crop which belongs to the family graminae. The crop has C₄ photosynthetic pathway and the plants are characterized by long root systems which maximize water absorption and as a result the crop can perform well in areas with water stress (Muui *et al.*, 2013; Kange *et al.*, 2014).

Sorghum plant has two types of roots which include primary and secondary. The first root which develops when the seed germinates is called the primary root and it is used by the seedling for absorption of water and nutrients from the soil. The secondary roots come from nodes below the soil. Sorghum leaves are green, grass like and flat. The leaves vary from 8-22 leaves per plant depending on the environmental conditions (Plessis, 2008). The stem of sorghum is solid, erect and it can grow from 0.8 m to 5 m in height. Sorghum plant may form tillers depending on variety, nitrogen supply and temperature (Prasad and Staggenborg, 2010). The inflorescence of sorghum may be compact or open. The shape and colour of the flower panicle varies between cultivars. Panicles are carried on a main stem or peduncle with primary and secondary branches on which the florets are borne. The number of kernels in each panicle varies from 800 to 3 000 which are usually partly enclosed by glumes. The flowers of sorghum open during the night or early morning. Those at the top of the panicle open first and it takes approximately 6 to 9 days for the entire panicle to flower (Plessis, 2008).

2.2 Growth and Development of Sorghum

Time from planting to emergence of sorghum is 5 to 10 days depending on the growing conditions, soil temperature, moisture, seed quality and the depth of planting. After seedling emergence, the plant develops through three growth stages. The first growth stage is vegetative phase which is characterized by development of vegetative structures, leaves and tillers. The crop can tolerate a high degree of water stress at this stage (Gerik *et al.*, 2003). According to Prasad and Staggenborg (2010), at vegetative stage, the sorghum crop forms about 12-18 leaves and remains in this phase for about 30-40 days.

The second growth stage is when the plant forms reproductive structures, the panicle, seed setting and grain filling. This is considered to be the most critical period for grain production because the number of seed set per plant determines the final yield of the crop. Therefore, anything that interferes with panicle formation reduces the number of seed to be set per plant and hence lowers the yield (Gerik *et al.*, 2003). Sorghum flowering occur after 40-70 days from the day of effective germination depending on variety and environmental temperature (Prasad and Staggenborg, 2010).

The final growth stage of sorghum is grain filling which starts with flowering and continues until dry matter accumulation in the grain stops. The time taken from flowering to physiological maturity is about one – third (1/3) of the total time from planting. However, this can vary depending on variety and environmental conditions. Also, the time required between physiological maturity and grain moisture suitable for harvesting depends upon variety and weather conditions. The moisture content of the seed at physiological maturity varies with variety and growing conditions and it is usually between 25% and 35% (Vanderlip, 1993). Early sorghum varieties take 90-110 days while medium varieties take 110-140 days to mature. When the environmental temperature is below 20°C, the number of

days to maturity extends for about 10-20 days depending on variety. It has been reported that, at 15°C, the crop would take about 250-300 days to mature (USAID, 2014).

2.3 Ecological Requirement of Sorghum

Sorghum is grown as an annual crop and has ability to yield in harsh environment. Sorghum requires well drained fertile soil although it can perform well in soil with high clay content. The crop grows in areas with annual rainfall of about 300 mm and it performs well at temperatures range from 26-30°C and the crop can tolerate high temperatures than other crops (Kange *et al.*, 2014; USAID, 2014). It grows in areas between 500-1700 metres above sea level and responds positively to irrigation in areas with very minimal rainfall (Plessis, 2008; Kange *et al.*, 2014).

The daily water use of sorghum crop is about 300-500 mm/ha depending on the growth stage although it can reach maximum of 600-700 mm/ha. An acceptable yield of sorghum requires soil moisture of about 400-500 mm; however maximum yield of sorghum require moisture of about 600-800 mm (Prasad and Staggenborg, 2010).

2.4 Economic Importance of Sorghum

Sorghum is an important cereal crop which is grown globally for human food, animal feed as well as for industrial use (Kange *et al.*, 2014). It also has high nutritional content which allows it to be used either as alternative food or feedstuff. Sorghum grains can substitute maize and rice because the nutritional content of sorghum is close to that of maize and rice. For example, sorghum has carbohydrate content of 80.42% compared to 86.45% in milled rice and 79.95% in maize. Sorghum has slightly higher protein content (10.11%) than milled rice (9.28%), but lower than maize (11.02%). The lipid content in sorghum is 3.65% which is higher than milled rice 1.88% and it is lower than that in maize 5.42% (Dharmaputra *et al.*,

2012). In African societies, main food products prepared from sorghum are porridge, fermented and unfermented bread, alcoholic beers and beverages, weaning foods and malted flours for brewing (FAO, 1999).

Around 32 million people in Tanzania, Kenya and Uganda depend entirely on sorghum for their livelihoods and this is about one third of the population in the region (ASARECA, 2011). Although the production level is not stable and varies from year to year, Tanzania ranks number 14 in sorghum production in the World (FACTFISH, 2015). For example, the production level in the year 2000 was 598,200 tonnes but dropped sharply to 198,870 tonnes in 2003. It increased to 971,198 tonnes in 2007 and slightly dropped to 55,1270 in 2008 (Figure 2).

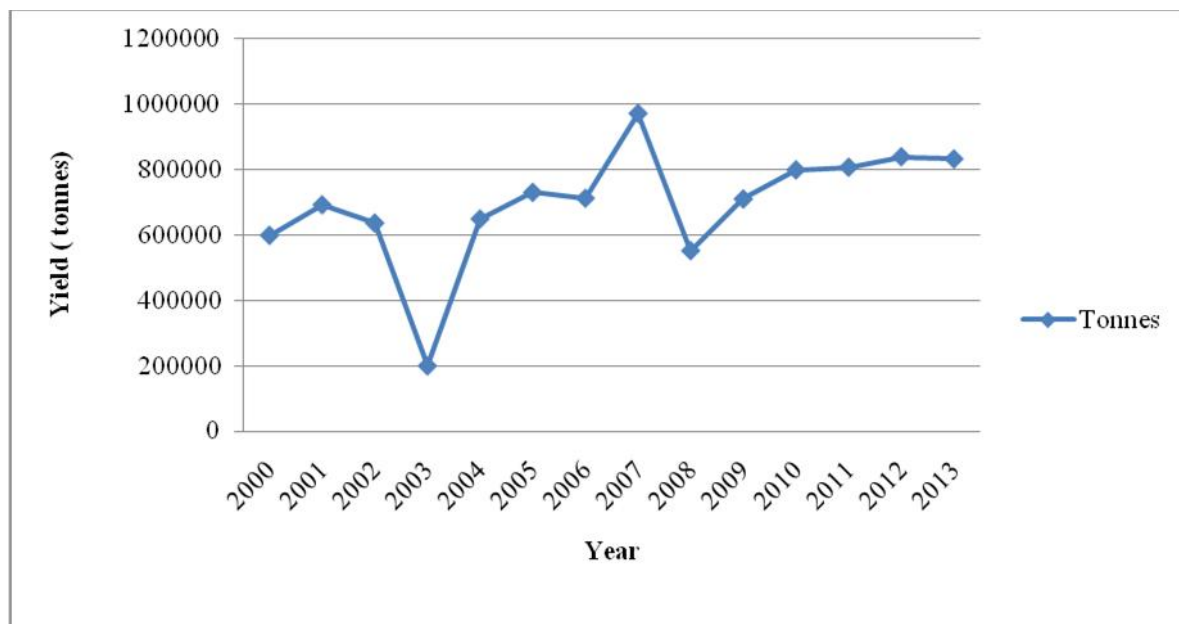


Figure 2: Sorghum production levels in Tanzania from 2000 to 2013; Source// (FAOSTAT, 2015).

Most sorghum (95%) produced in Tanzania is consumed on-farm and only small surplus enters the market (Rohrbach and Kiriwaggulu, 2007). In Kenya, sorghum is currently gaining popularity due to its wide adaptability compared to other crops (Kigenet *al.*, 2014). Increase

in sorghum popularity is an indication that people in Kenya are getting increasingly aware of the potential of the crop as a food security crop although the adoption of improved sorghum varieties is still very low. Sorghum has the potential to solve the food insecurity problem in arid and semi-arid areas, due to its ability to yield in harsh environments and to grow well under various types of soils (Mwadalu and Mwangi, 2013). Trials conducted in Kenya also showed that, sorghum has the capacity to produce higher yields than maize due to its ability to produce grain with minimal rainfall (Taylor, 2003).

2.5 Constraints to Sorghum Production

According to Muui *et al.* (2013) and Kange *et al.* (2014), production constraints of sorghum are lack of inputs, non-availability of quality seeds, rainfall variability, diseases and pests. Majority of sorghum farmers are small scale with low income and hence are unable to purchase necessary inputs such as fertilizers, quality seeds and chemicals for pest's control.

Low production can also be attributed to infestation by birds such as sudan dioch (*Quelea quelea*) and poor pre-harvest and post-harvest handling of sorghum seeds. Poor pre-harvest and post-harvest practices of seed influence the storability of the seed. The quality of seed entering the store determines the storage life of seed and performance of the seed when planted. The quality of the seeds cannot be compensated by the storage facilities. Therefore poor pre-harvest and post-harvest handling such as delay in harvesting, rough handling and improper drying methods results into low yield due to deterioration of seed quality. Most sorghum farmers thresh their seed at unsuitable seed moisture content which results into seed damage. Normally, farmers thresh their seed during harvesting by use of combine harvesters or immediately after harvesting. At this stage, sorghum seeds have high moisture content and they are too soft and prone to damage (Sumner, 2012). Once the seed has deteriorated due to poor pre-harvest and post-harvest practices, its quality will remain poor even if

modern storage facilities are used (Thai, 2015). This result into yield problems as deteriorated seeds leads to poor crop establishment.

2.6 Sorghum Seed Systems

Quality seed has become a big challenge to smallholder farmers in Africa due to its limited access. Most of the time for varieties developed locally, basic seed necessary for producing certified seed is available in limited quantities and hence, seed enterprises cannot produce large quantities of certified seeds (Jones and Rakotoarisaona, 2007). Furthermore, the supply of seed is even more limited or completely absent when it comes to indigenous or local crops like sorghum which plays an important role in food security. In sorghum production, farmers are the major source of seeds because in most countries there is a weak supply of formal seeds. In many African countries, sorghum seed industry is not well developed hence farmers use farm saved seeds or buy from the local market (Ahmed and Alama, 2010). In a survey conducted at Bomet in Kenya by Moi University researchers, it was observed that 98% of sorghum farmers use informal seed supply for sorghum, 69% saved their own seed for planting, while 24% obtained seeds from their neighbours (Ochieng *et al.*, 2011). Also in the same survey, 82% of the farmers stated that they were not using improved varieties because they were not easily available.

2.7 Postharvest Handling and Quality of Sorghum Seeds

During the growth of field crops, maximum seed quality is gained at physiological maturity (Kavak *et al.*, 2012). After harvest, seeds are removed from plant material by threshing. The threshing process involves application of mechanical force using hand or by machine. Postharvest handling of sorghum such as threshing, drying and storing affect the quality of the seeds. According to Dharmaputra *et al.* (2010), based on the surveys conducted in

Demak and Wonogiri Regencies in Central Java, the postharvest handling of sorghum practiced by farmers is not carried out appropriately resulting to deterioration of sorghum seeds.

2.7.1 Sorghum threshability and threshing methods

Threshability is one of the important considerations in sorghum production especially in smallholder farmers where seed threshing is practised manually. The ease with which seed grains are detached from the panicle and glumes can be due to genetic variability of this trait between varieties (Adeyanju *et al.*, 2015). According to Mekbib (2009), farmers developed traditional classification of sorghum into three groups based on threshability which are free threshing with 0-10% unthreshed kernels, semi-threshable with 10-15% unthreshed kernels and poor threshing with greater than 50% unthreshable kernels. Similarly, International Board of Plant Genetics Resources (IBPGR) group sorghum into five classes depending on threshability. These include very difficult (less than 50% threshed seeds), difficult (60%-80% threshed seeds), intermediate (80-84 threshed seeds), good (90-94 threshed seeds) and excellent (99-100%) threshed seeds (Adeyanju *et al.*, 2015).

Threshability of a variety can be affected by, threshing methods, moisture of the seeds and drought stress. Drought stress causes premature termination of grain filling and hence poor threshability (Adeyanju *et al.*, 2015). Sorghum seeds reach physiological maturity when moisture of the seeds drops to about 30%. However, sorghum seeds are too soft when the moisture content exceeds 25% and results into poor threshability and cracked seed grains (Sumner, 2012). The common threshing practices of sorghum involve beating the dried sorghum panicles with sticks on the ground or in sacks, trampling by cattle and pounding. It has been reported that, in developing countries, most farmers thresh their seeds by traditional

methods and by the use of threshing machine. These traditional methods include pounding in a mortar and pestle, beating with sticks or rubbing panicles on hard surfaces and treading under the feet of man or hooves of animals (Kange *et al.*, 2014; Dibaba and Tesfaye, 2015; Adeyanju *et al.*, 2015). Research done in Kenya in 2011, revealed that 98% of sorghum farmers thresh their seeds by beating with sticks or rubbing panicles on hard surfaces (Ochieng *et al.*, 2011). Grain is separated from dirt and chaff by winnowing (USAID, 2012). The time required for threshing depends on variety, the degree of dryness of the grain, and the method of threshing (FAO, 1999).

2.7.2 Effects of threshing method and moisture content on damage and germination of seeds

The recommended threshing moisture for sorghum seeds is around 14%-16% and therefore, threshing above this moisture content results in seed quality deterioration (WFP, 2012). The mechanical damage to the seed during threshing varies depending on the genetics of the variety. It has been reported that, grain hardness plays an important role in seed processing and vitreous endosperm variety pose breakage resistance (Felker and Paulis, 1993; Ioerger *et al.*, 2007). Dharmaputra *et al.* (2012) studied post harvest quality improvement of sorghum grain and showed that method of threshing of sorghum seeds have significant effects on grain damage in terms of cracked and broken grains and germination. The percentage of damaged grain of sorghum threshed using a wooden stick was higher and significantly different from that threshed with a paddy thresher. Also, the percentage of seed germination was higher in sorghum threshed using paddy thresher (93.3%) and significantly different from that of sorghum threshed using a wooden stick (91.04%).

Sinha *et al.* (2009) studied the effect of moisture content, concave clearance and cylinder speed on visible injury, internal injury, germination percentage and threshing efficiency of chickpea seed crop. The result showed that, seeds that were threshed at various moisture contents had significant difference in internal injury. Cylinder speed at 8.94 meter per second (m s^{-1}), concave clearance at 14 mm and moisture content at 10% resulted in seeds of minimal visible and internal injury, and optimum threshing efficiency. Similarly, Koyuncu *et al.* (2007) found that, the chickpea varieties varied significantly in threshing efficiency depending on the physical characteristics and mechanical specifications among varieties. Such adverse effects on seed quality may affect sorghum seeds if processed with similar machines.

Vejasit and Salokhe (2004) studied machine-crop parameters of an axial flow thresher for soybean and reported that, moisture content, feed rate and threshing drum speed significantly affects the output capacity, threshing efficiency, grain damage and grain losses during soybean threshing. Similarly, Kavak *et al.* (2012) reported that, seed moisture content and threshing methods significantly affected the quality of bean seeds and seeds threshed at below 14% seed moisture content (SMC), had higher incidence of cracked seed coats and had the lowest percentage of normal seedling. Other researchers have also shown that, too much moisture content can be as damaging to seed quality just as too little moisture. Saeidirad and Javadi (2011) and Ajav and Adejumo (2005) evaluated the effect of thresher variables including seed moisture content in cumin and okra, respectively and found that moisture content significantly affects seed damage and germination. In cumin seeds, the results showed that as moisture content increased from 7% to 13%, separated and damaged seed decreased from 92.8% to 90.4% and from 10.1% to 7.6%, respectively.

2.7.3 Sorghum drying and its effects to seed quality

Drying is very important in sorghum like in other crops since mature seed of any crop tend to have high moisture content which is not suitable for threshing and seed storage (Sumner, 2012). Sorghum grain is usually dried until it reaches a moisture level which is suitable for storage. For optimum storage, drying to a 10-13% moisture level is good because this moisture level prevents germination, mould growth and reduces insects attack to the seed grain (USAID, 2012). Wet sorghum cannot be handled in storage because it encourages germination and mould growth. There are various seed drying methods such as sun drying, oven drying and use of a mechanical drier but sun drying is the common method and the most widely used by farmers. However this method has been reported to result in deterioration of seed quality (Thai, 2015). The most important consideration in choosing a drying method is that, the method should dry seed efficiently and has no serious effects on seed quality.

Babiker *et al.* (2010) studied the effects of low cost drying methods on seed quality of sorghum and reported that sorghum seed viability as represented by germination percentage is significantly affected by seed drying methods irrespective of the genotype. Seedling vigour which was assessed in terms of radical length, shoot dry weight and germination speed was also significantly affected by drying methods. In the same study, it was reported that, drying methods significantly affected the speed of germination in terms of number of days. The fastest germination rate was found in shade drying while the lowest was in sun drying among the four drying methods which were evaluated namely, sun, shade, seed drier and silica gel. Similarly, Thai (2015) studied the effects of three methods of drying on viability, vigour and storability of maize, sorghum and soybean seeds. The results showed that drying methods significantly affected the quality of seeds. The germination percentage and vigour

was low from the seed dried by sun compared to other drying methods namely oven and mechanical drier. Also in the same study, it was observed that the germination of seed was decreasing with storage time depending on drying method. For maize; sorghum and soybean, the decrease in germination percentage was rapid in sun drying than in oven and mechanical drier. Oven and mechanically dried seeds had significantly high germination percentage than sun dried seeds during storage while there was no significant difference between the seeds dried by oven and mechanical drier in all three crops.

3.0 CHAPTER THREE

Influence of Variety Endosperm Type, Seed Moisture Content and Threshing Methods on Threshability and Mechanical Damage of Sorghum Seeds from Panicles Dried in the Sun and Oven

3.1 Abstract

Sorghum is an important cereal crop and is native to African tropical areas. It is a globally cultivated crop and the fifth most important cereal after maize, rice, wheat and barley. The objectives of this study was to determine the effects of endosperm type, seed moisture content and threshing methods on panicle threshability and seed mechanical damage of sorghum. Two varieties of sorghum were grown into two diverse locations, Kiboko and Katumani. One variety Kari-mtama 1 has hard (vitreous) endosperm while another variety Seredo has soft (non-vitreous) endosperm. After harvesting, sorghum panicles were dried in the sun and oven. The panicles were threshed separately for each drying method at two moisture levels including 18-20% and 13-14%. The three threshing methods used included beating by wooden stick in tied sack, using a wooden mortar and pestle as well as using threshing machine.

The results showed that vitreous endosperm variety had significantly ($P < 0.05$) high percentage threshability and significantly low mechanical damage than non-vitreous endosperm variety under both drying methods. Also, panicles threshed using machine had significantly lower threshability and seed mechanical damage than the other two threshing methods. There was significant ($P < 0.05$) increase in threshability and decrease in seed mechanical damage when the panicles were threshed at 13%-14% moisture content compared to 18%-20% moisture content especially using a mortar and pestle method. The lowest seed mechanical damage was recorded from the seeds threshed by machine at seed moisture

content 13%-14% while the highest damage was recorded for the mortar and pestle method at 18%-20%.

The results suggested that, sorghum panicles should be threshed at low moisture content (13%-14%) to maximize threshability and minimize mechanical damage. For better seed quality; machine threshing is the best method to be used to avoid mechanical damage and seed quality deterioration. Although the mortar and pestle method results in high threshability percent, it should be avoided because it results into high mechanical damage and hence affects germination and seedling vigour as compared to beating with wooden stick and threshing machine. Drying methods used to dry seed panicles before threshing had no effects on threshability and mechanical damage. This implies that sorghum panicles can be dried either in the sun or oven without affecting threshability and mechanical damage at the two moisture levels and by using the three threshing methods.

3.2 Introduction

Threshing process involves application of mechanical force using hands or by machines to separate the seed grains from panicles. Threshability is one of the important considerations in sorghum production due to its impact on total grain yield, grain quality and hence market value. The ease with which seeds are detached from the panicles and glumes are important especially to smallholder farmers where threshing is practiced manually (Adeyanju *et al.*, 2015). It has been reported that, some sorghum varieties are free threshing where seeds are detached easily from the panicles and glumes while other varieties have sticky glumes where seed get off from the panicles easily but the glumes remain attached to the seed (Adeyanju *et al.*, 2015). Free threshing varieties produce clean and quality seeds. This saves time and energy during processing. The vitreosity or hardness of seed grains and environmental

conditions during crop growth also plays an important role in panicle threshing and seed quality (Ioerger *et al.*, 2007; Adeyanju *et al.*, 2015).

During threshing of panicles, mechanical damage is one of the great concerns to the seed producers. It is the most common reason for poor seed quality due to the mechanical injury the seed receives during threshing. Damaged seeds have minimum storage life and poor germination because they have damaged embryos and are less resistant against pests and diseases, furthermore, damaged seeds weaken germination capacity (Spokas *et al.*, 2008). The mechanical damage of the seed can occur when the seed is threshed at unsuitable seed moisture content or using improper threshing method (Kavak *et al.*, 2012). Seed damage also depends on the vitreosity of the variety. It has been reported that vitreous or hard kernels have better breakage resistance than non-vitreous kernels (Felker and Paulis, 1993). According to Saedirad *et al.* (2013) and Adeyanju *et al.* (2015), there is inadequate knowledge about threshing of sorghum and few studies have been conducted on threshability with no focus on the quality aspects of threshed seed grain. Therefore the aim of this study was to determine the effects of endosperm type, seed moisture content and threshing methods on panicle threshability and seed mechanical damage of sorghum.

3.3 Materials and Methods

3.3.1 Study area

The seed crop was planted at two locations Kiboko and Katumani which are under Agricultural Mechanization Research Institute (AMRI). Kiboko research sub centre is located in Kiboko, Makindu Division, Makindu sub-county, Makueni County. It lies within longitudes 37.7235°E and latitudes 2.2172°S. Kiboko is 975 m above sea level and the station receives between 545 and 629 mm of rainfall coming in two seasons. The long rain

season is between April and July while the short rain season is between October and January. This is a hot dry location with a mean annual temperature of 22.6°C, mean annual maximum of 28.6°C and mean annual minimum of 16.5°C. Soils are well drained, very deep, dark reddish brown to dark red, friable sandy clay to clay (Acric-Rhodic Ferrassols) developed from undifferentiated basement system rocks, predominantly banded gneisses (CYMMIT, 2013).

Katamani is the AMRI headquarter and is located in Machakos County, on latitude 1°35'S and longitude 37°14'E, and at an altitude of about 1600 m. It receives mean annual rainfall of around 655 mm. The average seasonal rainfall for the long rains is 272 mm while that for the short rains is 382 mm. The mean maximum and minimum temperatures at the centre are 24.7°C and 13.7°C, respectively. The soils in the area show a strong coherence to the different rock types and landforms and mainly cambisols, ferralsols, luvisols and vertisols (KALRO, 2016).

3.3.2 Experimental design

The crop was established under split-split plot on Randomized Completely Block design (RCBD) with three factors and these are varieties (V) as main factor, moisture level (M) as sub factor and threshing method (T) as sub-sub factor with three replications. The main treatments were two varieties used which were the vitreous (hard) endosperm variety (KARI-Mtama I) as variety 1 and non-vitreous (soft) endosperm (Seredo) as variety 2. The seeds were threshed at two moisture levels which are between 18%-20% moisture content (M1) and 13%-14% moisture content (M2) using three threshing methods. The threshing methods that were used are beating by wooden stick (T1); threshing by wooden mortar and pestle (T2) and threshing by using machine (T3). There were 12 treatments in each location which are

variety 1, moisture level 1, threshing method 1 (V1M1T1), variety 1, moisture level 1, threshing method 2 (V1M1T2), variety 1, moisture level 1, threshing method 3 (V1M1T3), variety 1, moisture level 2, threshing method 1 (V1M2T1), variety 1, moisture level 2, threshing method 2 (V1M2T2), variety 1, moisture level 2, threshing method 3 (V1M2T3), variety 2, moisture level 1, threshing method 1 (V2M1T1), variety 2, moisture level 1, threshing method 2 (V2M1T2), variety 2, moisture level 1, threshing method 3 (V2M1T3), variety 2, moisture level 2, threshing method 1 (V2M2T1), variety 2, moisture level 2, threshing method 2 (V2M2T2) and variety 2, moisture level 2, threshing method 3 (V2M2T3).

3.3.3 Set up of the experiment

The size of each experimental plot was 5.0 m x 3.0 m totalling 15 m² and plots were separated by one meter path. There were 12 plots in each replication/block; therefore, the total number of plots in all three replications was 36. The path between one block/replication to another was 1.5meters. In each plot, sorghum seeds were drill sown at a spacing of 60 cm x 25 cm and there were 6 rows which were thinned to 20 plants per row. Thinning was done three weeks after germination and the total number of plants in each plot was 120. The inner four rows were used as net plot for taking data.

3.3.4 Seed harvesting, panicle drying and threshing

The seed crop was harvested by hand and the panicles were cut using a knife after seed grain had reached the physiological maturity (PM) three months after planting. The panicles that were threshed at higher moisture level (18%-20%) were harvested when the seed was about 25% moisture content while the panicles that were threshed at lower moisture level (13%-14%) were left in the field. These were harvested when moisture content was about 20%.

From each plot, only 60 plants were harvested from the inner rows (net plots). The harvesting was done in two batches, each containing 30 randomly selected plants. After harvesting, sorghum heads/panicles were dried to the required moisture levels namely 18%-20% and 13%-14% for threshing. Two drying methods used for drying included sun and oven. Therefore, from 60 plants harvested in each plot, 30 heads/panicles were dried in the sun before threshing and the other 30 were dried in the oven at 36⁰ C before threshing.

In the sun, sorghum panicles were placed on the ground spread on top of papers direct to the sun light. In the oven, sorghum panicles were placed inside the oven per samples without mixing and the oven was set at 36⁰ C. Extra five heads/panicles were included in each drying methods and these were used to regularly monitor the moisture content until the seeds attained the required moisture for threshing. The moisture content of seeds was determined using agraTronix MT-16 grain moisture tester before threshing. Machine threshing was done by one specific bulk machine thresher in both locations which contained rotating rasp bar cylinder. The machine used was from Allan Machine Company (ALMACO 99, M AVE NEVADA 10WA 50201 USA) (Annex 1). The mortar hole depth was 22 cm and weight of the pestle and wooden stick was 1.5Kg (Annex 2). After threshing, the seeds were separated from dirt and chaffs by manual winnowing, and then the seeds from each sample were divided into two groups; completely threshed seeds and the seeds that remained in glumes. Percentage threshability was calculated as percentage weight of completely threshed seed (seeds without glumes) out of total seed weight threshed from 30 panicles in each sample as described by (Nalamet *al.*, 2007; Adeyanjuet *al.*,2015)i.e.

$$\text{Percentage threshability} = \frac{\text{completely threshed seed (seeds without glumes)}}{\text{Completely threshed + seeds in glumes}} \times 100\%$$

Completely threshed + seeds in glumes

3.3.5 Mechanical Damage Test

After threshing, the seed samples were taken to the University of Nairobi laboratory for mechanical damage test. The mechanical damage was determined using 200 seeds for each sample. The seeds were pre-conditioned in moistening paper towel for 18 hours at room temperature. After pre-conditioning, the seeds were cut longitudinally with a sharp surgical blade through the centre of the embryo. The seeds were completely bisected and one half of each seed was used to represent one seed in the evaluation. After cutting, the seeds were immersed in 1% aqueous solution of 2, 3, 5 triphenyltetrazolium chloride for about 3 hours for staining at room temperature. The procedures were done according to ISTA (2015). Each seed was evaluated based on staining pattern, intensity, location of stain and unstained embryonic tissue and the seeds were divided into three groups namely; undamaged seeds, mechanically damaged seeds and dead seeds. The undamaged seeds were uniformly stained with dark pink at the embryonic axis. Damaged seeds had very darker stained embryonic tissue or the embryo had very weak stain which was not uniform with some darkish parts at the embryonic axis. The dead category included seeds which had not stained or part of embryonic axis were completely unstained. The number of seeds with mechanical damage plus dead seeds category was considered as damaged seed in the calculation of percentage of mechanically damaged seeds. The results were presented in percentage of mechanical damage seed as number of mechanically damage seed out of total number of seed tested per each sample.

3.4 Data Collection and Analysis

Data collection included percentage threshability and percentage mechanical damage of the seeds. All data were subjected to analysis of variance using the General Statistical package (GENSTAT) edition 13 for windows. The means were separated using least significant difference (LSD) test at 5% and 1% levels of significance.

3.5 Results

Influence of Location, Variety, Seed Moisture Content, Threshing Methods and Their Interaction on Threshability and Mechanical Damage of Sorghum Seeds

The analysis of variance (ANOVA) for panicle threshability and seed mechanical damage percent are presented in Table 1. Significant ($P < 0.05$) differences for panicle threshability were observed between locations, varieties, seed moisture content and among threshing methods under both drying methods. There were no significant differences in threshability in all the interactions except from the oven dried panicles where the results showed significant interaction between variety and threshing method.

In mechanical damage, significant ($P < 0.05$) differences were observed between the varieties, seed moisture contents and among the threshing methods under both drying methods. In both drying methods, significant interaction for mechanical damage was only recorded between moisture and threshing method while the interactions between other factors were not different.

Table 1: Summary for analysis of variance (ANOVA) for the effects of threshing methods, seed moisture content, endosperm types and their interaction on percentage threshability and mechanical damage of sorghum seeds from sun and oven dried panicles

Source of variation	d.f.	<u>Mean threshability (%)</u>		<u>Mean mechanical damage (%)</u>	
		Sun dried panicles	oven dried panicles	Sun dried panicles	oven dried panicles
		m.s.	m.s.	m.s.	m.s.
Location (L)	1	301.35*	420.5*	3.24ns	3.02ns
Residual	4	6.89	31.13	1.03	2.59
Variety (v)	1	1520.76*	2289.39*	790.16*	356.67*
L.V	1	0.55ns	2.88ns	1.99ns	58.23ns
Residual	4	158.7	60.31	9.14	9.27
Moisture (M)	1	328.11*	264.5*	313.67*	142.38*
L.M	1	107.31ns	2.72ns	0.11ns	2.44ns
V.M	1	0.91ns	15.31ns	6.98ns	14ns
L.V.M	1	5.39ns	61.98ns	2.32ns	0.46ns
Residual	8	47.39	29.9	17.18	13.12
Threshing methods (T)	2	564.01**	918.88**	1822.99**	1944.59**
L.T	2	24.55ns	6.65ns	5.76ns	114.5ns
V.T	2	64.82ns	207.42*	11.71ns	7.74ns
M.T	2	92.77ns	1.5ns	86.15*	59.5*
L.V.T	2	135.81ns	8.41ns	0.81ns	8.32ns
L.M.T	2	122.35ns	75.95ns	0.36ns	9.83ns
V.M.T	2	12.64ns	57.25ns	0.05ns	11.47ns
Residual	34	49.42	40.28	14.63	11.94
Total	71				

ns-non significant

*-Significant

**-Highly significant

m.s-mean squares

3.5.1 Influence of location on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Means for panicle threshability were significantly ($P < 0.05$) high in Katumani at 86.86% and 86.30% when panicles were dried in the sun and oven, respectively compared to Kiboko

which were low at 82.72% and 81.50% when panicles were dried in the sun and oven, respectively. The mean seed mechanical damage were not significantly different between locations where at Katumani, they were 15.84% and 16.31% when panicles were dried in the sun and oven, respectively and at Kiboko were 16.26% and 15.9% when panicles were dried in the sun and oven, respectively. The coefficients of variations were low indicating that variability between and among treatments were low (Table2).

Table 2: Influence of location on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Location	Mean threshability (%)		Mean mechanical damage (%)	
	sun dried panicles	Oven dried panicles	sun dried panicles	Oven dried panicles
Katumani	86.86a	86.30a	15.84a	16.310a
Kiboko	82.72b	81.59b	16.26a	15.90a
LSD (P 0.05)	1.72	4.33	0.67	1.05
CV %	0.9	2.3	1.8	2.7

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

3.5.2 Influence of endosperm types on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Means for panicle threshability of vitreous variety Kari- mtama 1 were significantly (P 0.05) high at 89.41% and 89.65% when panicles were dried in the sun and oven, respectively compared to panicle threshability of non-vitreous variety Seredo which was low at 80.21% and 78.24%, respectively. The mean seed mechanical damage was 12.74% and 13.88% for vitreous variety Kari- mtama 1 when panicles were dried in the sun and oven, respectively. Mean seed mechanical damage of non-vitreous variety Seredo was significantly high at

19.37% and 18.33% when panicles were dried in the sun and oven, respectively compared to Kari- mtama 1 (Table 3). Variety with vitreous endosperm (Kari-mtama 1) had significantly high percentage threshability and low seed mechanical damage compared to non-vitreous variety (Seredo) which had low threshability and high mechanical damage in both drying methods. Coefficients of variations were low indicating that variability between and among treatments were low.

Table 3: Influence of variety endosperm types on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Variety	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Kari-mtama 1	89.41a	89.65a	12.74a	13.88a
Seredo	80.21b	78.24b	19.37b	18.33b
LSD (P 0.05)	8.244	5.05	1.98	1.99
CV %	6.1	3.8	7.7	7.7

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

3.5.3 Influence of seed moisture content on threshability and seed mechanical damage of sorghum from panicles dried in the sun and oven

Sorghum panicles that were threshed at lower moisture level (13%-14%) had significantly (P 0.05) high percentage threshability and low seed mechanical damage compared to panicles that were threshed at higher moisture level for both drying methods. The mean threshability of panicles that were threshed at low moisture content was significantly high at 86.94 % and 85.93% when panicles were dried in the sun and oven, respectively compared with the mean threshability of panicles that were threshed at high moisture content was at

82.67 % and 82.09%. The mean seed mechanical damage was 13.97% and 14.7% for panicles that were threshed at low moisture content and were dried in the sun and oven, respectively. Mean seed mechanical damage of panicles that were threshed at high moisture content was significantly high at 18.14% and 17.51% compared to those threshed at 13%-14% dried in the sun and oven, respectively (Table 4).

Table 4: Influence of seed moisture content (SMC) on panicle threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Seed moisture content (%)	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
18-20	82.67a	82.09a	18.14a	17.51a
13-14	86.94b	85.93b	13.97b	14.70b
LSD (P 0.05)	3.74	3.82	2.25	1.97
CV %	4.7	3.8	14.9	13

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

3.5.4 Influence of threshing method on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

There were significant difference in panicle threshability and seed mechanical damage among threshing methods at P 0.001 in both drying methods. Means for panicle threshability and seed mechanical damage percentages of the threshing methods for panicles dried in the sun and oven are presented in Table 5. Means for percent threshability of panicles threshed in mortar and pestle was 87.55% and 87.65% when panicles were dried in the sun and oven, respectively. Means percent threshability of panicles threshed by beating with wooden stick was 87.67% and 87.32% when panicles dried in the sun and oven respectively. There was no significant difference in panicle threshability between panicles threshed by using mortar and

pestle and beating with wooden stick. However, means for percentage panicle threshability of panicles threshed using machine were significantly lower at 79.21% and 76.87% compared to those percentage achieved under wooden stick and mortar and pestle threshing methods.

The means for seed mechanical damage percentage for panicles dried in the sun and oven and threshed using the three threshing methods were significantly different. The means for seed mechanical damage of panicles dried in the sun and threshed by mortar and pestle was 26.06%, threshed by beating in bags with stick was 12.98% and threshed by machine was lowest at 10.12%. The means for seed mechanical damage of panicles dried in the oven and threshed in mortar and pestle was 25.98%, threshed by beating in bags with stick was 13.99% and the lowest was threshing by machine at 8.35%.

Table 5: Influence of threshing method on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Threshing methods	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Mortar and pestle	87.55a	87.65a	26.06a	25.98a
Beating with stick	87.67a	87.32a	12.98b	13.99b
Threshing machine	79.21b	76.87b	10.12c	8.35c
LSD (P 0.001)	4.12	2.89	2.24	2.03
CV %	8.3	7.6	23.8	21.4

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.001

In oven dried panicles, the results showed significant interaction for threshability between variety and threshing methods. The percentage threshability of vitreous (hard) endosperm

variety Kari-*mtama* 1 when threshed by machine was not significantly different from percentage threshability of non-vitreous (soft) endosperm variety *Seredo* when threshed using wooden stick or mortar and pestle (Figure 3). There was a significant increase in threshability when the seeds were threshed at 13%-14% M.C especially using a mortar and pestle or wooden stick. Threshability of the seeds threshed with machine had no significant difference between the two seed moisture levels for both drying methods (Figure 3 and 4).

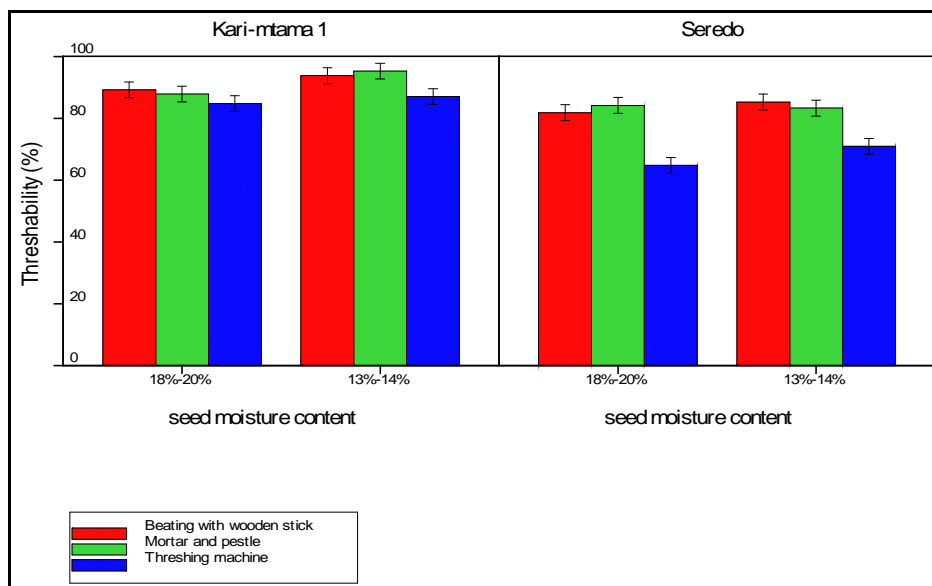


Figure 3: Mean percent threshability for sorghum panicles threshed at two moisture contents using three threshing methods (oven dried panicles)

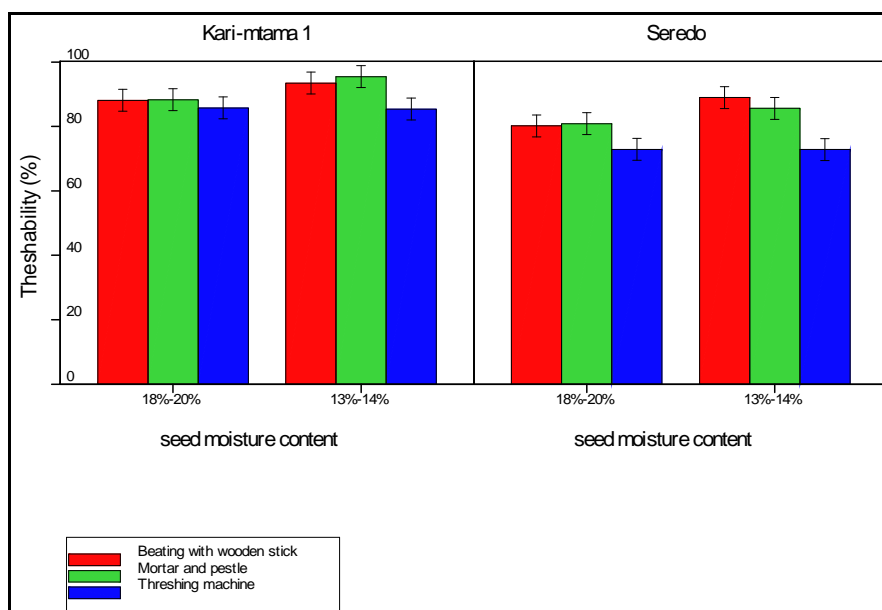


Figure 4: Mean percent threshability for sorghum panicles threshed at two moisture contents using three threshing methods (sun dried panicles)

Similarly, for both varieties, there was a decrease in mechanical damage when the seed were threshed at 13%-14% SMC. However, the difference in mechanical damage between the seed moisture content was not significantly different from the seeds that were threshed using machine and wooden stick. There was a significant difference in mechanical damage between moisture levels when the seeds were threshed using mortar and pestle. The lowest mechanical damage was recorded from the seeds threshed by machine at SMC 13%-14% while the highest damage was recorded in mortar and pestle at SMC 18%-20% in both varieties (Figure 5 and 6).

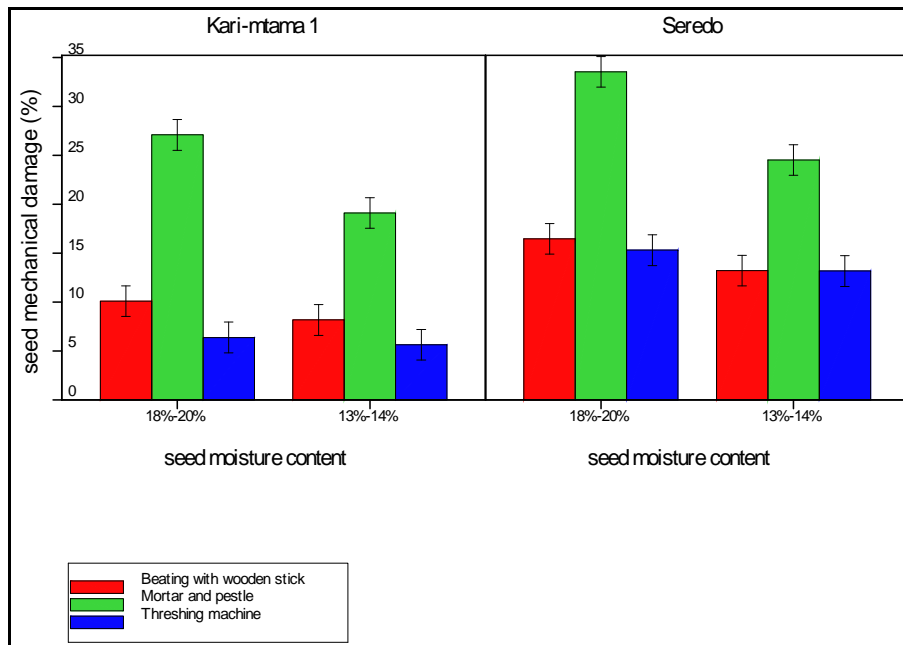


Figure 5: Mean percent mechanical damage for seeds from two sorghum varieties threshed at two moisture content using three threshing methods (sun dried panicles)

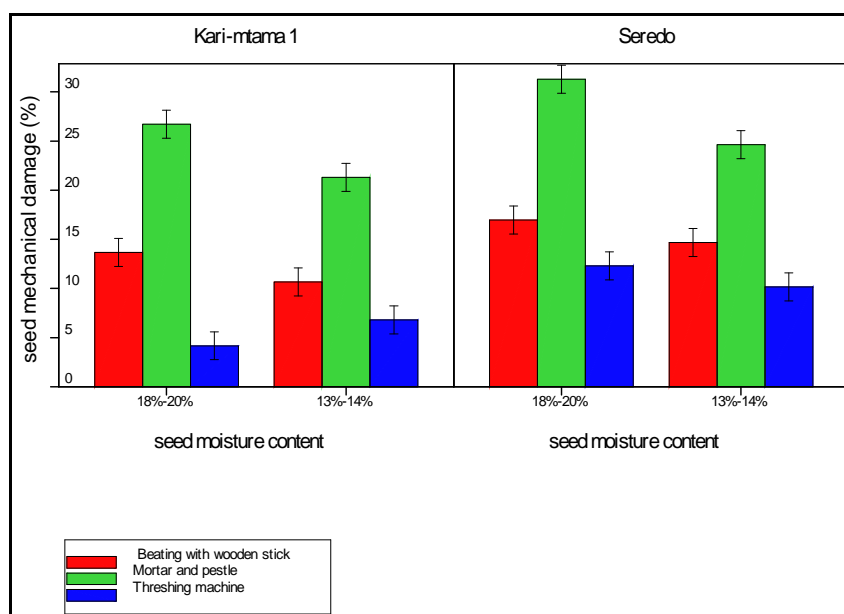


Figure 6: Mean percent mechanical damage for seeds from two sorghum varieties threshed at two moisture contents using three threshing methods (oven dried panicles)

3.5.5 Influence of panicle drying method on threshability and mechanical damage of sorghum seeds

There was no significant difference between the drying methods in threshability and mechanical damage (Table 6). Mean threshability for panicles dried in the sun was 84.81% similar to panicles dried in the oven which was 84.01%. Mean seed mechanical damage for panicles dried in the sun was 16.05% similar to the seeds from panicles dried in oven was 16.11%.

Table 6: Influence of panicle drying method on threshability and mechanical damage of sorghum seeds

Drying method	Mean threshability (%)	Mean mechanical damage (%)
Sun	84.81a	16.05a
Oven	84.01a	16.11a
LSD (P 0.05)	2.514	0.541
CV %	1.3	1.5

Numbers followed by the same letters within columns do not differ significantly according to LSD test at P 0.05

3.6 Discussion

3.6.1 Influence of location on sorghum threshability

Threshability of sorghum panicles from Katumani was significantly higher than the one from Kiboko. This could be attributed to the difference in growing conditions such as environmental temperature and relative humidity which influenced drought stress at Kiboko. It was reported by Adeyanju *et al.* (2015), that certain environmental conditions during growth such as drought stress lead to premature termination of grain filling which may cause poor threshability. Robertson *et al.* (2004) also reported that, the threshability of the seed could be affected by the environmental conditions of the day and time during harvesting. The poor threshability of sorghum grown at Kiboko could be due to drought stress which the crop experienced. The crop at Kiboko was grown late in the season and the area had water stress conditions compared to Katumani where the crop was grown in season and received enough rainfall (weather data in Appendix 1 and 2). At Kiboko when the crop was at critical stage of grain filling, there was water stress resulting in small grains and the temperatures were too high to the extent that the seeds dried within a short period of time which could have resulted into premature termination of grain filling and hence poor threshability. It is therefore important to grow seed crop under optimum conditions in order to produce high quality seeds.

3.6.2 Influence of endosperm type on sorghum threshability and seed mechanical damage

Panicles of vitreous (hard endosperm) variety (Kari-mtama 1) had significantly high threshability than the panicles of non-vitreous variety (Seredo). During threshing, most of the seeds from non-vitreous variety appeared tightly attached to the glumes. This could be due to the inherent genetic trait of the Seredo. It has been reported that genotype with tight

sticky glumes are difficult to thresh and when the seeds are threshed, they tend to remain in glumes (Adeyanju *et al.*, 2015). Another reason could be the non-vitreous nature of endosperm of Seredo variety which caused the seed grain not to be detached easily from the glumes especially when threshed at higher seed moisture content (18%-20%). Ioerger *et al.* (2007) reported that, grain hardness plays a significant role on threshability and seed quality during seed processing. This could be the reason for easy threshability of vitreous endosperm variety (Kari-mtama 1) especially at low moisture content (13%-14%).

There was a significant difference in seed mechanical damage caused by threshing methods between the two varieties. The possible reason for the significant difference between the two varieties is that, the soft endosperm was easier to get damaged than vitreous variety. It has been reported that, vitreous kernel are resistant to breakage during seed processing (Felker and Paulis, 1993).

3.6.3 Influence of seed moisture content and threshing methods on sorghum threshability and seed mechanical damage

Threshing methods showed significant differences in panicle threshability. In both drying methods used to dry panicles, machine showed significant lower panicle threshability than the other two methods. There was no significance difference between wooden stick and mortar and pestle. The significant higher percentage of threshability in beating with wooden stick; and using mortar and pestle could be due to the high impact of wooden stick, mortar and pestle and forces that were used to beat panicles. The machine had rotating rasp bar cylinder which had soft surface and may have induced little force to the panicles. The increase in threshability at low SMC (13%-14%) could be due to the fact that at low moisture, the seeds become harder and were easily detached from the panicles and glumes

(Prasad and Sterggenborg, 2010). Also, the seeds at high moisture content were soft and may have resulted to poor threshability and cracked grains (Sumner, 2012).

Although threshability was higher for panicles threshed using a mortar and pestle and beating with wooden sticks, percentage seed mechanical damage was also equally high compared to the machine threshing method. This could be due to the impact of wooden materials on the seeds during beating and pounding. Wooden mortar and pestle had higher mechanical damage followed by wooden stick while threshing by machine had the lowest seed mechanical damage. Dharmaputra *et al.* (2012) reported similar results that, the method of threshing of sorghum seeds had significant effects on grain damage in terms of cracked and broken grains. According to Dharmaputra *et al.* (2012), the percentage of damaged grain of sorghum threshed using a wooden stick was higher compared to those that were threshed with a paddy thresher. This could be related to the results of mechanical damage in this experiment because the mechanical damage of the seeds may be due to the physical impacts which the seeds receive during threshing by wooden mortar and pestle, and beating with stick. The mechanical damage for seeds from panicles that were threshed with machine was significantly lower and this contributed to high seed quality although panicles threshability was low than the other two methods.

For both varieties, there was a decrease in mechanical damage for the seed from panicles that were threshed at 13%-14% SMC. This could be due to the hardness of the seed grains at this moisture level. The seeds with high moisture content are soft which may have resulted into more cracked grains than seeds with low moisture content (Sumner, 2012). Other research has also shown that too low moisture content below 13% can be as damaging to seed quality as too much moisture. When seeds are over dried to below 13% seed moisture content, seeds

become more brittle and can be cracked and break easily and much damage can occur when the seeds is too wet above 22% moisture content (Missouri University, 2003). Saeidirad and Javadi (2011) and Ajav and Adejumo (2005) evaluated the effect of thresher variables including seed moisture content in cumin and okra respectively and they found that, moisture contents significantly affects seed mechanical damage and germination. In cumin seeds, the results showed that as moisture content increased from 7% to 13%, separated seed and damaged seed decreased from 92.8% to 90.4% and from 10.1% to 7.6% respectively. In this study the seed mechanical damage was significantly higher at 18%-20% seed moisture content compared to low moisture content (13%-14%).

CHAPTER FOUR

Influence of Endosperm Type, Seed Moisture Contents and Threshing Methods on Germination and Seedling Vigour of Sorghum

4.1 Abstract

Sorghum (*Sorghum bicolor* L. Moench) is among the most important cereal crop in the world. It is adapted to wide agro ecological zones. It has high production compared to most other cereal crops in drought conditions. The objective of this study was to determine the effects of endosperm type, seed moisture content and threshing methods on germination percent, mean germination time and seedling vigour of sorghum. Two varieties of sorghum were grown in two diverse locations namely Kiboko and Katumani. One variety Kari-mtama 1 has hard (vitreous) endosperm while another variety Seredo has a soft (non-vitreous) endosperm. After harvesting, sorghum panicles were dried in the sun and in the oven. The panicles were threshed separately for each drying method at two moisture levels namely 18-20% and 13-14%. The three threshing methods used included beating by wooden stick in tied sack, using a wooden mortar and pestle as well as using a threshing machine. The seeds from various treatments were evaluated for germination percent, mean germination time and seedling vigour using ISTA rules at the University of Nairobi Laboratory.

The results showed that, germination percent, mean germination time and seedling vigour of sorghum was significantly influenced by seed moisture content and threshing methods. In both drying methods, the seeds from panicles that were threshed at low moisture content (13%-14%) had significantly higher germination percentage than those which were threshed at high moisture content (18%-20%). Similarly, seeds from panicles that were threshed using the threshing machine had significantly higher germination percent compared to beating with wooden stick and mortar and pestle. Germination time also was significantly influenced by

seed moisture content and threshing methods. The seeds from panicles that were threshed at low moisture content germinated faster compared to those that were threshed at higher moisture content. Seeds from threshing machine also germinated faster compared to beating with stick and mortar and pestle. Seedling vigour was also influenced by seed moisture content and threshing methods. The seeds from panicles that were threshed at low moisture content produced seedlings with significantly higher vigour compared to higher moisture content in both drying methods. Seedlings for the seeds from panicles that were threshed using machine had significantly higher vigour followed by beating with wooden stick and mortar and pestle in both drying methods.

The results suggested that, sorghum panicles have to be threshed at low moisture content (13%-14%) to obtain high seed quality. Threshing by machine is the best method to be used to avoid poor seed quality followed by beating with wooden stick. Mortar and pestle threshing method should be avoided in threshing sorghum panicles because it results in high mechanical damage and hence lowering germination and seedling vigour as compared to beating with wooden stick and threshing by machine. There was no genotype by environment interactions for germination and seedling vigour. This suggested that, the results are applicable for sorghum crop across the environments.

4.2 Introduction

Sorghum grains can be used to substitute maize and rice because the nutritional content of sorghum is close to that of maize and rice. Sorghum has carbohydrate content of 80.42% as compared to 86.45% in milled rice and 79.95% in maize. Sorghum has slightly higher protein content (10.11%) than milled rice (9.28%), but lower than maize (11.02%). The lipid content in sorghum is (3.65%) which is higher than milled rice (1.88%) although it is lower than that in maize (5.42%) (Dharmaputra *et al.*, 2012). Although the cultivation of sorghum is important in semi- arid areas, yields are low among the farmers. One of the reasons for low yield is lack of quality seeds due to poor postharvest handling and processing of sorghum seeds. There is insufficient knowledge on sorghum processing (threshing, drying, cleaning and storing). All these affect the quality of seeds which determine the yield of sorghum. Majority of sorghum farmers in Kenya and other African countries thresh their seed by beating with sticks or rubbing the panicles on a hard surface or by pounding and trampling by cattle (Adeyanju *et al.*, 2015; Ochieng *et al.*, 2011). These methods may cause mechanical damage to the seeds and this damage may be higher when the seeds are threshed at unsuitable moisture content (World Food Programme, 2011; Kavak *et al.*, 2012). When the seeds are damaged, its quality and germination ability is impaired (Spokas *et al.*, 2008). Seed damage depends on the vitreosity of the sorghum variety. A vitreous variety with hard kernels has a better breakage resistance than non-vitreous kernels (Felker and Paulis, 1993).

The objectives of this research were to investigate the effects of variety endosperm type, seed moisture contents and threshing methods on germination percent, germination time and seedling vigour of sorghum.

4.3 Materials and Methods

Sorghum varieties used were hard (vitreous) endosperm variety Kari-mtama-1 and soft (non-vitreous) variety Seredo. The seed crop was planted at two locations which are Kiboko and Katuamani in Agricultural Mechanization Research Institute Centres. The description of the study area is as described in chapter three (Section 3.3.1). The experimental design and set up of the experiment as per description of chapter three sections 3.3.2 and 3.3.3, respectively.

4.4 Seed Harvesting, Panicle Drying and Threshing

The crop was harvested by hand and panicles were cut using a knife after seed grain had reached physiological maturity (PM) three months after planting. The panicles that were threshed at higher moisture level (18%-20%) were harvested when the seed was about 25% while the panicles that were threshed at lower moisture level (13%-14%) were left in the field and harvested when moisture content was about 20%. From each plot, 60 plants were harvested from the inner rows (net plots) and the harvesting was done in two batches, each containing 30 randomly selected plants. After harvesting, sorghum heads/panicles were dried to the required moisture content. Panicles were dried in the sun and oven. From 60 panicles harvested from each plot, 30 heads/panicles were dried in the sun before threshing and the other 30 were dried in the oven at 36° C before threshing. Extra five heads/panicles were included in each drying method. These were used to regularly monitor the moisture content until the seeds attained the required moisture for threshing. The moisture content of seeds was determined using agraTronix MT-16 grain moisture tester before threshing. Machine threshing was done by one specific bulk machine thresher in both locations which contained rotating rasp bar cylinder. The machine used was from Allan Machine Company (ALMACO 99, M AVE NEVADA 10WA 50201 USA) (Annex 1). The mortar hole depth was 22 cm

and weight of the pestle and wooden stick was 1.5Kg (Annex 2). After threshing, the seeds were separated from dirt and chaff by manual winnowing.

4.5 Laboratory tests

After threshing, the seed samples were taken to the University of Nairobi laboratory for seed quality tests namely germination percentage, mean germination time and seedling vigour (Root length, shoot length and seedling vigour index).

4.5.1 Germination percentage and mean germination time

The germination test was carried out using 200 seeds per each sample. The seeds were surface sterilized in 2% of aqueous sodium hypochlorite solution for three minutes and rinsed three times in sterile distilled water. The seeds were placed on top of two layers of moist paper towel in sterilized transparent plastic containers. Another layer of moist paper towel was placed on top to cover the seeds. The containers were covered with lids and placed at room temperature for the seeds to germinate. The count of germinated seeds was taken every day until the tenth day from sowing date when the final evaluation was done. The seeds were evaluated into various categories including normal seedling with intact roots and shoot systems, abnormal seedlings (deformed seedling), ungerminated seeds and infected seedling (Abuelgasim and Dessougi, 2011; ISTA, 2015).

The germination percentage was calculated based on normal seedlings as follows:-

$$\text{Germination percent} = \frac{\text{Number of germinated seeds (Normal seedlings)}}{\text{Total number of seeds planted}} \times 100$$

4.5.2 Mean germination time

Mean germination time was calculated from the number of newly germinated seeds which were counted every day from sowing date until the final evaluation. Seeds were considered to have germinated when the radical had emerged and elongated by at least 2 mm. The following formula was used to determine mean germination time according to Afrakhteh *et al.* (2013) and Ochieng *et al.* (2013):

$$\text{Germination time} = \frac{\sum (nd)}{n}$$

Where:

n is number of newly germinated seed counted every day

d is number of days from sowing date.

n is total number of seeds germinated at the end of the test

4.5.3 Seedling vigour

Seedling vigour was determined from the seedlings that were sown for germination test. After the final count in germination test, 20 normal seedlings from each sample were selected at random and used in measuring seedling vigour parameters which included the root, shoot and seedling length. The measurements were taken using a graduated ruler in centimetre (cm). Shoot length was measured from the point of attachment from the seed to the tip of the shoot. The root length was measured from the point of attachment from the seed to the tip of the root. Seedling length was calculated by adding root length and shoot length in each seedling. Mean seedling length was calculated by dividing the total seedling length by the number of normal seedlings measured (Abuelgasim and Dessougi, 2011). Seedling vigour index (SVI) was calculated using the following formula according to Adebisi *et al.* (2010):

$$\text{SVI} = \frac{\text{Mean seedling length} \times \text{germination percentage}}{100}$$

100

The seedlings with high SVI value were considered as vigorous seedlings.

4.6 Data Collection and Analysis

Data collection in this study included percentage germination, mean germination time, seedling root length, seedling shoot length and seedling vigour index. All data were subjected to analysis of variance using General Statistical package (GENSTAT) edition 13 for windows and the means separated using least significant difference (LSD) test at 5% and 1% level of significance.

4.7 Results

4.7.1 Influence of location, variety endosperm type, seed moisture content, threshing methods and their interaction on germination percent and mean germination time of sorghum seeds

Germination percent and germination time of sorghum seeds for location, variety endosperm type, threshed in two moisture levels using three methods and their interaction when panicles were dried in the sun and oven are presented in Table 7. Germination percent of sorghum seeds was significantly influenced by seed moisture content and threshing methods in both drying methods. There were no significant differences for all interactions among various parameters namely location, endosperm type, seed moisture level and threshing methods. Germination time of sorghum seeds was significantly influenced by seed moisture content and threshing methods for the sun dried panicles. For oven dried panicles, the results showed significant interaction in mean germination time between seed moisture content and threshing methods.

Table 7: Summary for analysis of variance (ANOVA) for the effects of variety endosperm type, seed moisture content, threshing methods and their interaction on germination percent and mean germination time of sorghum seeds from sun and oven dried panicles

Source of variation	d.f.	<u>Mean germination (%)</u>		<u>Mean germination time (days)</u>	
		Sun dried panicles m.s.	Oven dried panicles m.s.	Sun dried panicles m.s.	Oven dried panicles m.s.
Location (L)	1	1.00ns	130.95ns	0.00331ns	0.69014ns
Residual	4	83.99	130.95	0.16646	0.20723
Variety (v)	1	22.78ns	195.03ns	0.39659ns	0.03199ns
L.V	1	645ns	0.28ns	0.00373ns	0.08485ns
Residual	4	126.5	28.23	0.15151	0.10611
Moisture (M)	1	1444.53**	1412.46**	0.66875*	0.35924ns
L.M	1	31.34ns	10.05ns	0.00204ns	0.03915ns
V.M	1	42.78ns	5.28ns	0.00141ns	0.0929ns
L.V.M	1	15.59ns	1.53ns	0.00285ns	0.06811ns
Residual	8	28.85	83.91	0.01121	0.1342
Threshing methods (T)	2	3810.39**	5161.58**	0.24788*	0.06888ns
L.T	2	47.18ns	149.07ns	0.04446ns	0.17873ns
V.T	2	42.82ns	167.04ns	0.05447ns	0.05872ns
M.T	2	25.26ns	63.15ns	0.09859ns	0.35446*
L.V.T	2	53.76ns	31.54ns	0.09161ns	0.02877ns
L.M.T	2	26.01ns	130.04ns	0.03567ns	0.08534ns
V.M.T	2	27.95ns	11.79ns	0.03771ns	0.04977ns
Residual	34	47.18	89.88	0.0394	0.06688
Total	71				

ns-non significant

*-Significant

**-Highly significant

m.s-mean squares

4.7.2 Influence of seed moisture content on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

In both drying methods, the seeds that were threshed at low moisture content (13%-14%) had significantly higher germination percentage than those which were threshed at high moisture content (18%-20%). The mean germination percent for the seeds from panicles threshed at low moisture content was 75.25% and 76.5% when panicles were dried in sun and oven respectively. Mean germination percent for the seed from panicles that were threshed at high moisture content was significantly low at 66.29% and 67.7% when panicles were dried in the sun and oven respectively (Table 8). Similarly, seeds from panicles that were threshed at low moisture content took significantly less time to germinate (2.18 days) compared to the seeds that were threshed at high moisture content (2.37 days) especially the seed from the sun dried panicles. Seeds from oven dried panicles had no significant differences for the mean germination time between the moisture levels (Table 8).

Table 8: Influence of seed moisture content (SMC) on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

Seed moisture content (%)	Mean germination (%)		Mean germination time(days)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
13-14	75.25a	76.50a	2.18a	2.24a
18-20	66.29b	67.70b	2.37b	2.38a
LSD (P 0.05)	2.92	4.98	0.06	0.19
CV %	4.4	7.3	2.7	9.2

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.01

4.7.3 Influence of threshing methods on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

There was a significant difference in germination percent and germination time among the threshing methods. Seeds threshed using machine had germination percent (82.69 %) when panicles were dried in the sun and (83.2%) when dried in the oven which was significantly different from the seeds threshed by beating with wooden stick (72.04%) when panicles were dried in the sun and (77.6%) when panicles were dried in the oven. Seeds from panicles threshed using mortar and pestle had the lowest germination 57.58% when panicles were dried in the sun and 55.5% when panicles were dried in the oven. Similarly, in the sun dried panicles, the seeds that were threshed by machine had significantly less mean germination time (2.16 days) compared to those which were threshed using beating with wooden stick (2.31 days) and using mortar and pestle (2.36 days). Mean germination time for the seeds threshed by wooden stick was not significantly different from mortar and pestle (Table 9).

Table 9: Influence of threshing methods on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

Threshing methods	Mean germination (%)		Mean germination time (days)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Threshing machine	82.69a	83.2a	2.16a	2.37a
Beating with stick	72.04b	77.6b	2.31b	2.27a
Mortar and pestle	57.58c	55.5c	2.36b	2.29a
LSD (P 0.001)	4.03	5.56	0.116	0.152
CV %	9.7	13.1	8.7	11.2

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.01

For oven dried panicles, the results showed significant interaction between seed moisture content and threshing methods for mean germination time. For the seeds threshed at high moisture content (18%-20%), machine threshed seeds had significantly higher mean germination time compared to other two threshing methods. Seeds threshed at low moisture content had significantly higher mean germination time for mortar and pestle method in both varieties (Figure 7).

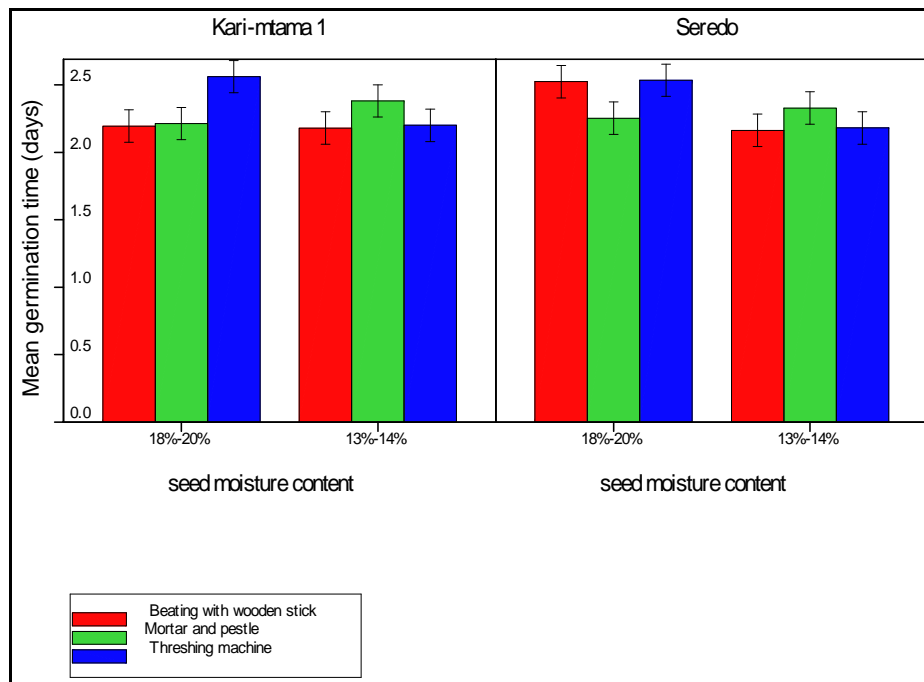


Figure 7: The effects of the interaction between seed moisture content and threshing methods on mean germination time for oven dried panicles

4.7.4 Influence of variety on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

Endosperm type and location had no significant influence on germination percent and germination time. Mean germination percent of vitreous variety (Kari-ntama 1) was 71.33% and 70.5% when panicles were dried in the sun and oven respectively. This was not significantly different from mean germination percent of non-vitreous variety (Seredo) which was 70.21% and 73.2% when panicles were dried in the sun and oven respectively.

Similarly, the mean germination time for Kari -mtama 1 was 2.20 days and 2.29 days for the seeds from panicles dried in the sun and oven respectively and this was not significantly different from Seredo which had 2.35 days and 2.33 when panicles were dried in the sun and oven respectively (Table 10).

Table 10: Influence of variety on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

Variety	Mean germination (%)		Mean germination time (days)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Kari-mtama 1	71.33a	70.5a	2.20a	2.29a
Seredo	70.21a	73.2a	2.35a	2.33a
LSD (P 0.05)	7.36	3.48	0.26	0.21
CV %	6.5	3	7	5.8

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

4.7.5 Influence of location on germination percent and mean germination time of sorghum seeds from panicles dried in the sun and oven

The mean germination percent for seeds from Katumani was 70.65% and 73.4% when panicles were dried in the sun and oven, respectively. This was not significantly different from the mean germination percent at Kiboko which was 70.87% and 70.7% when panicles were dried in the sun and oven, respectively. The mean germination time for the seeds from Katumani was 2.28 days when panicles were dried in the sun and 2.41 days when panicles were dried in the oven. The mean germination time for the seeds from Kiboko was 2.27 and 2.21 days when the panicles were dried in the sun and oven, respectively (Table 11).

Table 11: Influence of location on germination percent and mean germination time of sorghum seeds from panicles dried in sun and oven

Variety	Mean germination (%)		Mean germination time (days)	
	sun dried panicles	Oven dried panicles	sun dried panicles	Oven dried panicles
Katumani	70.65a	73.4a	2.28a	2.41a
Kiboko	70.87a	70.70a	2.27a	2.21a
LSD (P 0.05)	5.99	12.32	0.27	0.30
CV %	3.7	7.5	5.2	5.7

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

For both varieties, there was a significant increase in germination percentage when the seeds were threshed at low moisture content in each threshing method (Fig. 8 and 9). There was no interaction between location, variety, seed moisture content and threshing methods on germination percent of sorghum seeds.

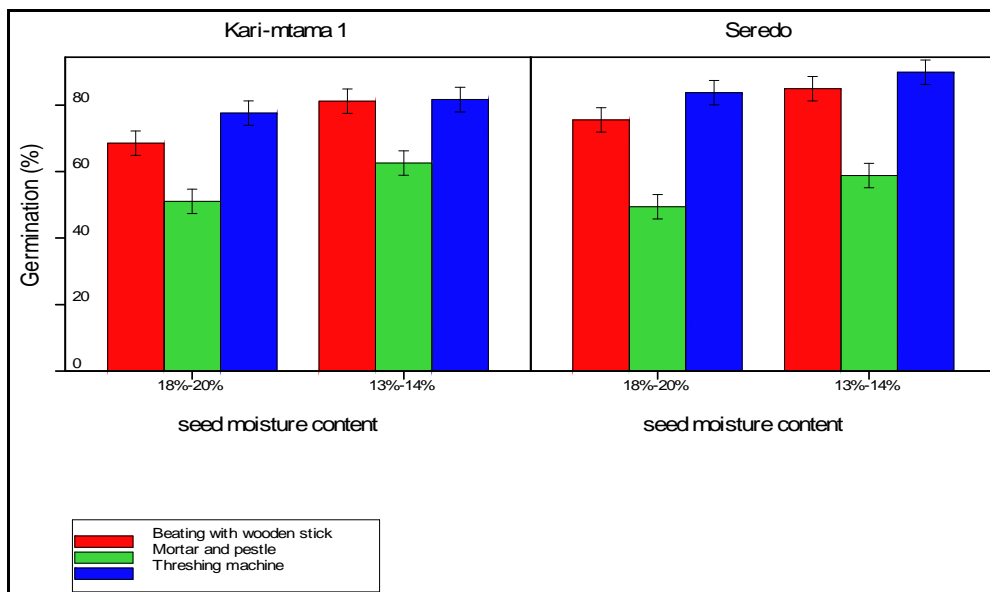


Figure 8: Mean percent germination for seeds from two sorghum varieties threshed at two moisture content using three threshing methods (oven dried panicles)

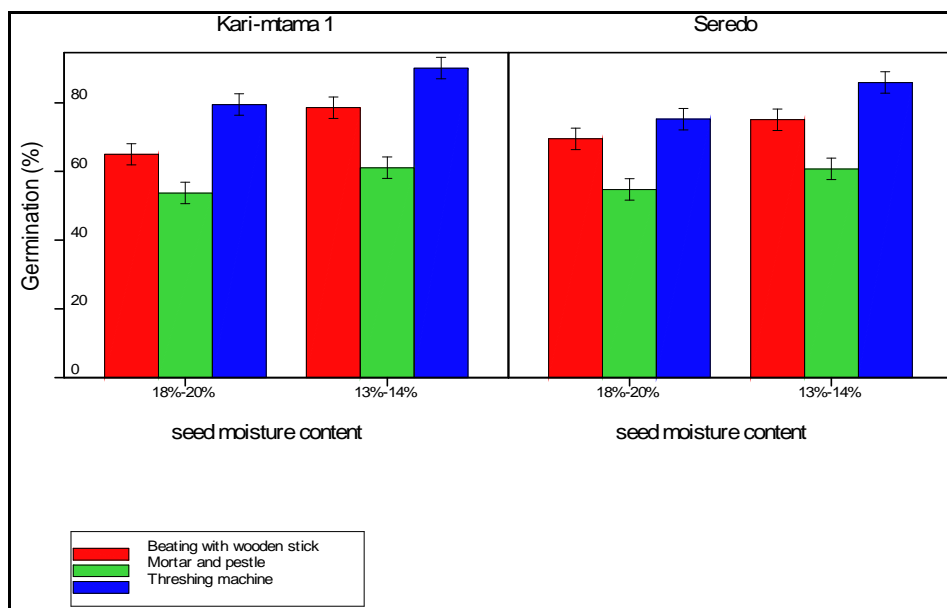


Figure 9: Mean percent germination for seeds from two sorghum varieties threshed at two moisture content using three threshing methods (sun dried panicles)

4.7.6 Influence of panicle drying method on germination percent and mean germination time

The percentage germination of the seeds of panicles that were dried using an oven was significantly higher (75%) compared to the seeds of sun dried panicles (70.77). However the germination time was not significantly different between the drying methods (Table 12).

Table 12: Influence of panicle drying method on germination percent and mean germination time

Drying method	Mean germination (%)	Mean germination time(days)
Oven	75a	2.31a
Sun	70.77b	2.28a
LSD (P 0.05)	4	0.227
CV %	5	4.4

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

4.8 Influence of location, variety, seed moisture, threshing methods and their interaction on root length, shoot length and seedling vigour index (SVI) of sorghum

From the analysis of variances (ANOVA), the results showed that, seedling vigour parameters (root length, shoot length and SVI) were significantly influenced by seed moisture content and threshing methods under both drying methods (Table 13).

Table 13: Summary for analysis of variance (ANOVA) for the effects of variety endosperm type, seed moisture content, threshing methods and their interaction in seedling vigour of seeds form sun and oven dried panicles

Source of variation	d.f.	Root length (cm)		Shoot length (cm)		SVI (cm)	
		Sun dried panicles	oven dried panicles	Sun dried panicles	oven dried panicles	Sun dried panicles	oven dried panicles
		m.s.	m.s.	m.s.	m.s.	m.s	m.s
Location (L)	1	0.0064ns	14.311ns	10.657ns	7.3536ns	3.661ns	8.266ns
Residual	4	0.0064	4.387	12.47	2.3598	21.22	24.669
Variety (v)	1	6.468ns	14.027ns	1.259ns	0.4186ns	11.612ns	0.227ns
L.V	1	0.2497ns	0.493ns	4.733ns	0.0159ns	17.962ns	0.32ns
Residual	4	1.8923	0.503	2.695	1.6367	5.782	2.956
Moisture (M)	1	0.1105*	9.621*	3.05*	17.1991**	103.997**	164.4**
L.M	1	0.1568ns	1.222ns	0.98ns	1.4821ns	0.793ns	0.436ns
V.M	1	3.2343ns	0.58ns	0.262ns	0.0292ns	0.001ns	1.182ns
L.V.M	1	0.7771ns	0.269ns	1.356ns	0.0325ns	0.076ns	0.013ns
Residual	8	0.5189	1.029	1.16	0.3866	3.396	6.253
Threshing methods							
(T)	2	27.1391**	6.089*	28.545**	29.4896**	373.851**	358.031**
L.T	2	0.3242ns	3.687ns	0.382ns	1.324ns	2.914ns	4.493ns
V.T	2	1.7782ns	0.29ns	3.197ns	0.4951ns	3.23ns	5.472ns
M.T	2	0.2769ns	4.19ns	1.589ns	0.7255ns	2.353ns	4.369ns
L.V.T	2	1.3753ns	0.423ns	0.653ns	0.3264ns	0.888ns	1.023ns
L.M.T	2	0.9815ns	0.23ns	0.117ns	1.1005ns	2.224ns	4.621ns
V.M.T	2	0.3537ns	0.511ns	1.619ns	0.3079ns	0.94ns	0.883ns
Residual	34	0.6826	1.352	1.106	0.4431	3.543	3.982
Total	71						
ns-non significant		*-Significant	** -Highly significant			m.s-mean squares	

4.8.1 Influence of threshing methods on seedling vigour of sorghum seeds from panicles dried in the sun and oven

Seed from panicles that were threshed using machine had significantly higher root length, shoot length and seedling vigour index compared to those from beating with stick and mortar and pestle. The mean root length for the seeds threshed using machine was 11.08 cm and 11.12 cm when panicles were dried in the sun and oven respectively, shoot length was 10.04 cm and 9.93 cm when panicles were dried in the sun and oven respectively and seedling vigour index was 17.89 cm and 18.55 cm when panicles were dried in the sun and oven respectively. The mean root length from the seeds threshed by beating with wooden stick was 10.59 cm and 10.46cm when panicles were dried in the sun and oven, respectively, shoot length was 10.01cm and 8.5cm when panicles were dried in the sun and oven respectively and SVI was 14.87 cm and 15.79cm when panicles were dried in the sun and oven respectively. In mortar and pestle threshing, the mean root length was 9.00 cm and 10.13cm when panicles were dried in the sun and oven respectively, shoot length was 8.35 cm and 7.7 cm when panicles were dried in the sun and oven, respectively and SVI was 10.06 cm and 10.92cm when panicles were dried in the sun and oven, respectively (Table 14). Although from sun dried panicles, the difference in shoot length from the seeds threshed using machine and beating with stick was not significantly different.

Table 14: Influence of threshing methods on seedling vigour of sorghum seeds from panicles dried in the sun and oven

Threshing methods	Root length (cm)		shoot length (cm)		Seedling vigour index	
	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles	Sun dried panicles	Oven dried panicles
Threshing machine	11.08a	11.12a	10.40a	9.93a	17.89a	18.55a
Beating with stick	10.59b	10.46ab	10.01a	8.5b	14.87b	15.79b
Mortar and pestle	9.00c	10.13b	8.35b	7.75c	10.06c	10.92c
LSD (P 0.001)	0.49	0.68	0.62	0.39	1.10	1.17
CV %	8.1	11	11	7.6	13.2	14.2

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05 and P 0.01

4.8.2 Influence of seed moisture content on seedling vigour of sorghum seeds from panicles that dried in sun and oven

Seeds that were threshed at low moisture content (13%-14%) significantly had long roots, shoots and high seedling vigour index compared to the seeds that were threshed at high moisture content (18%-20%). For the seeds from panicles threshed at low moisture content, the mean root length was 10.25 cm and 10.94 cm when panicles were dried in the sun and oven, respectively. The mean shoot length was 9.79 cm and 9.21 cm when panicles were dried in the sun and oven, respectively and SVI was 15.47 cm and 15.60 cm when panicles were dried in the sun and oven, respectively. The seeds from panicles that were threshed at high moisture content had significantly low root length, shoot length and SVI. The mean root length was 10.14 cm and 10.21 cm when panicles were dried in the sun and oven,

respectively, the mean shoot length was 9.38 cm and 8.23 cm when panicles were dried in the sun and oven respectively and SVI was 13.07 cm and 12.58 cm when panicles were dried in the sun and oven, respectively (Table 15). Seedling vigour parameters were influenced by seed moisture content and threshing methods under both drying methods. The seeds from panicles that were threshed using threshing machine showed significantly higher seedling vigour compared to the seed from panicles threshed by beating with wooden stick as well as mortar and pestle. Also the seeds from panicles that were threshed at low moisture content had significantly high seedling vigour compared to the seeds from panicles that were threshed at high moisture content.

Table 15: Influence of seed moisture content on seedling vigour of sorghum seeds from panicles dried in the sun and oven

Seed moisture content (%)	Root length (cm)		Shoot length (cm)		Seedling vigour index	
	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles
13-14	10.25a	10.94a	9.79a	9.21a	15.47a	15.6a
18-20	10.14a	10.21b	9.38a	8.24b	13.07b	12.58b
LSD (P 0.05)	0.39	0.55	0.58	0.34	1.002	1.36
CV %	4.1	5.5	6.5	4.1	7.5	10.2

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05 and P 0.01

4.8.3 Influence of location and variety on seedling vigour of sorghum seeds from panicles dried in the sun and oven

Location and variety had no significant influence on seedling vigour parameters which included root length, shoot length and seedling vigour index (Table 16 and 17). There was no interaction between location, variety, seed moisture content and threshing methods on seedling vigour parameters.

Table 16: Influence of variety on seedling vigour of sorghum seeds from panicles dried in sun and oven

Variety	Root length (cm)		shoot length (cm)		Seedling vigour index	
	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles
Kari-mtama 1	10.51a	10.01a	9.72a	8.80a	14.67a	14.14a
Seredo	9.91a	10.13a	9.45a	8.65a	13.87a	14.03a
LSD (P 0.05)	0.9	0.46	1.07	0.38	1.57	1.13
CV	5.5	2.7	7	6	6.9	5

Numbers followed by the same letters within column do not differ significantly according to LSD test at P 0.05

Table 17: Influence of location on seedling vigour of sorghum seeds from panicles dried in the sun and oven

Variety	Root length (cm)		shoot length (cm)		Seedling vigour index	
	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles	sun dried panicles	oven dried panicles
Katamani	10.19a	11.02a	9.97a	8.48a	14.5a	14.43a
Kiboko	10.22a	10.15a	9.2a	9.05a	14.05a	13.75a
LSD (P 0.05)	1.33	1.37	2.31	1	3.01	3.25
CV %	5.8	5.7	10.6	5.1	9.3	10.2

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

4.8.4 Influence of panicle drying methods on seedling vigour of sorghum seeds

Seedling vigour of the seeds from panicles that were dried by use of oven before threshing was significantly high compared to the seeds from sun dried panicles in terms of root length and seedling vigour index. However, the shoot length was not significantly different between the drying methods (Table 18).

Table 18: Influence of panicle drying methods on seedling vigour

Drying methods	Root length(CM)	Shoot length (CM)	SVI
Oven	10.6a	8.6a	14.3a
Sun	8.8b	8.6a	12.0b
LSD(P 0.05)	1.2	0.7	1.9
CV %	5	3.5	6.1

Numbers followed by the same letters within a column do not differ significantly according to LSD test at P 0.05

4.9 Discussion

4.9.1 Effects of Location, Variety Endosperm type, Seed Moisture Content and Threshing Methods on Germination Percent and Mean Germination Time

Germination percent and germination time was significantly influenced by seed moisture content and threshing methods. In both drying methods, the seeds from panicles that were threshed by machine had significantly higher germination percent followed by beating with wooden stick and mortar and pestle in that order. The lower germination for the seeds from panicles that were threshed using wooden stick as well as mortar and pestle could be due to the fact that these two methods caused higher mechanical damage. The impact of stick or mortar and pestle plus the forces used during threshing caused internal injury to the embryo which resulted into abnormal seedlings and non germinability of some seeds. Machine

threshing was done by rotating rasp bar which may have caused little internal injury and impact on the seeds resulting to higher germination percentage.

This agrees with results reported by Dharmaputra *et al.* (2012) that, when sorghum seeds were threshed by beating with wooden stick, seed had lower germination percent (91.04%) compared to the seeds threshed by threshing machine (93.33%). Dharmaputra *et al.* (2012) reported that, the results were strongly correlated with percentage damage caused by wooden stick and machine thresher.

The increase in germination percent when the seeds are threshed at low moisture content (13%-14%) compared to higher moisture content (18%-20%) could be due to the fact that at low moisture content, seeds became harder and are easily detached from the panicles and glumes during threshing and hence internal injury of the seed was minimized. While at higher moisture content, the seeds were too soft and were more prone to internal injury because the seeds tissues were still soft with a lot of water and the forces during threshing resulted into cracking of seed embryo (Sumner, 2012). Therefore, the seeds which were threshed at higher moisture content had low germination; many seedlings were abnormal and did not germinate due to mechanical damage to the seed embryo. According to Phillips (2010), excessively damaged seeds are unable to germinate and some may germinate but will not produce normal seedlings.

Similarly, the germination time of the seed from panicles threshed by machine was significantly low compared to the seeds from panicles threshed by beating with stick and mortar and pestle. This could be due to high quality of the seeds from panicles threshed by machine compared to the beating with wooden stick as well as mortar and pestle. The

significant interaction between moisture and threshing methods on germination time under oven dried method could be due to mechanical scarification effects caused by beating as well as mortar and pestle methods when the seeds are threshed at high moisture content compared to low moisture content. Krenchinsk *et al.* (2015) reported that, mechanical scarification of sorghum resulted in faster germination. The grinding effects of wooden stick and mortar and pestle caused abrasion to the seed coat which allowed easy water uptake resulting in faster germination. Therefore, due to this impact the seeds threshed at high moisture level using these methods germinated faster compared to the machine threshing. Location and variety had no influence on germination percent and germination time implying that varieties can be grown in different environment and give a similar quality in term of germination percent and mean germination time when all other conditions held constant.

4.9.2 Effect of seed moisture content during threshing and threshing methods on seedling vigour

Seeds from panicles that were threshed using machine had higher seedling vigour compared to those threshed by beating with wooden stick and mortar and pestle. Also the seeds from panicles that were threshed at low moisture content had higher seedling vigour compared to the seeds that were threshed at higher moisture content. This could be due to the difference in mechanical damage among threshing methods and between moisture levels. Seed from panicles that were threshed using machine had low mechanical damage compared to beating by wooden stick as well as by mortar and pestle. This could be the reason of high seedling vigour recorded from the seeds threshed using machine compared to those threshed by beating using wooden stick as well as mortar and pestle.

When the seeds were threshed at high moisture level, they were too soft and more prone to mechanical damage compared to those threshed at low moisture content. This mechanical damage could have caused low seedling vigour for the seeds threshed at high moisture level. Shelar (2008) reported that, any damage to the seed endosperm or embryo caused during seed processing, may result into blocking the translocation of essential nutrients for the seed growth. Block or poor translocation could be responsible for poor seedling growth for the seeds that were mechanically damaged during threshing either by threshing methods or threshing at unsuitable moisture content. Warzecha *et al.* (2011) who studied the effects of mechanical damage on vigour, physiological parameters and susceptibility of oat (*Avena sativa*) to *Fusarium culmorum* infection reported that, the seeds that were threshed using machine at high speed resulted in severe mechanical damage and consequently seedling vigour decreased by 16% compared to those threshed at low speed which had low damage. This confirms the results of this study that, mechanical damage of seeds results in decrease in vigour.

4.9.3 Influence of panicle drying method on germination and seedling vigour

The low germination and seedling vigour of the seeds from panicles dried in the sun could be due to the effects of non-uniformity of temperatures during drying in the sun. Also the sudden rise and fall of temperature in a day during drying results into seed quality deterioration. This is because seeds are heat sensitive and sudden changes in temperatures resulted into heat damage which impairs germination capacity due to enzyme inactivation (Thai, 2015). The results of this study agree with Babiker *et al.* (2010) who studied the effects of low cost drying methods on seed quality of sorghum and reported that, sorghum seed viability as represented by germination percentage is significantly affected by seed

drying method irrespective of the genotype. Babiker *et al.* (2010) further reported that, sun drying it is quicker, but is harmful to the seeds and affects seed viability.

Similarly, Thai (2015) studied the effects of three methods of drying namely sun, oven and mechanical drier on viability, vigour and storability of maize, sorghum and soybean seeds and the results showed that drying methods affected the quality of seeds. The germination percentage and vigour decreased rapidly in the seed dried in the sun compared to other drying methods namely oven and mechanical drier.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

Threshability of sorghum panicles that were grown at Katumani was significantly higher than those grown at Kiboko. This could be attributed to the difference in growing conditions such as environmental temperature, relative humidity and the influence of drought stress at Kiboko. Adeyanju *et al.* (2015) reported that, certain environmental growing conditions such as late season and drought stress lead to premature termination of grain filling which may cause poor threshability. The poor threshability of sorghum grown at Kiboko could be due to poor grain filling as a result of drought stress experienced as the crop was growing. The crop at Kiboko was grown late season and areas had drought conditions compared to Katumani where the crop was grown in good time as the season began.

Panicles from vitreous (hard endosperm) variety (Kari-mtama 1) had significantly high threshability percent and significantly low seed mechanical damage compared to those of non-vitreous variety (Seredo). Low threshability of seredo could be due to the inherent genetic trait of a variety. Adeyanju *et al.* (2015) reported that, genotypes with tight sticky glumes are difficult to thresh and when the seeds are threshed, they tend to remain in glumes. In addition, another reason could be the non-vitreous nature of endosperm of Seredo variety which caused the seed grain not to be detached easily from the glumes especially when threshed at higher seed moisture content. Ioerger *et al.* (2007) reported that, grain hardness plays a significant role in threshability and seed quality during seed processing. Furthermore, low mechanical damage in vitreous variety Kari-mtama 1 could be because of the hardness of sorghum kernels. It has been reported that, vitreous kernels are resistant to breakage during

seed processing and soft kernel may results into cracked grains (Felker and Paulis, 1993; Sumner, 2012).

The increase in threshability percent and decrease in seed mechanical damage when panicles were threshed at low moisture content (13%-14%) could be because at low moisture content the seeds becomes harder and are easily detached from the panicles and glumes (Prasad and Staggenborg, 2010). Also, the seeds at high moisture content were soft and may have resulted to poor threshability and cracked grains (Sumner, 2012). The significantly higher percentage of threshability in beating with wooden stick; and using mortar and pestle could be due to the high impacts of wooden stick, mortar and pestle and forces that were used to beat panicles. Machine had rotating rasp bar cylinder which had soft surface and may have induced little force to the panicles. In addition, high seed mechanical damage from panicles that were threshed using mortar and pestle or beating with wooden stick is due to the impact of wooden materials on the seeds during beating and pounding.

Dharmaputra *et al.* (2012) similarly found that, the method of threshing of sorghum seeds had significant effects on percentage of damaged grain in terms of cracked and broken grains. According to Dharmaputra *et al.* (2012), the percentage of damaged grain of sorghum threshed using a wooden stick was higher compared to those that were threshed with a paddy thresher. This is related to the results of mechanical damage in this experiment because the mechanical damage of the seeds is due to the physical impacts which the seeds receive during threshing by wooden mortar and pestle, and beating with stick.

In both drying methods, the seeds from panicles that were threshed by machine had higher germination percent and significantly high seedling vigour followed by beating with wooden

stick and by mortar and pestle. The lower germination percent and vigour from the seeds that were threshed using wooden stick as well as mortar and pestle is due to the fact that, these two methods caused higher mechanical damage compared to threshing machine. This confirmed results reported by Dharmaputra *et al.* (2012) that, when sorghum seeds were threshed by beating with wooden stick, seed had lower germination percent (91.04%) compared to the seeds threshed by threshing machine (93.33%). Dharmaputra *et al.* (2012) reported that, the results were strongly correlated with percentage damage caused by wooden stick and machine thresher. Also Warzecha *et al.* (2011) reported that, severe seed mechanical damage resulted into low seedling vigour of sorghum seeds.

The increase in germination percent and seedling vigour of the seeds from panicles that were threshed at low moisture content (13%-14%) compared to higher moisture content (18%-20%) could be due to the fact that at higher moisture content, the seeds were too soft and were more prone to damage. According to Phillips (2010), excessively damaged seeds are unable to germinate and some may germinate but will not produce normal seedlings. Shelar (2008) also reported that, any damage to the seed endosperm or embryo caused during seed processing, may result into blocking the translocation of essential nutrients for seedlings growth. This may have caused poor seedling growth for the seeds that were mechanically damaged during threshing either by threshing methods or threshing at unsuitable moisture content.

5.2 Conclusions

This study has shown that, vitreous endosperm sorghum varieties are better in threshability and has minimum seed mechanical damage caused by threshing practises compared to non-vitreous sorghum. In both varieties, mortar and pestle threshing methods resulted in high threshability compared to beating with wooden stick and threshing machine. Threshing machine yielded seeds with low mechanical damage compared to the seeds from beating with wooden stick and mortar and pestle methods. Similarly the seeds from panicles that were threshed at low moisture level 13%-14% had high percentage threshability and low seed mechanical damage compared to those threshed at high moisture level (18%-20%).

The seeds from panicles that were threshed at low moisture content (13%-14%) had high germination percent and seedling vigour compared to those from panicles that were threshed at high moisture level (18%-20%). The germination percent and seedling vigour was high for the seeds from panicles that were threshed by machine followed by beating with wooden stick. The germination results were above 70% for seeds from panicles threshed by beating with wooden stick and by using machine which is the minimum accepted in Kenya seed law cap 326 (Kenya seeds and plant varieties (seeds) regulations, 1991). The lowest germination percent and seedling vigour were recorded from the seeds threshed by the use of mortar and pestle. There was no genotype by environment interaction for germination and seedling vigour, therefore indicates that germination and seedling vigour tests could be applicable for sorghum grown in different environments.

5.3 Recommendations

- The study recommends that, sorghum seeds should be threshed at low moisture content between 13%-14% for better threshing efficiency and high seed quality.

- Mortar and pestle should be avoided when threshing sorghum seeds but it can be used if sorghum produced is for consumption because it results in clean grains.
- Breeders may focus on breeding vitreous endosperm varieties which are hard and hence good for threshability and seed quality.

Also the study recommends for further research to be conducted in:-

- Determination of the effects of threshing methods and seed moisture content in quality deterioration during seed storage so that farmers can obtain knowledge on how long seed can be stored without losing its quality depending on threshing methods used.
- Determination of the effects of threshing methods and seed moisture content on percentage disease infection during storage.
- The impacts of various machine threshers including combine harvester on mechanical damage.

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APPENDICES

Appendix 1: Weather data for Nov-2015 to February-2016 at Katumani

Months	Temperature (°C)	Relative Humidity(%)
November	25.0	83
December	24.8	87
January	25.8	85
February	25	84
Mean	25.15	84.75

Appendix 2: Weather data for Dec-2015 to March -2016 at Kiboko

Months	Temperature (°C)	Relative Humidity (%)
December	31.20	87.23
January	31.82	86.13
February	31.66	79.42
March	37.60	78.52
Mean	33.08	82.83

ANNEXES



Annex 1: Threshing machine



Annex 2: Mortar and pestle



Annex 3: Threshing by beating with stick in tied sack



Annex4: Threshing by using mortar and pestle