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EVALUATION OF FARMERS STORAGE STRUCTURES AND THEIR EFFECTS ON THE QUALITY OF SORGHUM GRAIN IN WA WEST DISTRICT IN THE UPPER WEST REGION OF GHANA

BY

STEPHEN NGMENGU JEBUNI

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A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN POSTHARVEST TECHNOLOGY

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DECLARATION

I declare that this submission is the result of my own work under supervision towards the MPhil. Postharvest Technology Programme. This study contains no material neither previously published by any person nor submitted for the award of any degree in any institution or University, except references which are duly acknowledged to the authors. Any opinion or views expressed and errors found in the work are my responsibility and do not necessarily represent the organizations or individuals who have been cited.

JEBUNI NGMENGU STEPHEN ....…………………....... ……………………

(STUDENT) Signature Date

Certified by:

MR PATRICK KUMAH ....…………………….... …………………….

(SUPERVISOR) Signature Date

Certified by:

DR FRANCIS APPIAH ....…………………... …………………….......

(HEAD OF DEPARTMENT) Signature Date

ABSTRACT

Grain storage structures have a great influence on the quality of the stored produce. The level of insect-pest infestation, damages or losses and overall quality of the stored produce over a period of time depends on the kind of storage structure used. Therefore, the study was conducted in Wa West District from January to July, 2013 with the aim to identify the common storage structures used in the storage of grain sorghum and evaluate their effects on the quality of stored sorghum. A survey was first conducted through the administration of questionnaire, personal observation and discussion to seek farmers' relevant knowledge with regards to the sorghum storage structures used by farmers, reasons for preferences and constraints of sorghum storage in the district. All communities in the district were put into five major clusters or zones and four communities were randomly selected from each cluster for the survey. Data gathered from the survey were analysed using Statistical Package for Social Scientist (SPSS) version 16 and presented in the form of pie charts, bar charts, histograms and tables. The experimental results were analysed using GENSTAT 9.2 Edition and means separated using Least Significance Difference (LSD) at 5% and the results presented in tables and graphs. It was revealed from the study that the major sorghum storage structures farmers used in the district were mud silos (35%), barns (15%), polypropylene bags (18.3%), jute sacks (12.5%), store rooms (houses) (8.4%), Purdue Improved Crop Storage (PICS) bags (5.83%), and baskets (2.5%) while 2.5% of the farmers stored in other structures such as earthen pots and metal containers (basins). Mud silos were the most preferred storage structures used by farmers with baskets and earthen pots been the least. Mud silos were the most preferred due to the numerous advantages associated with them. The use of storage structures by farmers were constraint by high insect infestation, structural failures, difficulties in acquiring structures, rodent destruction, inadequate capital to acquire storage structures and chemicals, transportation difficulties and high cost of the storage facilities. Further to the survey, field experiment was conducted to determine grain losses and evaluate the effects of the major sorghum storage structures used by farmers on grain quality. The grain of local sorghum variety (kazie) cultivated by majority of the farmers in the area was acquired after harvesting and stored in five common used grain storage structures (mud silo, barn, polypropylene bag, jute sack (bag) and PICS bag) with 100 kg each in a Complete Randomised Design (CRD) of three replications for each storage structure or treatment for 210 days (7 months). Samples were taken every 30 days (one month) interval for the determination of relevant parameters such as moisture content, insect count (live and dead), purity test, germination test, 1000-seed weight, weight loss, temperature and relative humidity of the storage structures. PICS bag kept the grains at mean lower moisture content, lowest insect population (28 live ones), lowest mean relative humidity (45.9%), lowest average grain loss (3.2%) caused by the major insect pest - lesser grain borer *(Rhyzopertha dominica)* that infested grains in the storage structures. Percentage mean grain loss caused by insects was highest in jute sack (8.2%) while that of PICS bag (3.2%) was the lowest, suggesting that PICS bag were better in maintaining the quantity and quality of the grain under storage. There was no significant difference ($p>0.05$) in germination and weight loss among the storage structures. Lowest germination losses (5.5%) occurred in the mud silo with greatest losses in jute sack (14.2%). Unthreshed grain stored in mud silo showed an overall better germination (90%) than the rest of the storage structures. However, there was no significant difference in the germination percentages among grain stored in the various storage structures. Correlation coefficient (r) analysis showed that weight loss strongly positively correlation with live insects, dead insects, moisture content and relative humidity ($r>0.05$). Therefore, insects, moisture content and relative humidity were the major influential factors responsible for loss. The purity test at the end of storage revealed that jute sack had high percentage of inert matter (4.7%) with mud silo recording the lowest (2.4%).

DEDICATION

I dedicated this work to Almighty God for helping me through to this stage of my education. I equally dedicate it to my lovely parents, Kyegluu Jebuni (Late) and Jebuni Fati for their prayers not forgetting of my lovely wife Kuri Felicia and my children for their patience and moral support while I undertook this study.

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LIST OF ACRONYMS

AD- After Death of Christ

ANOVA- Analysis of Variance

APHLIS- African Postharvest Losses Information System

BC- Before Christ

CAB- Crop Protection Compodium

CAC- Codex Alimentarius Commission

CIRAD-Centre de Cooperation Internationale en Recherché Agronomique pour le Development (French Agricultural Research Centre for International Development)

CRD- Complete Randomised Design

FAO- Food and Agricultural Organisation of United States

GTZ- Deutsche Gesellschaft für Technische Zusammenarbeit. German Agency for International Co-operation.

ICIRISAT- International Crops Research Institute for Semi-arid Tropics

IRRI- The International Rice Research Institute

ISTA-International Seed Testing Association

JHS- Junior High School

Kcal- Kilo calories

Km^2 – Square kilometres

LSD- Least Significance Difference

Mg- Milligrams

MDGs- Millennium Development Goals

MoFA- Ministry of Food and Agriculture

MSLC- Middle School Leaving Certificate

NGO- Non-Governmental Organisation

NRI- Natural Research Institute

NVS- New Variety of Sorghum

PICS- Purdue Improved Crops Storage

RADU- Regional Agricultural Development Unit

SHS- Senior High School

TDRI-Tropical Development and Research Institute

USA- United State of America

USDA- United States Department of Agriculture

WFP- World Food Programme

CHAPTER ONE

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor (L.) Moench*), popularly called guinea corn, is the commonest and one of the most important cereal crops cultivated in the Wa West District in the Upper West Region of Ghana. Low soil fertility, low yielding varieties coupled with erratic and unreliable rainfall in the area affect their production resulting in poor harvest from year to year. The agricultural economy in the district is basically rural in nature involving over 90% of the population who are subsistent farmers (MoFA, 2013). Farmers in Wa West District produce about 7100 tonnes of sorghum from 17,750 acres more than any other cereal crop (RADU, 2010). Sorghum is produced once in a year in the area which itself is subject to failure, but the demand for the commodity is more evenly spread throughout the year (Adejumo and Raji, 2007). Sorghum contributes to household food security, socio-cultural, economic, and religious aspects of the lives of people in northern Ghana (Kudadjie *et al.,* 2004). So, the food security, immediate or future food and other socio-economic needs of farmers and families in the study area largely depend on how well they keep the little they produced. The grain sorghum harvested by farmers is usually stored in locally available storage structures which do not give adequate protection against the various factors responsible for spoilage or damage of the food grains. Therefore, it has become difficult to preserve the quality of the sorghum for consumption throughout the year.

The effectiveness of the storage structures farmers in the district use to store their sorghum grain after harvest are questionable due to huge storage damages and losses each year. It is not uncommon to see stored sorghum consumed in our homes, those in the local markets for sale and those used as seeds for planting been damaged by biotic factors such as rodents, and insects; micro biological factors such as fungi and bacteria and chemical factors resulting in loss of colour, flavour, taste, texture and nutrient and most importantly abiotic or mechanical factors due to faulty storage structures ((Adejumo and Raji, 2007; Shaila, 2011). The quality of the stored grain is determined by several factors such as environmental conditions during seed production, pests, seed oil content, moisture content, mechanical damages of seed in processing, storage longevity, packaging materials, pesticides, air temperature, relative humidity in storage and biochemical injury of seed tissue (Guberac *et al.*, 2003). Unfavourable, storage conditions, particularly air temperature and air relative humidity, contribute to accelerating seed deterioration in storage (Heatherly and Elmore, 2004).

In recent times, safe grain storage and prevention of postharvest losses by farmers produce has become more a necessity than a rule to overcome the shortage of grain and to tackle the issue of starvation and hunger (Dejene, 2004). Postharvest losses of food grains and oilseeds are estimated to be 10 to 20 percent while that of different horticultural crops vary from 15 to 50 percent (Chahal, 2011) in developing countries of which Ghana is not an exception. It is also estimated that in the tropics, each year, between 25 to 40 percent of stored agricultural products are lost because of inadequate farm and village-level storage (Hayma, 2003). This often leads to hunger, malnutrition and frustration to farmers and families as considerable amount of grain are lost each year. Grain losses therefore contribute to food insecurity and low incomes in Sub-Saharan African countries (Compton *et al.*, 1993).

Despite several studies on postharvest management and grain losses during storage, little has been done to evaluate grain storage structures used by farmers and their effects on the quality of grain sorghum especially in the Wa West District. Since pesticides and other artificial gaseous techniques are no longer acceptable due to food quality and environmentally related issues in recent times (Svetlana, 1994), there was the need to assess the effects of common storage structures used by farmers on stored sorghum grain quality in ensuring food security in the district.

The main objective of this study was therefore to identify the common storage structures used by farmers in the storage of grain sorghum and evaluate their effectiveness in maintaining the quality of stored sorghum in Wa West District in the Upper West Region of Ghana. The specific objectives set out were to:

1. Identify the types and preferences of sorghum storage structures farmers used in the district.
2. Identify the constraints with the storage of sorghum by farmers in the study area.
3. Determine the germination and weight losses caused by insects on sorghum grain stored in the different storage structures commonly used by farmers in the district.
4. Evaluate the effects of the storage structures on the quality of stored sorghum.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 SORGHUM

Sorghum bicolor (L.) Moench is known under a variety of names: great millet and guinea corn in West Africa, kafir corn in South Africa, dura in Sudan, mtama in Eastern Africa, jowar in India and kaoliang in China, milo in the United States (FAO, 1995). The name "sorghum" comes from Italian "sorgo" in turn from Latin "Syricum (granum)" meaning "grain of Syria". Sorghum belongs to the tribe *Andropogonae*, order *Poales* and to the grass family *Poaceae (Gramineae)(*Owolade *et al.,* 2011). The species *Sorghum bicolor* covers a wide range of varieties, from white and yellow to brown, red and almost black.

2.2 TAXONOMY AND NOMENCLATURE OF SORGHUM

According to Léder, (2004), Pliny (ca. 60 to 70 A. D) was the first to give a written description of sorghum and after that there was hardly a mention of it until the sixteenth century. In 1753 Linnaeus described in his Species platarum three species of cultivated sorghum: *Holcus sorghum, Holcus saccaratus* and *Holcus tricolor*. In 1794 Moench distinguished and established the genus sorghum from the genus *Holcus* and brought all the sorghums together under the name *Sorghum bicolor* (Clayton, 1961). Snowden (1936) classified *Sorghum* into 52 species composed of 31 cultivated, 17 wild, and 4 weedy species. In 1961 Clayton proposed the name *Sorghum bicolor (L.) Moench* as the correct name for cultivated sorghum and this is currently being used. On the basis of the absence of genetic barriers among the *Sorghum* taxa, De Wet and Huckabay (1967) combined the 52 species into a single species. Harlan and De Wet (1972) developed a simplified classification that is in common use. There were a total of 15 races. The basic races they identified were *bicolor, guinea, caudatum, kafir, durra,* and ten hybrid races under *S. bicolor* subspecies.

2.3 BOTANIC DESCRIPTION OF SORGHUM

According to Léder (2004), cultivated sorghums are annuals or weak perennials and are essentially non-rhizomatous. The roots will continue to live and support crops. Sorghum plants are 0.5 to 4.0 m tall and the stems are from 0.5 to 5 cm in diameter at the base. The seed is white, yellow or brown, usually 4-5 mm long and 2.5 to 4.6 mm wide. The development of the plant takes 110 to 170 days, and is frequently considered to have three stages: emergence to floral initiation, floral initiation to flowering, and flowering to physiological maturity (Léder, 2004).

According to Rampho (2005), sorghum is cane-like grass up to 6 m tall with large brached clusters of grains. The individual grains are small- about 3-4 mm in diameter. They vary in colour from pale yellow through reddish brown to dark brown depending on the cultivar. Most cultivars are annuals, few are perennials. Cultivated and most weedy sorghum non-rhizomatous, culms nodes are either glabrous or shortly tomentose. The inflorescence is contracted. The branches of the inflorescence alternate. *Sorghum bicolor* includes all the cultivated sorghum as well as a group of semi-wild plants often regarded as weeds. Wild species are characterised by distinct ring of long leaves at the nodes. They have loose inflorescence with spreading branches. The branches of the inflorescence are whorled. The leaves look much like those of maize, they sometimes roll over. The flower head carries two types of flower, one type has no stalk and has both male and female parts and the other flower is stalked and is usually male (Rampho, 2005).

2.4 ORIGIN AND SPREAD OF SORGHUM

Ethiopia is the centre of origin and diversity for sorghum where the crop has been cultivated for many thousands of years (Ethnomed, 2007). Vavilov (1926) considered the old Abyssinian (Ethiopian) areas as the centre of origin of sorghum, but others (Harlan and Snowden) thought that sorghum arose in several separate centres and from different species: races *durra* and *bicolor* from *S. aethiopicum*, *guinea* from *S. arundinaceum*, and kafir from *S. verticilliflorum*. The greatest variation in the genus sorghum is observed in the region of the northeast quadrant of Africa comprising Ethiopia, the Sudan and East Africa (Doggett, 1988). Cultivated sorghum evolved from the wild *Sorghum bicolor* subsp *arundinaceum (*Faujdar *et al.*, 1997). The domestication of grain sorghum may have occurred before 2000 BC in Ethiopia (Doggett, 1988), but an estimate of 1000 BC is now more widely accepted (Balole and Legwaila, 2006).

According to De Wet, the *S. verticilliflorum* was the first to be domesticated some 3000 to 5000 years ago (Dendy, 1995). The cultivated sorghum of the present arose from a wild progenitor belonging to the subspecies verticilliflorum. It appears that sorghum moved into Eastern Africa from Ethiopia around 200 AD or earlier. It was adopted and carried to the savannah countries of Eastern and Southern Africa by the Bantu people, who used the grain mainly to make beer. The present-day sorghums of Central and Southern Africa are closely related to those of the United Republic of Tanzania and more distantly related to those of West Africa, as the equatorial forests were effective barrier to this spread (FAO, 1995). Grain sorghum appears to have arrived in America as "guinea corn" from West Africa with the slave traders around the middle of the nineteenth century. The spread along the coast of Southeast Asia and around China may have taken place at the beginning of Christian era, but it is also possible sorghum arrived much earlier in China via lilk trade routes (FAO, 1995).

2.5 PRODUCTION OF SORGHUM

Sorghum is a drought-tolerant cereal grain which requires little input during growth as compared to other crops; yield better with good husbandry (ICRISAT/FAO, 1996). Developing countries account for roughly over 90% of the world's sorghum area and 77% of the total output (Ethnomed, 2007). In the Upper West Region of Ghana, over 90% of households produce sorghum (Al-hassan and Poulton, 2009). Sorghum is usually grown as a field crop in Africa. It is grown in wide variety of soils, drought resistant, but does better on soils enriched with compost or fertilizers prior to planting. Cultivars have also been selected to suit different soils and climate conditions. It is best to practice crop rotation and only grow sorghum on the same land every four years. Sorghum is prone to various pests including birds and in some parts of Africa parasitic witchweed (striga) (Ethnomed, 2007).

2.6 USES AND POTENTIAL OF SORGHUM

Sorghum is one of the main staple food crops for the poorest, the most food insecure people of the world and food for more than 500 million people in more than 30 countries (Ethnomed, 2007). Because sorghum is mostly consumed by the disadvantaged groups, it is usually referred to as '*poor people's crop*' (FAO, 1995). While sorghum is a vital food crop for millions of people in parts of Africa, it is an underutilised resource in most developed countries, being used primarily as animal feed and little cultivated (ICRISAT/FAO, 1996). Sorghum plays a huge role on the world market as a means of livelihood for millions of farmers and as important part of food security (Duodu *et al.*, 2003). Food sorghum consumption in developing countries (in Africa, Asia, Central America, Caribbean, and South America) is projected to increase from 26 million to over 30 million tons (Léder, 2004). Sorghum is a dual-purpose crop providing staple food for human consumption (35%) and the rest as fodder for livestock, alcohol production, as well as preparation of industrial products

(Awika and Rooney 2004). Sorghum has also been used in the production of alcohol and the whole plant used for forage, hay or silage while the stems of some kind of sorghum are used for building, weaving, fencing, broom making, firewood and industrially for the production of vegetable oil, waxes and dyes (Rampho, 2005).

In many parts of the world sorghum has been used traditionally in food products and various food items such as porridge, unleavened bread, cookies, cakes, couscous, malted and distilled beverages, beers and special foods such as popped grain (Crop Plant Resources, 2006). Sorghum with large juicy stems which contain as much as 10% sucrose are used in the manufacture of syrup and sugar (Anon., 2010). Sorghum stems can also be chewed, especially the juicy, sweet stem variety (*kakanuo*) and the rusty-coloured leaf sheaths provide pigment (dye) that is traditionally used to colour food especially cooked rice and beans (*wakye*) (Buah *et al.*, 2010). Sorghum is used in the production of local beer, which has an important socio-cultural role in many African societies and is an important income earner for women while their by-products a source of fodder, the dried stems of the plants used as housing material and cooking fuel (World Bank Report, 2011).

The feed or energy value of sorghum is similar to corn, so it has been used successfully in balanced rations for cattle, poultry and swine and as a feedstock for ethanol production (Hamman *et al*., 2001). The 2002 Farm Bill encourages an increase in the production of grain sorghum because of its use as an ethanol feedstock and the current national interest in reducing foreign oil imports in the USA (USDA, 2002). With increasing world population and decreasing water supplies, sorghum represents an important crop for future human use. Sorghum has a considerable further potential to be used as a human food and beverage source. Besides, sorghum has large potential for its use in the fermentation industry, puffed products, and in weaning foods for the children of developing countries (Chavan *et al.*, 2009). The use of sorghum not only provides farmers with a market for their products but also serves as foreign exchange which would otherwise be required to import cereals.

2.7 VARIETIES OF SORGHUM

Sorghum is a cereal of remarkable genetic variability - more than 30000 varieties are present in the world sorghum collections (Léder, 2004). Javis *et al.* (2004) observed that many of the crop varieties used by farmers meet several different needs of small scale farmers and represent a valuable resource for farmers. In Ghana especially in the north where sorghum is largely grown, subsistence farmers generally place a high premium on their landraces and varieties based on the specific and distinct roles they play in socio-cultural, economic and religious lives (Buah *et al.*, 2010). The various varieties of sorghum grown by subsistence farmers in the Upper West Region as documented by Buah *et al.* (2010), most of which were endangered races consist of early (90-115 days), intermediate (120-135 days) and late-maturing varieties (140-180 days). The early maturing varieties include kapiela, cheri, chekpuri, medium maturing: gyibaraa, balur, beluru (red), kaza kpulekpule, gberre and late maturing: ollu-bile kazu, kabile, kakpong, kazie, donboro, oluu, donbora, pogkuori latuori, murapai, biakanayiri and dafaalo. There also existed early-maturing high yielding improved varieties like *naga white, framida, kapaala and dorado*. These had low preference in the area because of grain quality problems and high soil fertility requirement. Earliness alone cannot be sufficient for selecting suitable sorghum varieties for extension in the area (Buah *et al.*, 2010). Naming was given based on maturity periods by farmers. Naming of some varieties was also based on seed colour such as *kapiela* (white sorghum), *kazie* (red sorghum) which describes the grain colour (Buah *et al.*, 2010). Table 1 shows some sorghum varieties grown in Ghana and their physical characteristics as described by Demuyakor and Ohta, 1992.

Table 1: Some varieties of sorghum grown in Ghana

Variety	Days from planting to harvesting	Grain colour	Endosperm type
NVS-1	140	White	Hard and vitreous
NVS-2	140	Bluish	Hard and Vitreous
Naga white	95	White	Soft
Kadaga	105	Red	Soft
Framida	110	Red	Soft
Local 29	170	White	Hard and vitreous
White sorghum	150-180	White	Hard and vitreous
Red sorghum	150-180	Red	White and vitreous

Source: Demuyakor and Ohta, 1992

2.8 NUTRITIVE VALUE OF SORGHUM

The nutrient compositions of sorghum include carbohydrates, proteins, lipids, vitamins and minerals (Léder, 2004; FAO, 1995). In many households, sorghum is the primary source of energy, protein, vitamins and minerals (Klopfenstein and Hoseney, 1995). Sorghum is also relatively rich in iron and phosphorus. High fibre content and poor digestibility of nutrients are other characteristic features of sorghum grains severely influence consumer choice. Whole grains are important sources of vitamin B-complex, which are mainly concentrated in the outer bran layers of the grain. However, sorghum does not contain vitamin A, although the endosperms of some yellow varieties contain small amounts of ß-carotene, a precursor of vitamin A (FAO, 1995). Like other cereals, sorghum is predominantly starchy and the protein content and other chemical composition is nearly equal and comparable to that of wheat and maize (Léder, 2004). The nutrient composition of sorghum and other cereals are given in table 2 below.

Table 2: Nutrient Composition of sorghum and other cereals

Cereal type	Protein (g)	Fat (g)	Crude fibre (g)	Carbohydrate (g)	Energy (kcal)	Calcium (mg)	Iron (mg)
Wheat	11.6	2	2	71	348	30	3.5
Maize	9.2	4.6	2.8	73	358	26	2.7
Sorghum	10.4	3.1	2	70.7	329	25	5.4
Common millet	12.5	3.5	5.2	63.8	364	8	2.9
Rice (brown)	7.9	2.7	1	76	363	33	1.8

Source: FAO (1995)

Although it is important to emphasize quality of crop product, the quality of the grains for various end-users should also be evaluated. Traits such as grain hardness for extended storage and ease of processing should be considered for household food and nutritional security (Obilana, 2001).

2.9 QUALITY OF STORED GRAINS

The term 'quality' has different meanings for those who are concerned with the handling, storage, processing and utilisation of grain (FAO, 1994). Quality grains are grains that do not contain damaged grains, dead or immature grains, grains of other crops and foreign matter, and are evaluated for quality by comparison with standard samples for inspection (FAO, 2009). Quality traits such as grain hardness for extended storage and ease of processing should be considered for household food and nutritional security (Obilana, 2001). Quality cannot be improved during storage, handling or processing but can easily be lost. At best grain quality can only be maintained. During storage, seed quality is determined by several factors like environmental conditions during seed production, pests, diseases, seed oil content, seed moisture content, mechanical damages of seed in processing, storage longevity, packaging materials, pesticides, air temperature and relative air humidity in storage as well as the biochemical injury of seed tissue (Guberac *et al.*, 2003). The quality of cereal grains during storage is affected by entomological, microbiological and environmental factors, resulting in physiocochemical and organoleptic changes that lead to significant product qualitative and quantitative losses (Iconomou *et al.*, 2006). High temperatures and excessive moisture in stored products or high humidity under ambient storage conditions permit the proliferation of insects and moulds, which cause large losses of quality (Iconomou *et al.*, 2006). Myriad of factors influence the quality of stored grains. Some of these include: unseasonable weather and climatic conditions; the crop variety cultivated; how the crop is harvested, threshed and dried; type of storage structure or container; processing methods, including drying and threshing; and management practices employed, such as pest control procedures and standard of store hygiene (FAO, 2009). A combination of poor drying techniques, open storage systems, high relative humidity and high ambient temperatures contribute to reduction in seed and grain quality during storage period (Rickman and Aquino, 2004).

The price paid for produce does not depend only on the quantity sold but also on its quality (FAO, 2009). The emergence of institutional quality – conscious buyers such as the world Food Programme (WFP) has also created a demand for quality grain and provided an important market opportunity for farmers who can meet the required standard of quantity and quality (World Bank Report, 2011). Hence, it is essential that farmers keep their crop produce in the best possible condition until they are sold. The major quality changes during storage are: loss/gain of weight, changing of physical appearance, loss of nutritional food value, loss of culinary properties and total destruction of the grain (Mishra, 2012). Grain of high quality fetches a premium price both for the local trader and for the farmer, particularly as insect-undamaged grain is difficult to find. However, whilst remaining in the trader's store insect damage increases significantly; it is not unusual to see grain with more than 50% damage (Golob *et al*., 1999).

2.10 HARVESTING OF SORGHUM

Timely harvest is important to preserve grain quality and reduce mould, bird damage, insect pest infestation, and loss due to bad weather conditions (FAO, 1995; Beta *et al*., 2004). Traditionally, sorghum grains are harvested during the beginning of the dry season. It is critical for farmers to know when to harvest the grain in order to reduce losses (Beta *et al*., 2004). Sorghum can be harvested with machines or manually depending on the scale of production (NRI, 1999). The crop is harvested when it reaches its physiological maturity stage (moisture content of approximately 20-30%) (World Bank Report, 2011). Like corn and wheat, sorghum can be harvested at moderately high grain moistures (between 18 to 22%) if sufficient drying capacity is available. The optimum harvest moisture, about 20%, minimizes harvest losses and drying expenses (Beta *et al*., 2004).

According to Carter *et al*., (1989), nearly all grain sorghum is harvested as a standing crop especially in developing countries. Sorghum can also be harvested using knives or sickle bar headers. The heads or panicles of the sorghum are cut from the stalks either by hand, sickle or using knife; they are placed into sacks and taken to threshing platforms where they are placed on racks or spread on the platform for drying. Late harvesting can lead to spontaneous shedding of the grain from the panicles resulting in significant losses and grain deterioration due to rapid changes in temperature and humidity (NRI, 1999).

2.11 POSTHARVEST HANDLING OF SORGHUM

Postharvest handling includes on-farm pre-processing, including *threshing; grain drying, packaging, transporting and storage.* Proper postharvest handling is important to maintain grain quality. Women are primarily responsible for postharvest handling (Wortmann *et al*., 2006). The postharvest handling of sorghum varies widely from farmer to farmer and also from country to country. The levels of mechanization from country to country also differ widely, ranging from manual, animal or mechanically operated (FAO, 2007).

2.11.1 Drying

Sorghum does not normally dry in the field to a moisture level that is suitable for direct marketing (14%) or safe storage (13.5% or lower) unless it is further dried after harvesting; because allowing the crop to dry in the field to safe storage moisture levels can lead to significant yield loss (McNeil and Montross, 2003). Control of moisture is a necessary step towards successful storage. There is therefore an essential need to dry grain quickly and effectively after harvest to retain maximum quality, to attain moisture content sufficiently low to minimise infestation by insects and microorganisms such as bacteria and fungi and to prevent germination (FAO, 1994).

All small scale farmers in African rely on sun drying to ensure that their crop is sufficiently dry for storage (Nukenine, 2010). In developing countries, the sorghum grain is sun dried on the panicle and/or after threshing but when the economies of scale permit, sorghum grain may be dried by warm forced air (McFarlane *et al.*, 1995). During drying in the sun, grain on the panicles or as threshed grain should be kept off the ground on raised platforms or mats. Sorghum grain should be dried uniformly and thoroughly to a moisture level that matches the anticipated storage period to ensure product quality (McNeil and Montross, 2003). The purpose of drying is to reduce the moisture content of the seed to facilitate threshing and cleaning, to maintain seed viability and vigour, to reduce deterioration of the seed due to growth of moulds, microbes, and storage insects (Faujdar, 1997).

For all stored products, the maximum "safe" moisture content for storage is that which is in equilibrium with 70 percent Relative Humidity (RH), but lower levels (in equilibrium with 65 percent RH) are advisable if quality loss is to be minimised (McFarlane *et al.,* 1995). Moisture content of the grain will equilibrate to a level which equates with the vapour pressure deficit (which is a function of relative humidity and temperature). Moulds develop if the moisture content is above 15 percent and the temperature above 24°C (NRI, 1999).

2.11.2 Threshing

Threshing is the process of separating the grain from the seed heads or panicles (Rembold *et al*., 2011). It is important to minimize the damage as damaged grains are much more prone to attack by insects and fungi. Threshing should be done immediately after harvesting as the longer the harvested panicles remain in a stack, the higher the chance of discoloration and shattering (Rembold *et al*., 2011). Sorghum seeds are easily damaged in the threshing operation especially when the grains are too dry. Sorghum grain can be threshed free of the head when the seed moisture is 20-25 percent (FAO, 1994).

In rural Africa, threshing involves beating the dried sorghum panicles with sticks on the ground, in sacks or using a mortar and pestle (NRI, 1999; Beta *et al.*, 2004). This method is very inefficient and slow and complete recovery of grain is not easy. Threshing techniques that damage grains such as beating with sticks or trampling by cattle are not recommended. In some places, a common practice for threshing the grain is to place it on the road for vehicles to run over. This is economical and better and also reduces the amount of winnowing (NRI, 1999). Losses occur during threshing by spillage; incomplete removal of grain from stalks; damage to grain during threshing, cleaning or winnowing after threshing (FAO, 1994).

2.11.3 Winnowing

Winnowing is a simple traditional cleaning method which uses wind or a fan to remove the light elements from the grain (Guisse, 2010). According to FAO (1994), winnowing is a process of separating grains from chaff by wind or fan. The whole content is thrown up in the air and the grain chaff separated. Threshed sorghum can contain all kinds of trash like chaff, straw, empty grains, foreign seeds as well as mineral materials such as earth stones etc. Seeds should be cleaned as soon as possible after harvesting prior to storage (FAO, 1994).

2.11.4 Packaging

Sorghum can be packaged in bags made of jute, cotton, woven polypropylene or multi-layer paper. Woven polypropylene bags are light in weight, low cost and permit aeration. Their disadvantage is that hooks can irreparably damage the bags. They have a slippery surface and can be difficult to stack. Sacks are often re-used and care should be taken to prevent re-infestation of clean grain by boiling sacks in water and thorough drying (NRI, 1999).

2.11.5 Transporting

Sorghum grains are usually transported to the house for storage by humans-head loading, bicycles, motorbikes and vehicles. The mode of transports lead to high postharvest losses as the grains are prone to attack by insects, birds and theft (World Bank Report, 2011).

2.11.6 Storage of Grains

Storage is a way by which agricultural products or produce are kept for future use. It is an interim and repeated phase during transit of agricultural produce from producers to processors and its products from processors to consumers (Thamaga-Chitja *et al.*, 2004). Generally, over 70% of grains harvested in Africa are stored for human consumption, for marketing or resale by commercial traders (Talabi, 1989). Storage involves moving produce through time to provide subsistence families with food supply beyond harvest or provide for national food reserves in the event of emergency to ensure year-round availability for affluent consumers (ICRISAT/FAO, 1996). It is estimated that about 60-70 percent of food grains produced are stored at home level in indigenous storage structures (Nagnur *et al.*, 2006; Karthikeyan *et al.*, 2009; Mishra, 2012). Storage offers the opportunity by smoothening hunger between staple crop harvests and enables farmers to improve their farm incomes by storing crops and selling at premium prices when demand outstrips supply later in the post-harvest period (Florkowski and Xi-Ling, 1990).

Sorghum grain may be stored as unthreshed panicles or threshed. Both storage methods are practised, but small-scale producers tend to store the grains unthreshed (NRI, 1999). Specific storage practices vary widely according to the ethnic group, cultural traditions, climatic zone and production scale or socioeconomic condition of farmers (Adejumo and Raji, 2007).

Successful storage depends on the type of structure used, how well the grains are handled and protected against environmental conditions (Boxall *et al.*, 2002). At the household level sorghum is stored under traditional management conditions where it is susceptible to insect pest infestation (Rugumamu, 2002). The commodities stored and their relative quantities are generally related to their production statistics - the higher the quantity produced, the more grains of that commodity stored. Udoh *et al*. (2000) classified storage techniques into three categories namely: Traditional/ local grains storage (LS) techniques at farm and domestic level which includes local cribs and rhombus, platform, open field, roof and fire place; Improved/ semi modern grains storage (SMS) technique at farm and domestic level which are the ventilated cribs, improved rhombus; and brick bins and modern centralized storage (MS) at commercial level which includes silos and warehouses. Provision of good storage enhances the shelf life of the produce as well as reduces losses. This situation was observed in Guinea (FAO, 2008) when silos were provided, losses were reduced by 15 to 20%. Effective storage is therefore crucial to improve agricultural production and food security for small scale farmers. In Africa, especially for small scale farmers, the main purpose of storage is to ensure household food supplies (reserves) and seed for planting (Adetunji, 2007) and also stabilises seasonal market prices during off-season periods (Adejumo and Raji, 2007). Sawant *et al.* (2012) stated that the primary aim of grain storage is to prevent crop and monetary losses resulting from agents such as rain, insect, fungi, and rodents attack thereby maintaining the quality and quantity of grains from the beginning of storage until they are consumed or sold.

2.12 LENGTH OF STORAGE

Food grains commodities can be stored for considerable periods of time (Iconomou *et al.,* 2006). However, the quality of preservation during long-term storage of grains is a serious problem in many parts of the world (Gras *et al.,* 2000). The quality of the crop is influenced by many different factors. Most important is the length of time it remains in store (FAO, 2009). The length of time grain is stored affects the level of pest infestation (Utono *et al.,* 2013). The quantity of grain produced in a season influences the nature of storage method and the duration of the storage period (Owusu, 1981). The length of storage also depends on the agro-ecological zone, ethnic group, quantity of commodity stored, the storage condition and the crop variety (Hell *et al.*, 2000). Grain storage periods generally range between 3 and 12 months across Africa. A maximum storage period of between 7 and 10 years for sorghum in Sudan Savannah was recently reported by Adejumo and Raji (2007). It has also been reported that farmers store their grain between four months and one year (i.e., from one crop season to another) with the majority storing their grain for seven months (Utono *et al.*, 2013).

2.13 EFFECTS OF CLIMATIC FACTORS (TEMPERATURE, RELATIVE HUMIDITY AND MOISTURE) IN STORAGE

The principal physical factors that affect grain in storage are temperature, moisture content and relative humidity as well as oxygen and carbon dioxide (Anon., 2011). The temperature of the air, the relative humidity and the moisture content of the stored produce are closely interrelated (Gwinner *et al.,* 1996). Losses increase as moisture content and temperature of the grain increase (Beta *et al.*, 2004). A rise in temperature will cause the grain to lose moisture to the air thereby increasing the relative humidity. A drop in temperature will cause the relative humidity in the air to turn to water (dew) which settles on the grain. High relative humidity leads to a rise in the moisture content of the stored produce and under certain conditions to condensation. If no measures are taken to counteract this considerable losses are likely to occur. Only when the necessary steps are taken which include drying of the produce, good storage hygiene, controlled ventilation and pest control, the quality of the stored produce can be maintained. Cereals can be stored up to a period of a year or more under a wide range of temperatures provided that during storage the moisture level does not rise and precautions against insects are taken (Hayma, 2003). Storage pests like all living organisms have a specific temperature range within which they thrive. The optimum temperature for most insects' growth is around 30°C; temperatures of 40°C or higher will sooner or later kill off all insect species. The most favourable temperature for development and reproduction is about 28°C; below 21°C and above 35°C reproduction almost ceases (FAO, 1992). The lower the temperature, the longer the creature will take to develop. Below 10°C, insects become dormant and they cannot survive below zero. At a temperature over 34°C, insects usually cannot develop. Lesser grain borers and Khapra beetles will however continue to develop at 34°C and 40°C respectively (FAO, 1992). At higher temperature, the life cycle of insects becomes shorter while the oviposition rate increases (FAO, 1992). In general, the higher the temperature, the shorter the developmental period of insect pests. Developmental period from egg to adult becomes longer and the number of eggs laid fewer, at lower temperatures. Low, even temperatures and low relative humidity are favourable for maintaining the quality of the stored produce (Anon., 2011). It has also been reported by Owolade *et al.*, (2011) that low temperature condition associated with lower moisture content is very suitable for sorghum seed storage. Rainfall, ground moisture and a drop in temperature increase the relative humidity. Insects may still develop at a relative humidity of approximately 35% and temperatures of around 15% (Hayma, 2003).

Every type of grain has a safe moisture content level; this is the level of moisture content at which equilibrium humidity will not cause the development of insects or moulds. At this level or below, insects and moulds find it difficult to develop and multiply. The moisture content of grain plays a vital role in the development of agents of deterioration. It is difficult for insects to establish themselves below 9% moisture content but between 10 and 20% they proliferate, above 17% they may start to be replaced by mould (Anon., 2011). When grains are not very dry there is an increase in biological activity in the structure (CIRAD, 2002). Therefore, moisture content of the product itself as well as the moisture content of the surrounding air is important for safe storage (Hayma, 2003).

Stored products as well as the organisms attacking stored products are living things: they breathe. During respiration ("breathing"), oxygen is used up and carbon dioxide, water and heat are produced. The rate of respiration, thus the amount of carbon dioxide, water and heat produced strongly depend on the temperature and the moisture content of the product (Nukenine, 2010). Higher temperature and moisture content values of grains favours insect and fungus development and a decline in the germination capacity of the grains (Hayma, 2003). Insects developing in grain produce heat, moisture and waste products hence create conditions suitable for further deterioration especially the growth of moulds (FAO, 2009). Certain storage methods are more effective than others at preventing high grain moisture levels, which may lead to mould and fungi contamination, including aflatoxin proliferation (Hell *et al.*, 2000). Clay structures may be overly damp and dark for optimal drying, while improved cribs allow for open air flow and have been shown to reduce moisture contents from 20% to 14% over three months and are associated with decreased aflatoxin contamination in Nigeria and Benin (FAO, 1992; Hell *et al.*, 2000). Storage on floors and non-ventilated facilities however is not recommended due to ineffective drying and high residual levels of *Fusarium* and contamination of fumonisins (up to 40.3% of kernels infected) (Fandohan *et al.*, 2005).

2.14 STORAGE PESTS

Stored grains may suffer from serious attacks of pests (insects, fungi, rodents and birds), especially when not protected and in the presence of poor store hygiene. Insects, rodents, birds and micro-organisms are serious constraints to the traditional storage systems of Africa (Nukenine *et al.*, 2002; Haile, 2006). Amongst these living organisms such as insects are responsible for the greatest storage losses in cereals. According to Sharma *et al.* (2007) the important storage insect pests of sorghum are; rice or black weevil, maize weevil and the granary weevil. Storage insect pests are mainly beetles or moths with the beetle adults usually found crawling over the surface of grains while adult moths if not resting on surfaces are often found flying close to the store (FAO, 2009). Traditionally, the grain weevils, *Sitophilus* spp. (Coleoptera: Curculionidae) and the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) on cereals and three genera of bruchids, Acanthoscelides, Zabrotes and Callosobruchus spp. on pulses are the most important pests of stored grain in Africa (Abate *et al.*, 2000). In addition to direct destruction of grains through feeding and reproduction, insects' presence has direct influence on grains causing an increase in grain temperature and moisture contents which leads to an increase in respiration and consequently loss in quantity and quality of the grain (Odogola, 1994).

Fungi are the major microorganisms causing spoilage in stored grains and seeds resulting in significant losses to farmers, traders and food and feed manufacturers (Twiddy, 1994). The major grain storage fungi are Aspergillus, Fusarium and Penicillium spp. Rodent species that damage stored products vary from region to region and from country to country. The three common species across Africa are the black rat, Rattus rattus, Fischer de Waldheim, brown rat, Rattus norvegicus, (Berkenhout) and common mouse, Mus musculus L. Pests control are mainly traditional and also the use of synthetic chemicals.

2.15 GRAIN STORAGE STRUCTURES

The idea of storage structures is to prevent insect pests and rodents from attacking the grain (Adejumo and Raji, 2007). The grain storage structures are basically required to protect the grains from insects, rodents and prevent deterioration of the grains (Hall, 1970); however, traditional storage structures in Africa expose grains to serious insect infestations. Storage structures are many and varied in the way they are made or constructed (FAO, 1994;

Adejumo and Raji, 2007). They are usually made with local materials (plant materials and soil) by the indigenes and also depending on the climatic conditions of the area (Nagnur *et al,* 2006). Farmers and rural householders in developing countries store most of what is grown in small storage structures (FAO, 1995).

Maleka *et al*. (1993) in their study revealed that the most common structures for storing cereals and pulses in Tribal area were gunny bag, bamboo bins and mud pot. Neem leaves, salt, ash and oil were preservatives used by majority of tribal women for preserving cereals, pulses and legumes. Shashikala (1993) in her study on knowledge and adoption of improved methods of food grain storage by the farmers of Dharwad taluk indicated that 61, 35 and 3 percent of the jowar growers used gunny bags, earthen storage structures and metal bin for storage of jowar, respectively. Among paddy growers 39, 54 and 7 percent of them used gunny bag, bamboo storage structure and metal bin for storage of paddy, respectively.

According to Motte *et al.*(1995), the major storage techniques practiced by rural small-holder farmers in west Africa vary greatly but include on-field, open storage, jute bags, polyethylene or polypropylene bags, raised platforms, conical structures with thatched roofs, clay structures and giant woven baskets. Farmers also store bags in their personal rooms, on cobs above fireplaces, or simply heaped on floors (Hell *et al.*, 2000). Shobha *et al*. (2006) conducted a study on indigenous grain structures and methods of storage in Dharwad district of Karnataka state. The study revealed that the use of *Kanaja/Galagi*, a bamboo structure were very common in paddy growing areas. *Sandaka* is a wooden structure used to store smaller quantities of grains especially pulses for household consumption. *Kothi* is a proper room for storing large quantities of grains. *Utranis* are mud pots for storing small quantity of grains. *Hagevu* is an underground storage structure used to store large quantity of grains, common in the dry agro climatic zone where moisture level is low.

Adejumo and Raji, (2007) in their study identified some storage structures which include open platforms, woven baskets, pots, pits, mud rhombus, bamboo or straw roofs calabashes, gourds, warehouses and community stores. Karthikeyan *et al*. (2009) conducted a study on indigenous storage structures in 6 districts of Tamil Nadu. They found that farmers stored their grains either in containers or in bulk. The containers include earthen pots, jute bags. The grains were also stored in traditional storage structures such as *Kuthir, kodambae, thombarai, kalangiyam, macchu, paanai, mara thombai, orai, sakkupai, saal, arisi peti and vengaya*.

Producers in East and Southern Africa store grains in small bags with cow dung ash, wood and wire cribs, pits, metal bins, wooden open-air or roofed cribs, raised platforms and roofed iron drums enclosed with mud or may hang cobs over a fireplace (Kankolongo *et al.*, 2009). Many farmers prefer to store maize in a temporary outside structures in Zambia after harvest until they are fully dried, then shelled and transferred grain into polypropylene bags inside the house before sale, consumption or planting (Kankolongo *et al.*, 2009).

Shaila (2011) in his work on evaluation of storage methods adopted by farmers in Haveri and Dharwad districts revealed that majority of the respondents (73.75%) used gunny bags for storing grains. Another traditional practice of storing produce in the mud pots was adopted by 68.75 percent of farm women.

Mahama (2012), in a comparative assessment of some storage technologies used for cowpea storage in Nadowli district in Upper West region recently observed that the untreated control of the polypropylene sack, barn and pot recorded a substantial level of cowpea damage. As high as 87% of cowpea beans were infested with bruchids. With the exception of the triple bag, the untreated control of the polypropylene sack, barn and pot offered little protection.

A more recent but increasingly popular form of storage is the PICS (triple layer) bag. This system utilizes a thin, transparent and low permeability co-extruded multi layer plastic as a liner to a conventional jute or polypropylene bag. The triple bag consists of 2 layers of polyethylene bags which are expected to be as hermetic as possible and both are included in a protective polypropylene woven bag. Studies show that hermetic storage of cowpea for 8 months in triple layer bags maintains constant moisture and germination rates (Rickman and Aquino, 2004). Triple layer bag capacities range from 5 kg to 1,000 kg, with 43-60 kg capacity being the most common. Many studies in various countries have shown that triple-bagging maintains germination of 85% or more effectiveness for periods up to 9 months, while conventional storage jute bags reduces germination down by 14% to 76% within 3 months (Omandi *et al.*, 2011). This has led to the adoption of hermetic storage by some leading seed producers. Triple-bagging is a sustainable, cost effective, user- friendly and environmentally technology that makes the use of pesticide and fumigants in postharvest and seed storage unnecessary. The technology has already been adopted for the protection of many different commodities in quantities ranging from that of conventional grain bag size to many thousands of tones. Effective storage structures therefore play an important role in stabilising food supply at the household level by smoothing seasonal food production (Thamaga-Chitja *et al.* 2004).

2.16 MANAGEMENT OF STORAGE STRUCTURES FOR SAFETY STORAGE OF GRAINS

Storage management is important for all types of structures. According to Scotti (1978), losses are linked to two principal factors, which may be abiotic (granary architecture, humidity and temperature) or biotic (micro-organisms, rodents, birds and insects). Typical African traditional storage structures expose the grain to insect attack and favourable climatic conditions for the proliferation of micro-organisms and rodents (Nukenine, 2010).

For proper management, a storage structure should provide protection from common storage loss agents such as insect pests, rodents, moulds, birds and man, maintain an even, cool and dry storage environment, prevent re-wetting of grain by either moisture migration or rain, offer reasonable protection from thieves, be simple, easy to clean, repair and inexpensive to construct using where possible locally available materials and skills. Insect damage can be reduced by preventive action, including the removal of old grain before new crop, drying new crop rapidly and well cleaning of storage structures before putting in new grain and inspection at regular intervals (Golob and Webley, 1980). To avoid infestation of the new crop, the old grain must be removed preferably before the new crop is matured but certainly before the mature crop is brought to the homestead (Sharma *et al.*, 2007). Old grain from the previous season is often a major source of insects. The new crop must be rapidly dried to attain safe moisture content levels and threshed as soon as it is dry. The grain is then treated and put into store before any significant damage occurs. Before the new crop is brought in, the storage structures and their surroundings should be well cleaned and maintained. The storage structures should have no entry points at all times to prevent re-infestation with insects. Adequate system of inspecting the grain throughout the storage period should be put in place. If any pest or damage is detected, immediate action should be taken through the following exercises: repairing any damage to the storage structure, cleaning and drying the grain either by sunning or kilning, treating the grain again with a suitable insecticide such as pirimiphos-methyl (Actellic) or pyrethrum dust or with wood ash if necessary.

2.17 CAUSES OF GRAIN DAMAGE IN STORAGE STRUCTURES

Grain damage generally refers to superficial evidence of deterioration such as broken grains which may later result in loss (FAO, 1992). Insects are the major cause of damage in storage. They cause considerable damage to grain either by chewing from the outside or boring holes inside the grain. Insects also damage grain directly by feeding on kernels and indirectly by contaminating the grain with their wastes, webbing and body parts (Haile, 2006). Rodents also chew grain usually starting at the embryo end. Moulds and bacteria will spread through grains causing unhealthy discoloration and lesions which may be the only manifestations of infection indicating the grain was not dried properly (Anon., 2011).

Insects reduce the quality of grain and therefore the market price. During the usual 5-12 month storage period of grains in the Sudan and Guinea Savannah of Nigeria, insect damage ranged from 40-60% for unthreshed sorghum (Ivbijaro, 1989). The range for grain damage and losses across Africa are very broad. There are reported cases of 50%, 47% and 3% stored damage due to insects, rodents and micro-organisms, respectively (Nukenine *et al*., 2002).

Traditional storage structures in Africa expose grains to serious insect infestations. A study by Shaila (2011) showed that the main causes of grain damage in storage include rats which burrow the mud floor (18.3%) followed by oily nature of food grains (15%) and external entry through burrows (13.33%). Insect damage to food grains was caused by excess moisture in grains followed by improper drying (11.67%), improper ventilation (10%) and excess aeration (6.67%), lack of cleanliness (5.83%) and ventilation (5.0%). The type of damage due to insects was mostly in the form of powder formation, chaffy seeds and development of holes on seeds and aggregate formation. In case of rodents the loss was in the form of broken grains (20.5%), whole grains eaten by rats (21.67%) and mixed with soil (2.5%).

2.18 LOSSES OF GRAIN IN STORAGE STRUCTURES

Loss is a measurable qualitative or quantitative decrease of the foodstuff (Anon., 2011., FAO, 1992). Loss and deterioration during the storage of food grains may arise if the condition of the grain in store is unsatisfactory, if the storage place is unsuitable for safe storage and if during storage there is inadequate store management or the environmental conditions become unfavourable (Boxall, 2001). The factors affecting grain loss are moisture, temperature, insects and rodents, quality before storing, the type of storage structure, use of pesticides and fumigants, mechanical loss factors and the condition or location of storage (Mishra, 2012). There are many kinds of losses on stored grain. These include: weight loss, quality loss, and nutritional loss, loss of seed viability and commercial loss (FAO, 1992; Magrath *et al.*, 1996). During storage, grains are subjected to losses due to several agents including insects, fungi, rodents and mites. Insects cause loss in weight and the nutrient content of grain so that there will be less food to eat and remains less nutritious (FAO, 2009). Grain losses caused by insect pests in Africa are quite high and vary from country to country and from region to region. However, annual grain losses of over 50% in cereals have been reported although the average stands at 20% (Philips and Throne, 2010). In general, the damage caused by insects is much higher than those caused by other agents like rodents and micro-organisms. Insects and rodents eat the grain and also contaminate the grain with their eggs, exoskeleton (insects) droppings, hairs and urine in the case of rodents. The magnitude of losses due to these agents is believed to be high. Losses in storage are caused possibly by man's failure to understand and follow proper storage principles and practices (Hayma, 2003). Losses caused by the activities of microorganisms are less understood and often unrecognized (Ramirez and Bernal, 2002). The major cause of losses has also been attributed to lack of hygiene in traditional storage structures (Bell, 1996). According to Boxall (2001), the losses in grain quantity and economic values are between 10-20% during a storage period of 6 months to 3 years.

According to Hayma (2003), losses during storage may occur in many ways. This include losses in weight due to insects, rodents or birds eating the grain, losses in quality through biting damage, insect and rodent excrement, deterioration through fungus growth and rotting, decline in germination capacity of stored seed, loss of motivation in the farmer to grow more because he is not able to store his harvest or part thereof in a safe way for any long time. Loss may be caused by changes of light, temperature, moisture content, excessive respiration, infestation and in some cases, the methods used to control infestation. Insects that selectively attack the germ will cause a greater loss in germination than others (FAO, 1992). Postharvest losses during transit and from rats, moulds and insects during storage average about 25% of the total crop harvest. As high as 30% weight loss and an average of 8.7% during 3 to 6 months storage period has been reported in Tanzania due to the outbreak of Prostephanus/truncatus (Horn) (Golop and Hodges, 1982). In Mali, losses were found to be 2-3% in sorghum stored for 5 months where the main pest was the lesser grain borer (Ratnadass *et al.*, 1994). Average dry weight losses of farm-stored maize in Togo were estimated to have risen from 7 to 30%, for a storage period of 6 months (Pantenius, 1988). Results of detailed field studies suggest that under traditional storage systems in tropical countries, losses are typically around 5% over a storage season depending upon the crop, the ambient conditions, the period of storage and other factors (FAO, 1994). Somewhat higher levels have been encountered in the wetter parts of West Africa and Central America.

Kimenju *et al.* (2010) in their study on grain loss of maize stored with different storage technologies for a period of six months observed that most of the storage options apart from the metal silos, percentage crop loss increased with time and was highest in the sixth month. The polypropylene bag with no pesticide registered the highest percentage loss, reaching 24% in the sixth month. The second highest loss was found in the polypropylene bag with actellic super (8.4% in the sixth month) followed by the super grain bag (6.3%). Percentage loss observed in the metal silos, whether with pesticide or not, was small: 1.7% for metal silo with actellic, 1.4% for metal silo without pesticide and 0.5% for metal silo with phostoxin.

On-farm storage studies made in Eritrea under the Drylands Coordination Group showed that staple grain of cereals and pulses produced by small farmers in Eritrea were attacked by different storage pest species of insects, rodents and birds (Haile, 2006). Germination losses due to attack of storage pests on cereals and pulses grains ranged from 3-37% and 4-88%, respectively.

Chaudhary *et al. (*1993) studied grain infestation in traditional storage structures in rural Haryana. Grain infestation was maximum in Kothies (24.3%) followed by heaps in living rooms (21.6%), bags kept without bhusa (18.3%), separate store rooms (17.7%), bhukhari (16.85%) and metal bins (10.8%). Even in those structures in which small quantity was stored, grain infestation was recorded. It was highest in Harra (82.8%) followed by Padkhala (28.0%), Parchhattis (2.2%). The most safe grain structure, (metal bin) was used by about 94% of the sample farmers. The rest, about 6 percent of the farmers used bharola for storage of grains. The storage loss of wheat kept for family consumption and seed was 4.62% and 3.3%, respectively. The major causes of storage loss were rats, insects, dampness and birds.

Singh and Sidhu (2000) in their study on postharvest losses at farm level in Punjab revealed that most of the farmers (99%) used gunny bags for storage of wheat and paddy. Sexena *et al.* *(*2000) studied the postharvest storage losses in wheat observed various methods of storage that prevailed in the study area to include bulk, bag, steel bin and kuthila. The losses in steel bin were minimum among all the methods of storage. While among bulk, bag and kuthila methods of storage, storage losses were minimum in bag followed by bulk and kuthila. The study further revealed that percentage storage losses increased with increase in period of storage.

Mundinamani *et al. (*2007) in their study on scientific grain storage with *Pacca kot*i in Lokur village of Dharwad district found losses to be 20 to 30% in case of sorghum, wheat, maize and Pulses.

A study by Patil *et al.* (2000) on the economics of storage of food grains at farm level in Buldana district of Vidarbha region revealed that, the important factors leading to storage losses were, non-availability of separate godowns, poor types of storage structure and lack of drainage provided to gunny bag storage room.

Storage losses among cereals ranged between 11 and 100% and weight loss between 2.9 and 20% for storage periods of 2-12 months (Tadesse and Eticha, 1999). On-farm physical losses in grain weight were crudely estimated to range from 10% after one storage year to more than 30% over longer storage periods in Namibia (NRI, 1997).

Boxall (2001) suggested that reduction of postharvest losses can lead to substantial increases in food availability to feed the increasing world population. Therefore, the degree and extent of postharvest losses caused by insects is the matter of considerable concern.

2.19 PROBLEMS/CONSTRAINTS OF GRAIN STORAGE STRUCTURES

The storage of sorghum and other cereals grains is a challenge as a result of lack of improved storage structures. Most of the postharvest technical problems in Northern Ghana relates to storage issues which include: high insect infestation of stored produce, destruction of produce by rodents, limited market for sorghum, high cost of storage materials, poor threshing technologies, poor storage facilities/conditions, poor transportation, inadequate capital and access to credit and lack of extension services regarding postharvest management (Golob *et al.,* 1995). Postharvest insect pests are major constraint to food security and income generation in Sub Saharan Africa because of significant yield losses and grain quality degradation (Abebe *et al*., 2009).

One of the main problems in storage is the management of the store. This is because farmers mostly keep old and new harvested grains in the same vicinity, which causes an easy migration or infestation of the new grains from the old grains (Haile, 2006). Inadequate and inefficient storage methods in developing countries like Ghana are major problems that lead to losses in food of an unacceptable degree (Gwinner *et al.,* 1996). It has been reported by Rajulanchan (1998) in a study in Sudan village of Jodhpur district to know the constraints of arid farm women in grain storage found the major problem to be rats. Their fast multiplicity and quick adaptability to different situations are the two important characteristics, which are responsible for large damage caused by rats. Incidence of storage pests, lack of proper knowledge about the use of chemicals to control storage pests and inability to identify the storage pest were some of the problems. He also observed that higher percentage (78%) of the women felt that storage structures used by them could not protect their grains from damage caused by rats and other insects. Sometimes, the grains get spoiled due to the moisture absorbed by these containers from the surroundings.

Waman and Patil (2000) in a study observed the first ranked constraint to be lack of knowledge about improved storage structures (75.33%), less knowledge about grading (58.66%) and lack of knowledge about handling/care during storage period were also important constraints (50.55%). Other constraints were costly storage facilities (42.67%).

Omoruyi *et al.* (1995) observed that, produce stored under the traditional system usually do not keep long and farmers usually suffer great losses. One of their major weaknesses in traditional storage structures is the presence of a single orifice for loading and removing grains which also serve as an entry point for pests (FAO, 1994; Adejumo and Raji, 2007).

Kanwar and Sharma (2006) in their study on traditional grain storage structures in Himachal Pradesh realised that rural people feel that traditional storage structures were fixed, required regular maintenance and needed local skilled persons for their construction but whose number is also decreasing day by day. Moreover, improved grain storage structures are also status symbol for rural family. They were also of the opinion that as the improved storage structures are airtight, the chances of infestation of grains were less, while it was a drawback of traditional storage structures. However for the storage of seeds, farm families still prefer traditional storage structures over improved ones. The response perceived that seed stored in metal bins has low germination rate in comparison to traditional structures. It may be because of the reason that metal bins do not maintain consistent temperature, which is not so in traditional storage structures.

Karthikeyan *et al*. (2009) in their study on traditional storage practices in dry tracts of Tamil Nadu reported that indigenous practices have advantage over outside knowledge; it has little or no cost and is readily available. Because traditional storage structures are generally not hermetically sealed give room for pests to make their way into the structures. When constructed with plant materials, rodents easily destroy the structures and favour other sources of infestation (CIRAD, 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 THE STUDY AREA

The Wa West District is one of the nine districts that make up the Upper West Region. It was created in 2004 by legislative instrument 175 with Wechiau as the District capital. The District is located in the Western part of the Upper West Region, approximately between longitudes 40ºN and 45ºN and Latitudes 9ºW and 32ºW. It shares borders to the South with Northern Region, North-West by Nadowli District, East by Wa Municipal and to the West by the Republic of Burkina Faso. The district lies in the Savannah high plains, which is generally undulating with an average height of between 180 m and 300 m above sea level. A distinct uni-modal rainfall pattern is experienced in the district. The rolling nature of the landscape is good for agriculture and other physical developments. The main drainage system is the Black Volta River and its tributaries.

The district is underlain predominantly by Precambrian, Granite and Metamorphic rocks that have seen less weathering due to low rainfall, high evapo-transpiration and less vegetation. There are two main soil types, the most extensive being the ground water lateritic soil. There is also the Savannah orchrosols found along the Black Volta. The soil types vary from shallow and gravelly soils on undulating terrains to deep, grayish brown alluvial clay bottomlands.

The Wa West District has two marked seasons. The rainy season begins in May and ends in September and the dry season begins in October and ends in April. The mean annual rainfall figures vary between 840 mm and 1400 mm. A very important feature of rainfall in the district is that it is erratic in nature; torrential and poorly distributed. The soil moisture is adequate for the cultivation of crops such as sorghum (guinea corn), millet, maize, yam, groundnuts, soya beans and cowpea. Vegetables are also planted. Yields realized on farms are usually not the best due to low yielding varieties coupled with low soil fertility and erratic rainfall. The unreliable nature of rainfall in the district affects plant growth negatively resulting in poor harvest from year to year. Temperatures are high for most part of the year, ranging between 22.5ºC to 45ºC, low between December and January, and high between March and April. Average monthly maximum temperature is 33ºC whereas the daily highest is 35ºC. The vegetation of the Wa West District is of the Guinea Savannah grassland. There are also gallery forests along the Black Volta River and its tributaries. Figure 1 below shows the study area.

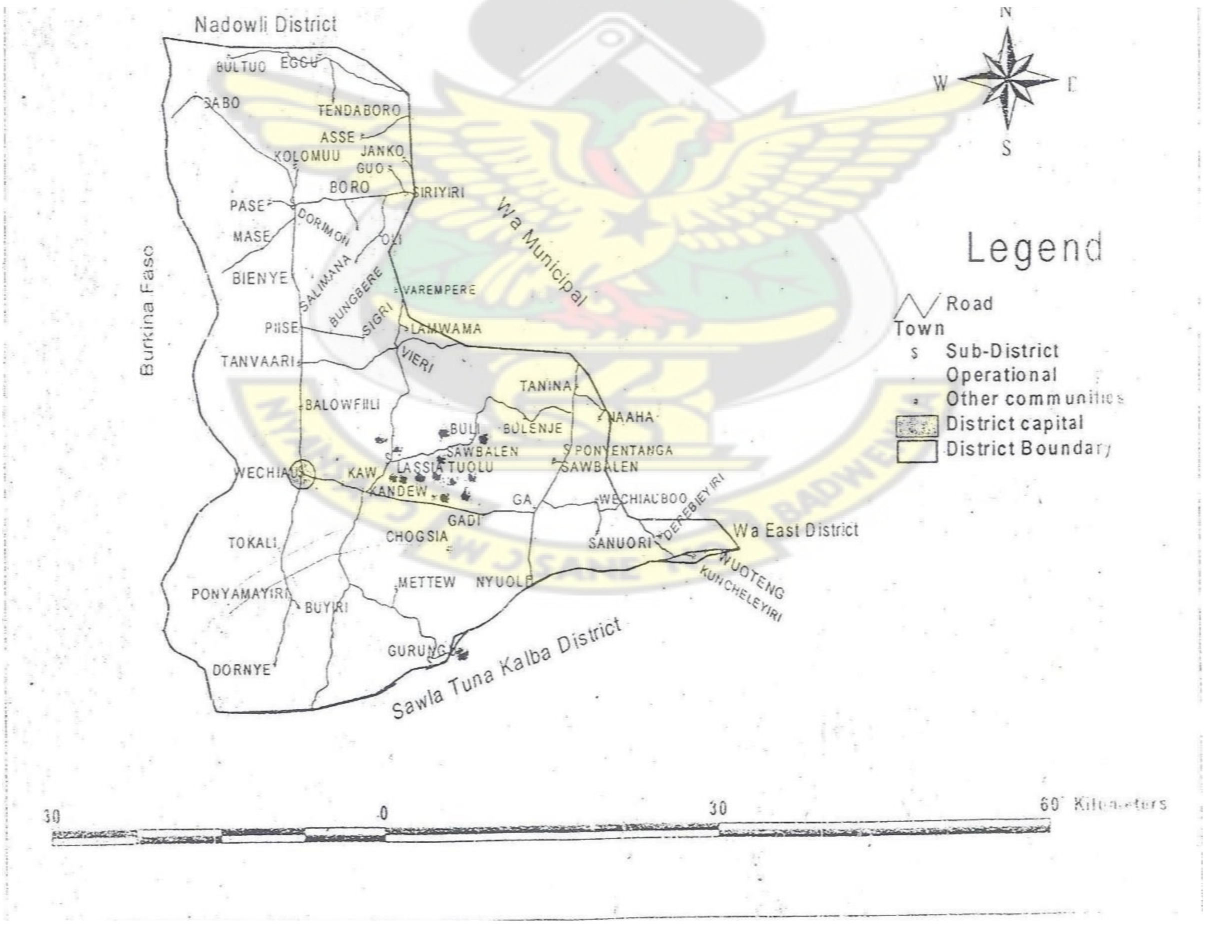

Figure 1: Sketch Map of Wa West District showing some of the surveyed villages

Source: Wa West District Assembly.

3.2 DESIGN AND PERIOD OF STUDY

The study was conducted in two phases: A field survey and an experiment. The survey was first carried out in early January, 2013. At that time of the year farmers in the area had harvested their sorghum and were involved in postharvest handling activities. The field storage experiment also took place from the middle of January through to July 2013.

3.3 THE FIELD SURVEY

This was carried out through the administration of questionnaires and Participatory Rural Appraisal Techniques (observations and discussions) with farmers to seek relevant information with regards to the types of storage structures, reasons for preference of a particular storage structure, forms and reasons for storing sorghum grain, maintenance methods, the form sorghum grains are stored, cost of various storage structures or facilities, duration of storage, varieties of sorghum, farmers sources of seeds and labour, time and tools used to harvest sorghum, problems that confront farmers in the storage of sorghum and in the use of storage structures.

3.3.1 The Questionnaire

A set of semi-structured questionnaire was designed to obtain the requisite data needed. The parameters considered in the questionnaire were the demographic characteristics of respondents, principal sorghum grain production, sorghum grain storage activities and sorghum grain storage structures in the area. The questionnaires were personally administered to 120 respondents in the twenty (20) communities that were randomly selected. The questionnaires were translated into the local dialect for the understanding of those farmers who could not read. The questionnaire is presented in Appendix 1.

3.3.2 Participatory Rural Appraisal Technique

The technology (observation and discussion) was used to identify and gather description about the sorghum grain storage structures that were prevalent in the communities, how to build or acquire them, how produce were stored in them, reasons for storing sorghum threshed or unthreshed forms and the problems that confronted farmers in the storage of sorghum grains.

3.3.3 Selection of Communities for the Survey

A cluster sampling technique was used to select the communities. The district was divided into five zones based on the five Area Councils, namely Dorimon, Ga, Gurungu, Vieri, and Wechiau. The communities in each zone were listed and a simple random method of selection was then employed to select four (4) communities from each cluster for the survey. The communities selected include: Dorimon zone/cluster (Dabo, Dorimon, Varempere and Bienye), Wechiau zone/cluster (Wechiau, Kantu, Tokali and Gojuyiri), Vieri zone/cluster (Kandeu, Lassia Tuolu, laadayiri and Bakpaateng), Gurungu zone (Meteu, Chogsia, Gurungu, and Yuonuuri), Ga zone/cluster (Poyentanga, Nyoli, Buligen and Gbaalwob).

3.3.4 Analysis of Survey Data

Data gathered from the survey were analyzed using Statistical Package for the Social Scientist Version 16 (SPSS 16) and presented in the form of pie charts, tables, graphs and percentages.

3.4 THE FIELD EXPERIMENT

This was carried out to further determine the efficacy and effects of the commonly used storage structures by farmers in the area.

3.4.1 Experimental Design

The experimental design used was Complete Randomised Design (CRD) with five treatments and three replications each. These included the five commonly used storage facilities: Barns with threshed grain, mud silos with unthreshed grain, polypropylene bags, jute sacks, and Purdue Improved Crop Storage (PICS) - triple-layer hermetic storage bags with threshed grain.

3.4.2 Experimental Equipment

The major equipment used in the study were top-loading electronic balance, thermometer, moisture tester, hygrometer and a sieve.

3.4.3 Research Crop

The research crop was a common local sorghum variety (Kazie) cultivated by most farmers in the area. This grain was obtained from farmers in the area.

3.4.4 Storage Methods

Hundred (100) kg of sorghum grain was stored in three replications each of the different storage structures without adding any chemical as practiced by most farmers in the district.

3.4.5 Parameters Studied

The quality parameters measured were: temperature and relative humidity of the storage structures, moisture content, insect count (dead and live insects), germination (viability) test, 1000 - seed weight, percentage weight loss and purity test of the sorghum grain.

3.4.6 Data Collection Procedure

The relevant parameters were taken at 30 days (one month) interval from each storage structure as follows: All determinations were carried out according to the Rules of International Seed Testing Association (ISTA, 2007).

1. Testing moisture content from samples: A standard digital moisture tester was used for moisture content determination soon after grain removal of samples from the storage structures.

2. 1000-seed weight: 4 x 1000 seeds were counted manually and weighed (every 30 days interval) with a sensitive balance from each treatment expressed in g.

3. Insect count (dead and live insects): The insect fauna was determined by taking samples of 1 kg from each treatment every 30 days and by sieving with 2.00 mm sieve the number of dead and live insects was counted manually and recorded (Ratnadass *et al.*, 1994).

4. Purity test: Random samples of 4×90 g from each treatment were sorted into components of pure seeds, other seeds and inert matter. This was expressed as percentages using the equation as follows:

Percentage component part=Weight of component part/ Weight of total sample × 100.

5. Germination test: This was done randomly by taking 4×100 pure grains from each treatment. The samples were then placed and rolled on a moist germination paper and watered with cleaned water at room temperature. Germination percentage was taken on the 10th day.

6. Assessment of losses:

(A) Loss caused by insects: This was done by randomly counting 100 undamaged and 100 damaged grains. The weight of both damaged and undamaged grains were taken using an Ohaus brand of top-loading electronic balance (See Plate 3). Using the count and weigh method, the loss in each treatment was assessed by substituting the values into the formula. The percentage weight loss was according to Harris and Lindblad (1978) FAO (1992) as follows:

$$\%\ \text{weight loss} = \frac{(UNd) - (DNu)}{U(Nd + Nu)} \times 100$$

Where U= weight of undamaged grains

D= weight of damaged grains

Nu=number of undamaged grains

Nd= number of damaged grains

This method (count and weigh method) has been used extensively in research to quantify the amount of storage loss in on-station and on-farm experiments (Boxall (2002); Ratnadass Fleurat-Lessard (1991) and Tefera *et al.* (2011).

(B) Germination loss: Initial germination percentage - Final germination percentage of grains stored in storage structures.

7. Temperature and relative humidity: The temperature and relative humidity in the storage structures were taken every 30 days (one month interval) immediately after partial opening of the storage structures as well as the ambient temperature of the surroundings.

3.4.7 Analysis of Experimental Data

Analysis of variance (ANOVA) in CRD was performed on experimental data collected using GENSTAT release 9.2 Discovery Edition. Means were separated using Least Significance Difference (LSD) at 5% significance level. Simple correlation coefficient (r) was computed on the quality parameters taken. The results of the analyses presented in graphs and tables.

CHAPTER FOUR

4.0 RESULTS

4.1 BASELINE SURVEY RESULTS

The baseline survey involved the administration of questionnaire, personal observation of sorghum storage structures in the district. Analyses of data from the survey are presented in Figures 2 to 23 and Tables 3 to 7 while the analyses of the Field Experiment are presented in Table 8 to 10 as well as Figures 24 to 36.

4.1.1 Gender Distribution of Respondents

Figure 2 shows the number of male and female respondents that were contacted in the Wa West District in the Upper West Region of Ghana. The Figure indicates that out of the 120 farmers 93 were males and 27 females representing 77% and 23%, respectively.

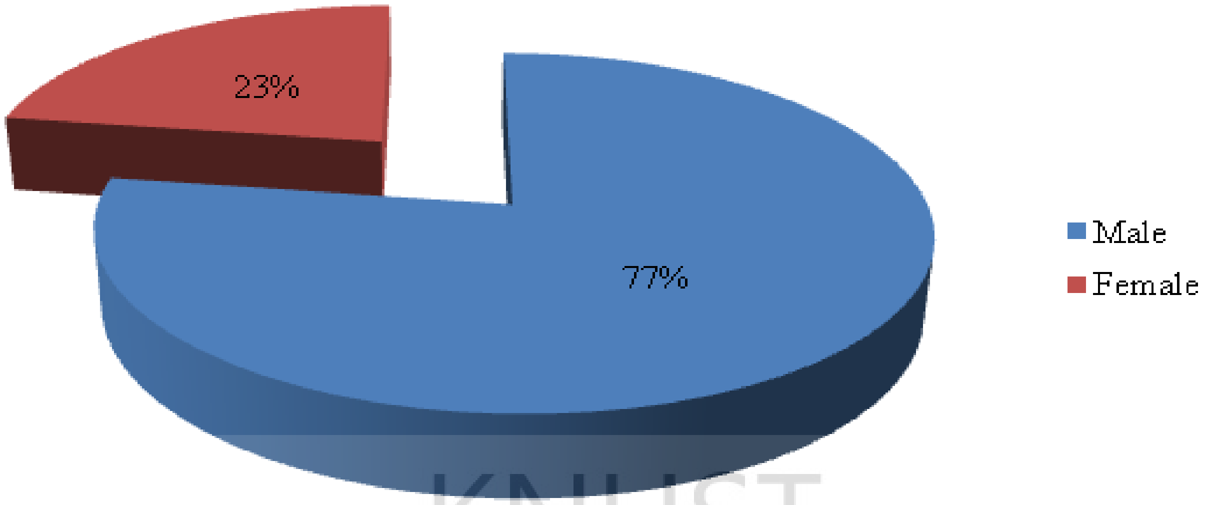

Figure 2: Gender distributions of respondents

4.1.2 Age Distribution of Respondents

The age distributions of respondent farmers are shown in Figure 3. Majority of the respondents (21.7%) were within the age brackets of 30-39, followed by the age group of 40-49 which was 20.0%; 17.5% of the respondents were of the age range of 20-29 while 50-59 age group was 12.5%. The age groups of 10-19 and 60-69 represent 10.8% each while the age group of 70 and above was 6.7% hence the least of the total respondents.

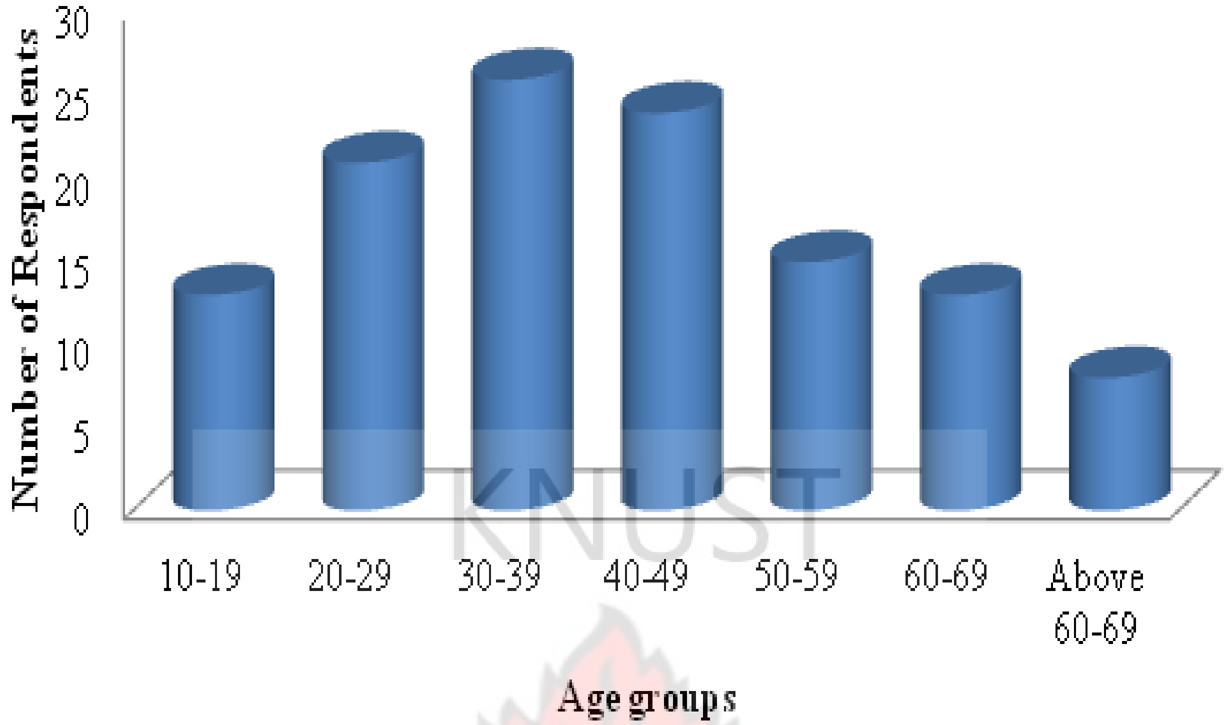

Figure 3: Age distribution of respondents

4.1.3 Religious Background of Respondents

Majority of respondents were traditional believers representing 44% of the respondents while 30% being Christians and 26% Muslims. This is shown in Figure 4 below.

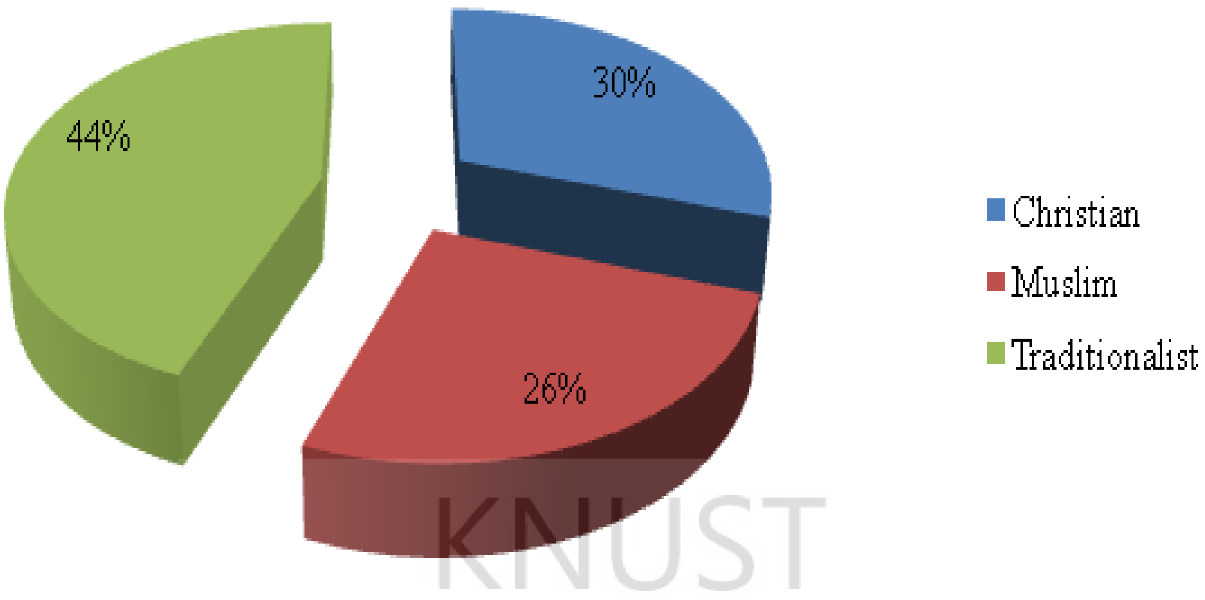

Figure 4: Religious background of respondents

4.1.4. Marital Status of Respondents

Majority (66.7%) of the respondents were married couples with 27.5% being single while 2.5% and 3.3% were divorced and widowed, respectively.

Table 3: Marital status of respondents

Response	Frequency	Percentage
Single	33	27.5
Married	80	66.7
Divorced	3	2.5
Widowed	4	3.3
Total	120	100

4.1.5 Educational Background of Respondents

The results showed that, greater proportion (54.6%) of the respondents did not have any form of formal education (Figure 5), 8.4% had non-formal education, 10.1% had primary education, 7.6% had MSLC/JHS education and 12.6% had SHS/Voc/Tech education while 6.7% had tertiary education.

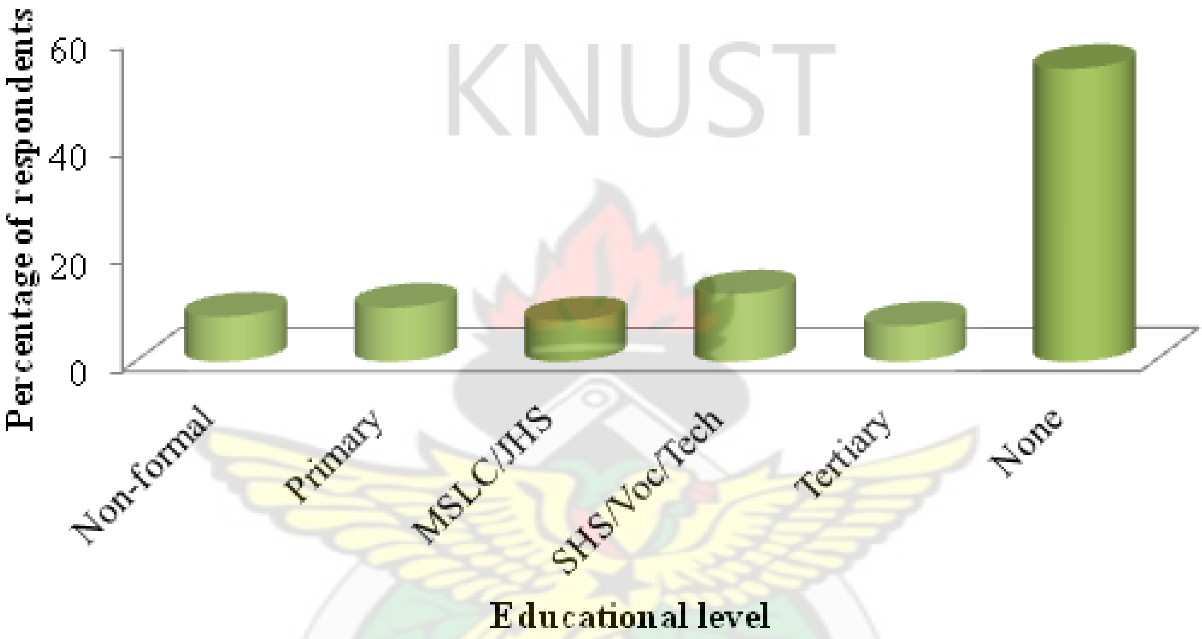

Figure 5: Educational backgrounds of respondents

4.1.6 Varieties of Sorghum Farmers Grow

Figure 6 shows that about 87% of the respondents grew local varieties/cultivars of sorghum and 13% of them grew some improved varieties supplied by the Agricultural Extension Agents of MoFA and NGOs in the area. Some local varieties of sorghum grown in the area consist of endangered races such as kapiela, kakpong, kabile and kazie. Some were early maturing varieties (90-115 days), intermediate (120-135 days) and late-maturing varieties (140-180 days). There also existed early-maturing high yielding improved variety like kapaala. Table 1 shows the percentage of farmers that grow the sorghum varieties.

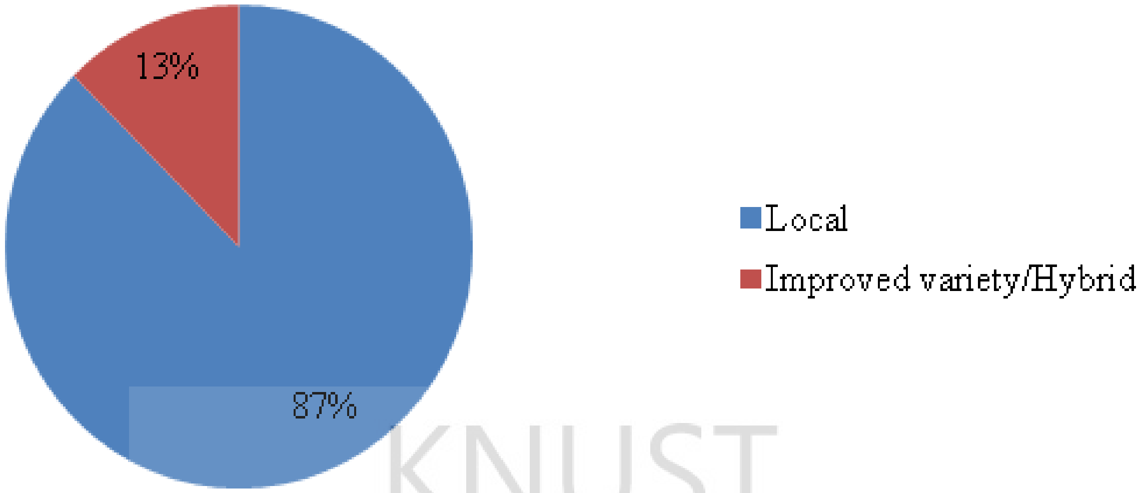

Figure 6: Varieties of sorghum grown by farmers in the area

4.1.7 Farmers Sources of Seeds for Producing Sorghum

A lot of the farmers (75%) personally stored sorghum grains as seeds source for planting in the following season. Few of the respondents (20%) bought seeds from the market, retailers and other people to plant, 2% of the respondents obtained their seeds for planting from friends while 3% store, buy or collect from friends (Figure 7).

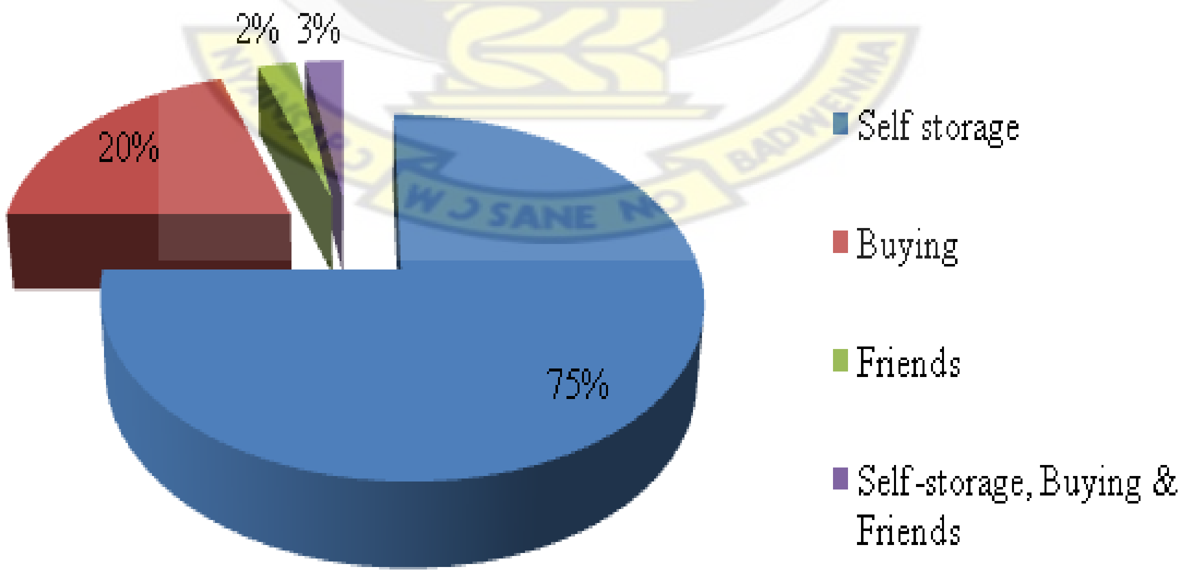

Figure 7: Farmers sources of sorghum seeds for production

4.1.8 Sizes of Respondent Farms

Figure 8 shows that 52.5% of the sorghum farmers cultivated farm sizes of 1-3 acres, 15% farm between 4-5 acres annually, 12.5% of the respondents had 6-8 acres, 5% cultivated less than an acre and only 5% farmed more than 10 acres.

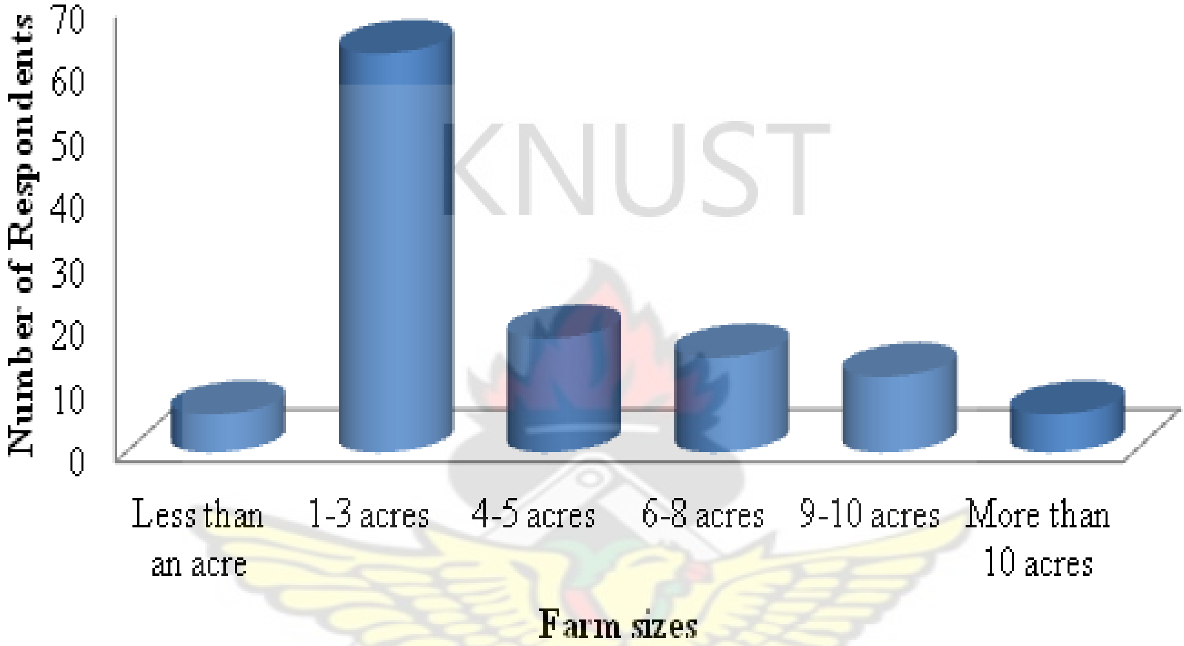

Figure 8: Sizes of respondents' farms

4.1.9 Land Preparation by Farmers

Land preparation was mainly by the hand hoeing and the use of tractor for the cultivation of sorghum. Fifty three percent (53%) of the farmers interviewed used both tractor and the hoe to till the land; 42.5% of the farmers used only the hoe while 5% used only tractor (Figure 9).

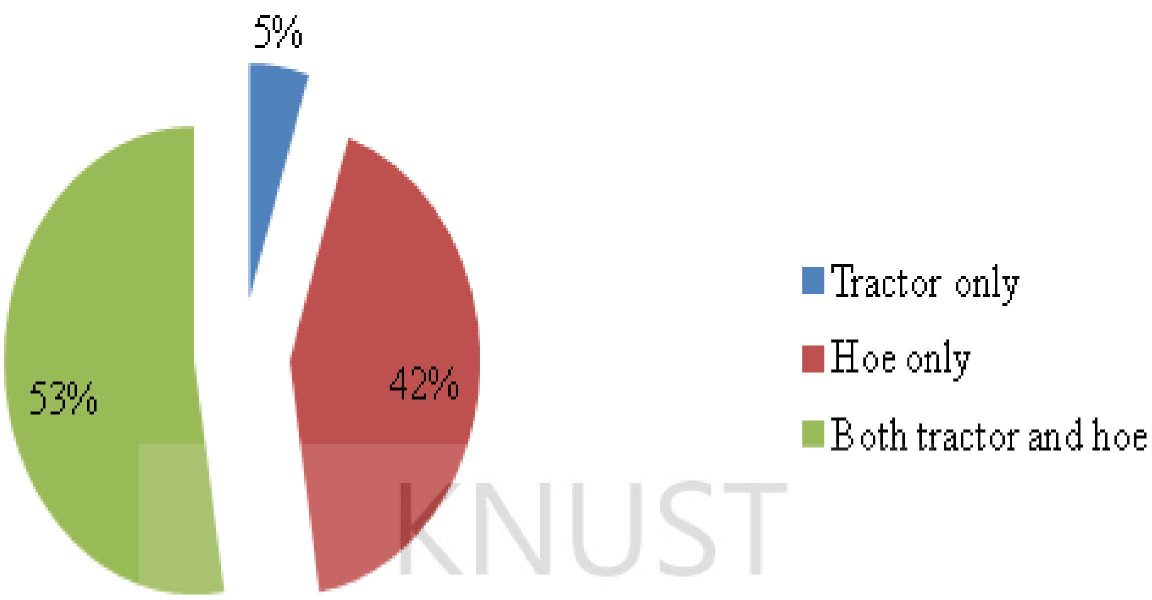

Figure 9: Land preparation by farmers

4.1.10 Sources of Labour for Producing Sorghum

Figure 10 indicates that 50% of the farmers used both family and hired labour, 37% used only family labour whiles 13% depended on only hired labour to produce sorghum.

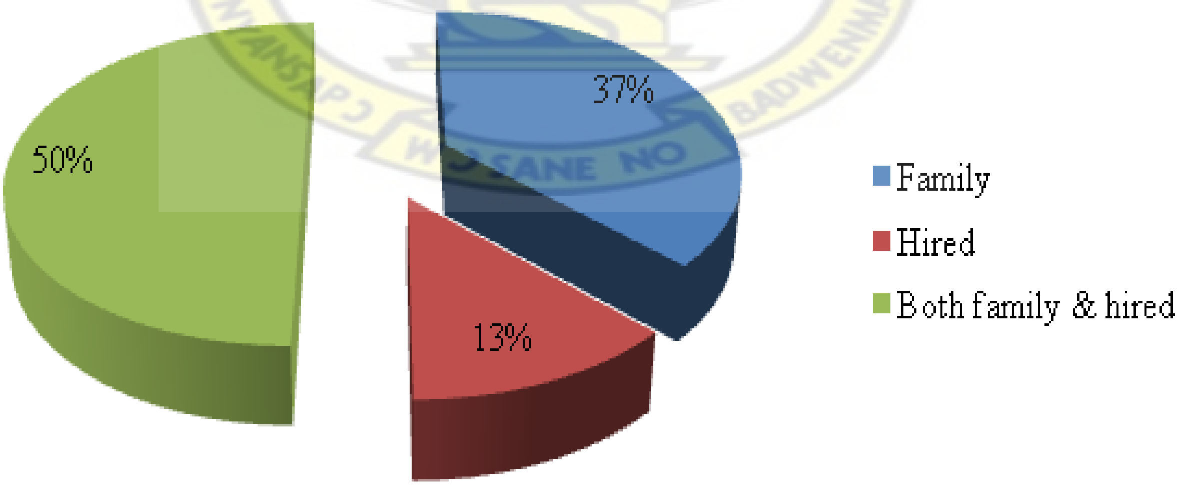

Figure 10: Sources of farm labour

4.1.11 Duration of Sorghum Production in Wa West District

This was to find out the duration of sorghum production in the study area from planting to harvesting among the 120 farmers. Fifty two farmers, that is, over forty three percent (43.3%) of the farmers spent more than 3 months to produce sorghum in a season, 44 farmers representing 36.7% used 6 months in producing sorghum, while 15 farmers (12.5%) spent seven months. The rest (5% and 2.5%) spent 5 months and 4 months respectively in producing the crop per season (Figure 11). Some farmers considered the time for clearing, gathering and burning stocks till harvesting of the crop as their production period. This therefore made some farmers to estimate long duration of production.

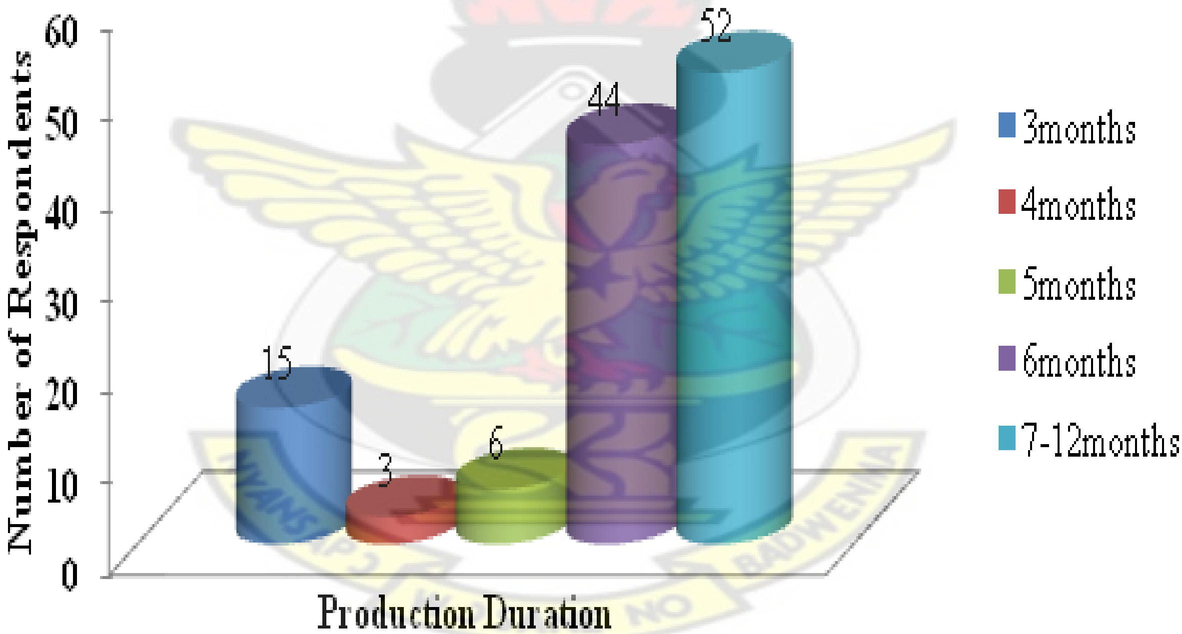

Figure 11: Duration of sorghum production in Wa West District

4.1.12 Time for Harvesting Sorghum

Sorghum is harvested from October through to December every year. The result depicts that majority (75.8%) of the farmers in the district usually harvest their sorghum around November - December. Some of the farmers cultivated early maturing varieties/cultivars which are usually ready for harvesting before November. Over twelve percent (12.5%) of farmers harvested their sorghum between October and December. The rest of the farmers (5%) harvested between October and November with few harvesting around September to December (3.3%). The harvesting was done when rainfall had stopped or about to stop and the dry season has set in (Figure 12).

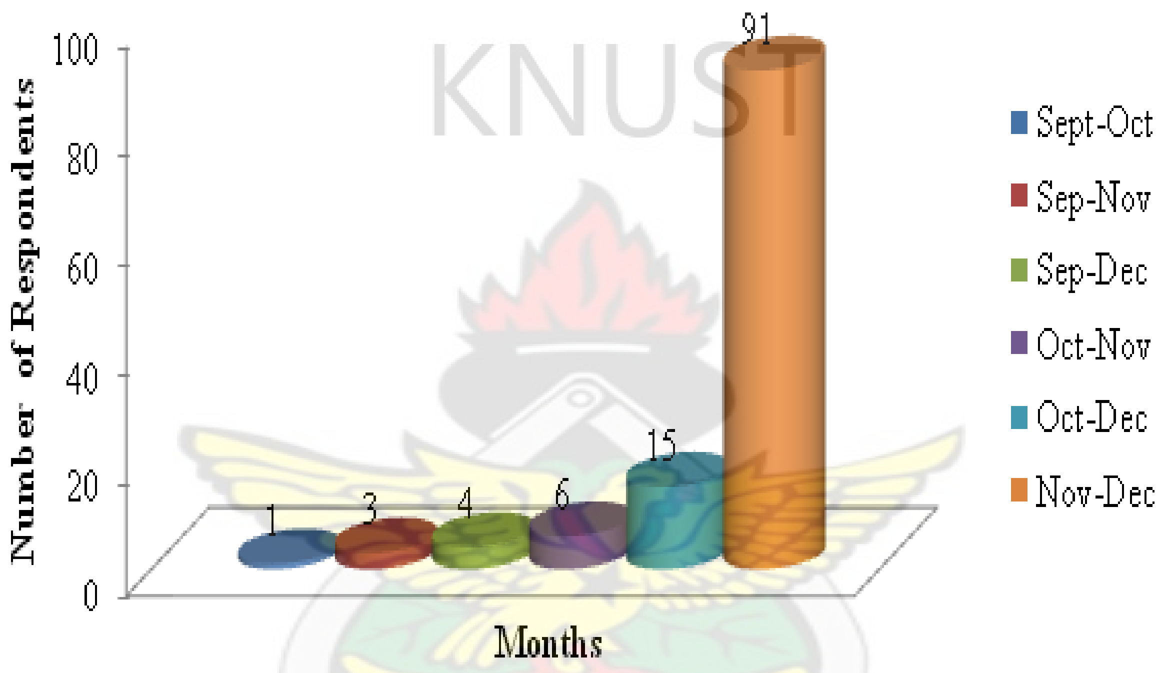

Figure 12: Time sorghum is harvested

4.1.13 Tools Used to Harvest Sorghum

Majority of the farmers (95.8%) harvested sorghum with cutlasses and knives, 2.5% used hoes and knives whilst only 1.7% used knives and sickles (Figure 13).

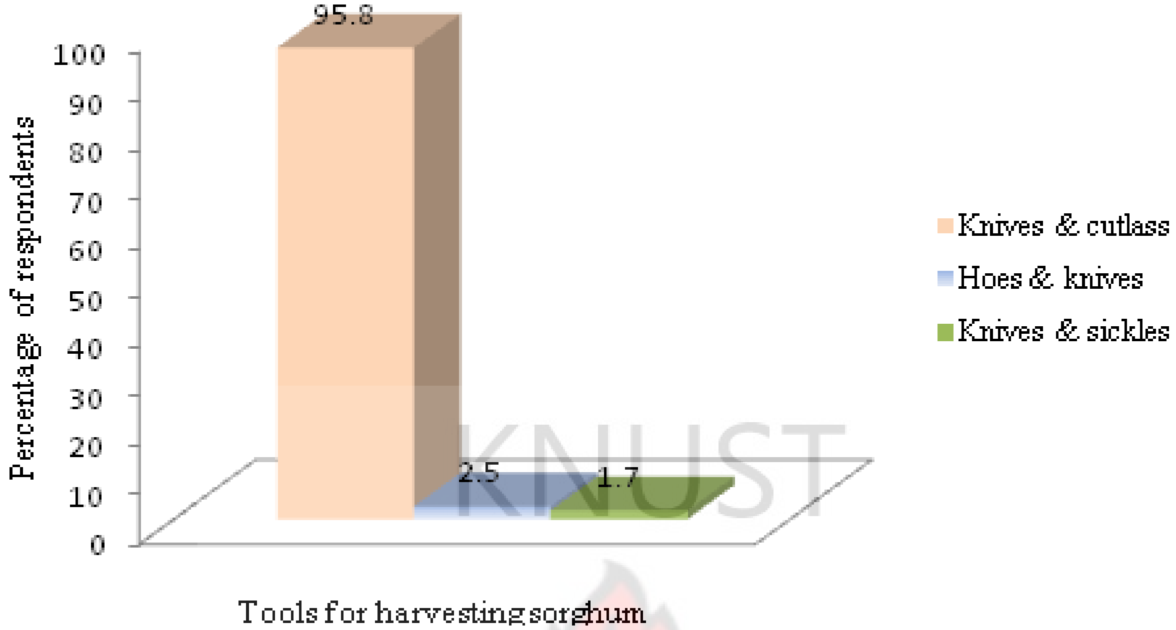

Figure 13: Tools used to harvest sorghum

4.1.14 Types of Storage Structures for Storing Sorghum Grain

The survey revealed that farmers in the district stored their grain sorghum in different kinds of structures (Figure 14). They stored in structures such as barns (katanga), mud silos (buori), store rooms (houses), jute bags (sacks), polypropylene bags, PICS bags, baskets, earthen pots and basins. According to the survey, mud silos were the most commonly (35%) used structures in the storage of sorghum. The second most frequent used storage structure in the area was polypropylene bags representing 18.3% of the respondents, closely followed by the use of barns (15%). Some of the respondents (12.5%) stored in jute sacks, while 8.4% of the farmers reported storing their grains in store rooms in the unthreshed form. Few (5.83%) used Hermetic Purdue Improved Crop Storage (PICS) bags introduced by MoFA in the area. Very few (2.5%) stored in baskets with 2.5% of the farmers stored in other facilities such as earthen pots and basins.

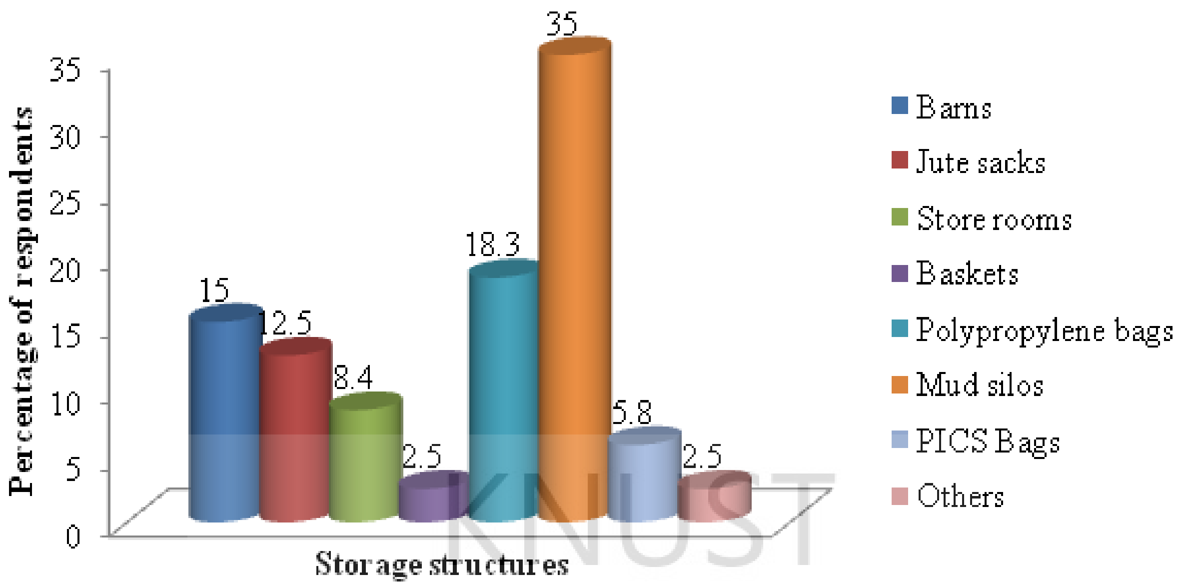

Figure 14: Sorghum storage structures in Wa West District

4.1.15 Capacities of Sorghum Storage Structures

The storage structures encountered in the study area had different capacities. The capacities of the storage structures were in proportion to the space of storage structures which varied from 50 kg to 1000 kg. Thus, they could contain between one to 10 bags. Many (35%) of the respondents testified that their structures could contain between 600-1000 kg (6-10 bags) of sorghum while 25% confirmed their structures could take 300-500 kg (3-5 bags). Twenty five percent (25%) indicated that their structures could take up to 100-200 kg (1-2 bags) of sorghum; 10% of the respondents used storage structures that could contain more than 1000 kg (10 bags), whereas 2.5% respondents reported that their structures had a capacity of less than 100 kg (one bag) (Figure 15).

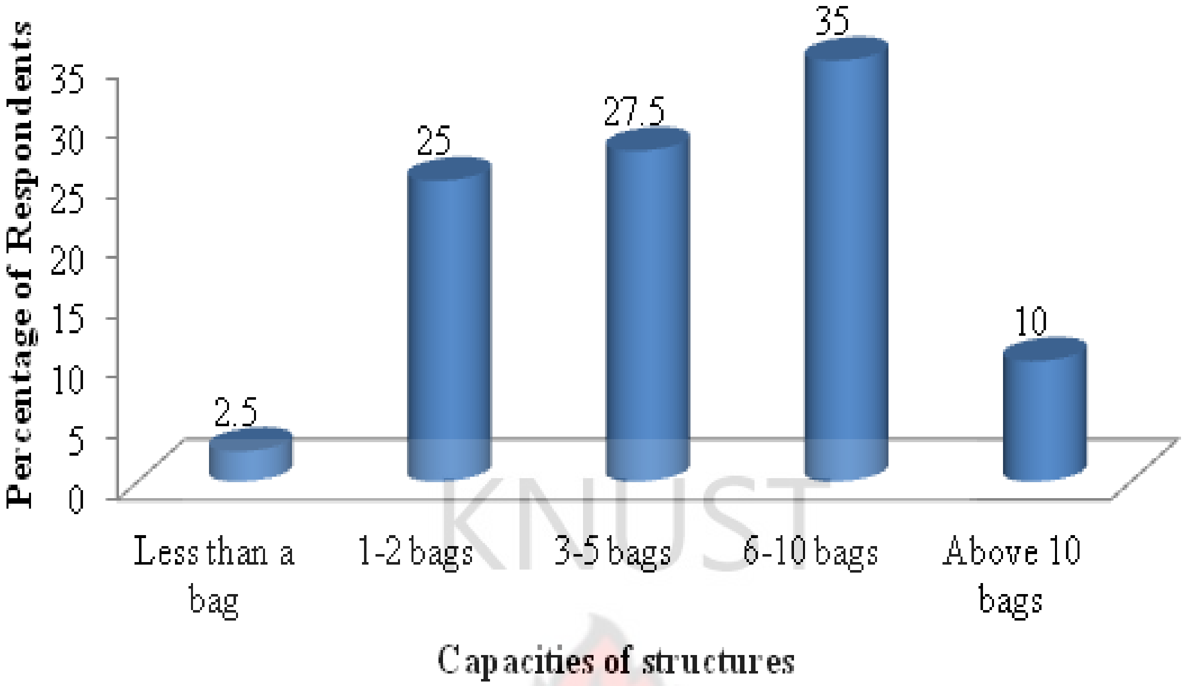

Figure 15: Capacities of sorghum storage structures

4.1.16 Treatment Given to Storage Structures before Use

Most of the farmers (41.7%) heated their storage structures, especially the barns and mud silos with fire and dry grass or sticks while 35% of the respondents sprinkle inside the storage structures with certain synthetic chemicals before storing sorghum grains (Figure 16). Others washed the storage facilities with water (2.5%) especially the polypropylene and the PICS bags when they become too dirty, 13.3% cleaned inside with brooms and other treatment apart from what has been mentioned above representing 7.5% of responses from the farmers.

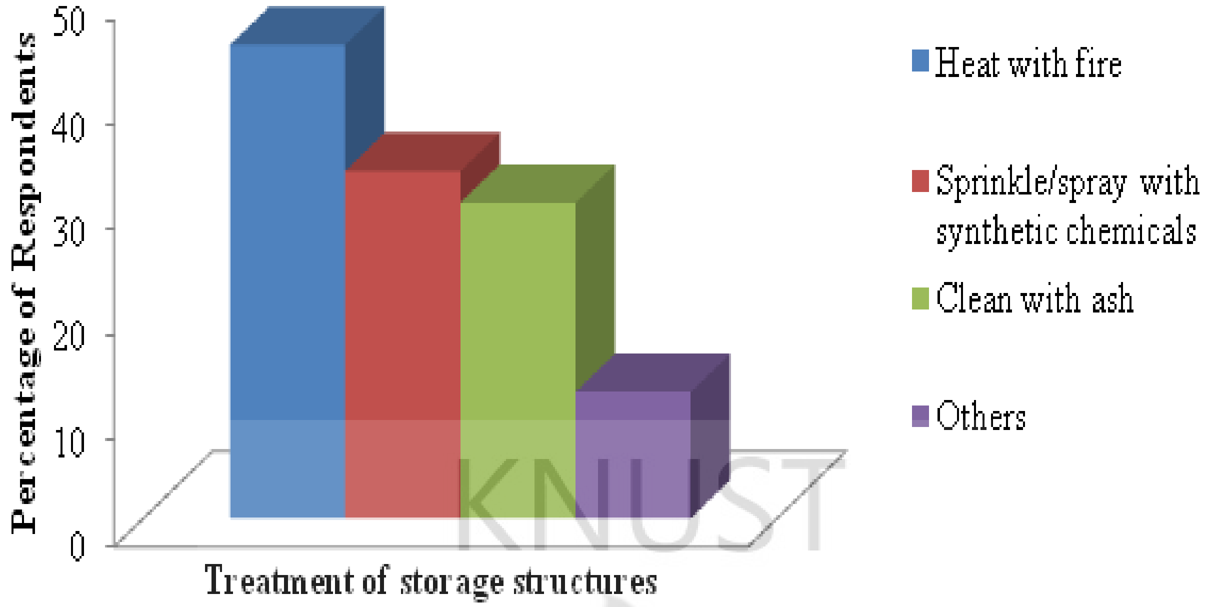

Figure 16: Treatments of grain structures before storage

4.1.17 Loading and Unloading of Grain Sorghum into the Storage Structures

Figure 17 shows how respondents load and unload the grain into the storage structures. Fifty percent (50%) of the respondents poured the grains into the storage structure or facility by using basins; others (44.2%) reported that, they fetched grains with smaller containers and poured into the structures or facilities especially the threshed grains. Others (5.8%) also fetched with the hand, especially, the unthreshed and pack inside the structures.

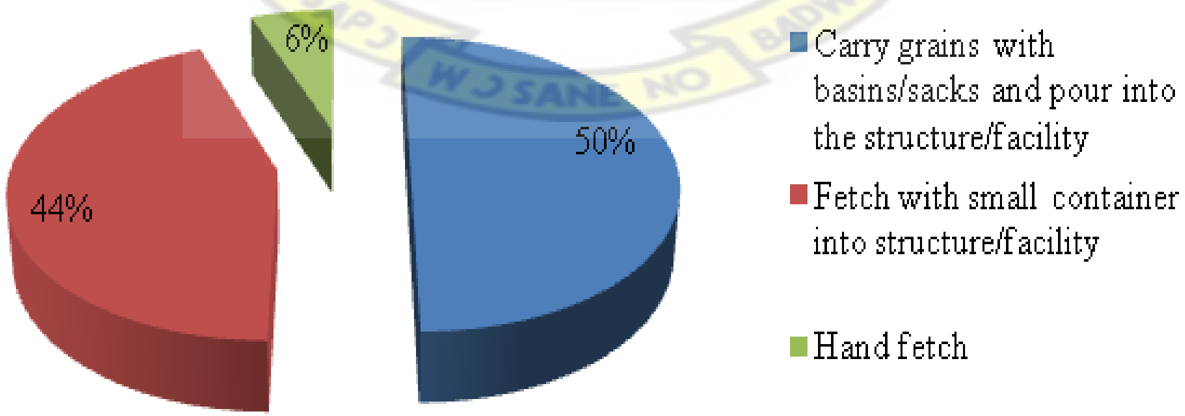

Figure 17: Loading and unloading of storage structures

4.1.18 Maintenance of the Storage Structures

Majority of the farmers (75) representing 62.5% repaired their storage structures any time there was fault with their structures and 37.5% said they did not repair their storage structures; the structures were only abandoned or used for other purposes in order to acquire a new one (Figure 18). With regard to the 75 respondents who repaired their structures, 31% said they repaired theirs' yearly, 40% repaired their structures any time there was a fault or crack, 16% said every two (2) years interval while 13% gave other reasons regarding when they repair their storage structures.

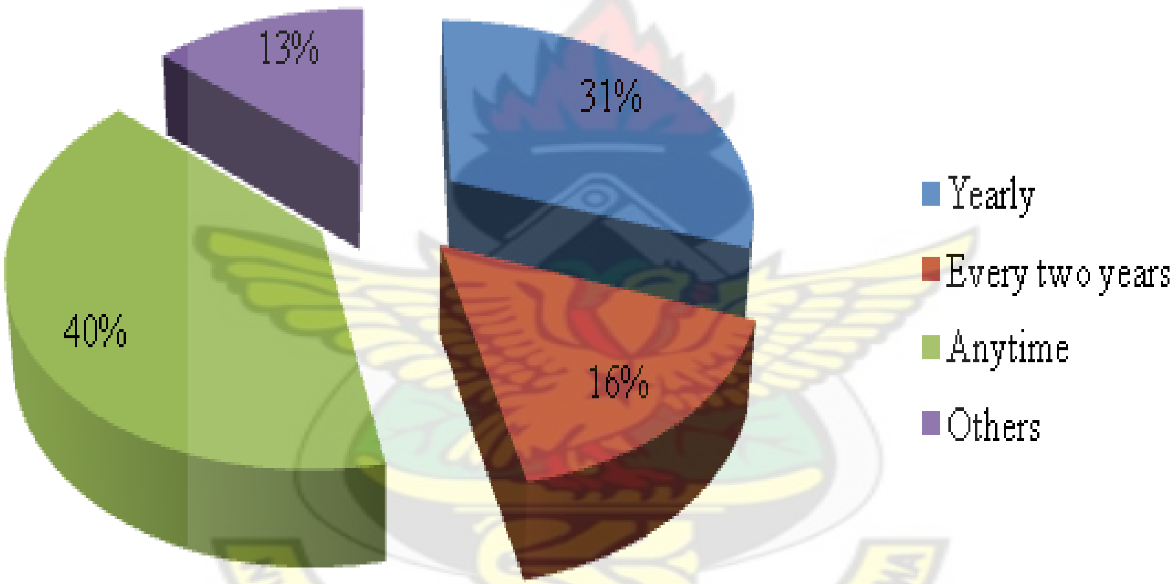

Figure 18: Maintenance of sorghum storage structures

4.1.19 Pests that Destroy the Storage Structures

The major pests that destroyed various storage structures were rodents which represented 40% according to the responses (Figure 19). Termites also caused considerable destruction representing 15% while 40% of the structures were been destroyed by both rodents and termites. Other agents that also destroyed the structures represented 5%.

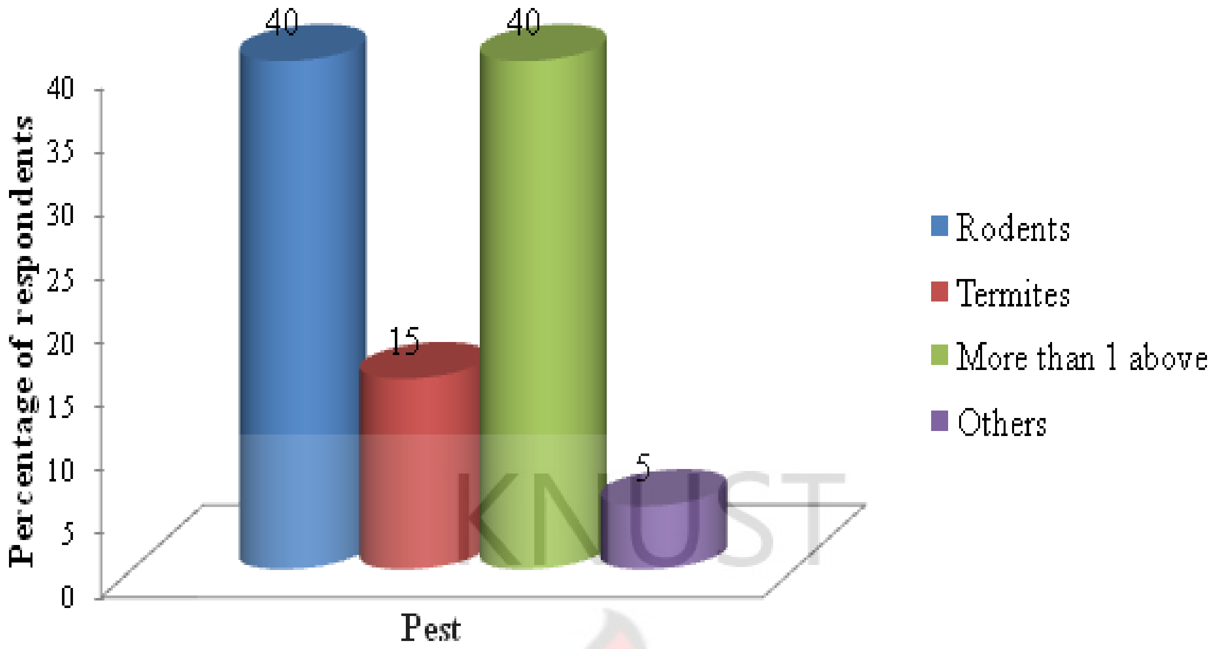

Figure 19: Pests that destroyed the storage structures

4.1.20 Reasons Why Farmers Preferred to Use the Different Storage Structures to Store Sorghum in the District.

Farmers concern about storage structures was the prevention of grain from insects, rodents, adequate space as well as moisture damage and its ability to keep the produce safe for a reasonable period of time. The 120 respondents gave various reasons for using a particular storage structure. As shown in table 4 below, mud silos were the most preferred used storage structure as they were used by 35% of the respondents due to the reasons that 'they were not expensive to construct since construction materials were locally available, had large capacity, ability to prevent insect infestation and rodent damage. They were also considered durable and could contain different kinds of grain in different compartments'. They however had the limitations of not being airtight and moisture proof.

Polypropylene bags were the second most preferred storage structures used by 18.3% of the respondents after mud silos because they were affordable, easy to handle and detection of insect or rodent attack although they had the disadvantage of not being pest and moisture proof.

Barns were also preferably used by 15% of the respondents for the merits of being spacious; prevent insect and other pest damage, not expensive to build and its durability. Their use was however constrained by the gradual decline of experts in their construction.

Jute sacks were preferably used by 12.5% of the farmers. This was because they were affordable, portable, easy to handle, occupy less space and ease to detect insect or rodents damage. They were however not airtight, rodent, insect and moisture proof thereby exposing the stored produce to damage and further losses.

Purdue Improved Crop Storage (PICS) bags were preferably used by 5.83% of the respondents. Farmers gave their reasons for preference such as 'they are insect and moisture proof, airtight, portable and capable of storing small quantities of grain. They were constraint by their unpopularity in the area. Their use was still on promotion by MoFA couple with their high price as compared to other storage structures like polypropylene bag, jute bag and other non-durable storage facilities. The price per PICS bag was Ghc 5 compared to Ghc 1.40p, Ghc 3.0 for polypropylene bag and jute sack, respectively.

Store rooms/houses were also used to store sorghum in some parts of the district especially in the Dorimon zone. Farmers after harvesting first carried the unthreshed grain to their stores or houses at home. They were stored for a number of months till there was the need for some grain for some purpose. They were later threshed and stored in bags and other containers for use. More than eight percent (8.3%) of the respondents used these structures. The store rooms had the advantage of being spacious, durable and easy to keep grain. However, grains stored in rooms were exposed to all sorts of pests.

Earthen pots have decline in their use in recent times in the area, however some 2.5% of the farmers were still glued to them for the fact they were less costly, rodent and insect proof, efficient in storing small quantities of grain as seeds.

Baskets were used by 2.5% of the farmers. They were perceived by the farmers to be cheap, portable and locally available.

Table 4: Major reasons farmers preferred to use a particular storage structure

Storage structure	Reasons for preference	Frequency	Percentage
Mud silo	Prevent insect infestation and rodent damage	15	35.7
	It is not expensive to construct	3	7.1
	It had large capacity	12	28.6
	Different kinds of grains can be stored in separate compartments in one structure	3	7.1
	It can be used for several years-it is durable	9	21.5
Polypropylene bag	It is affordable	11	50
	Easy to carry or handle	5	22.7
	Insect damage can easily be detected	6	27.3
Barn	Provides more space for storage	2	11.1
	Building materials are locally available	3	13.6
	Reduced insect and pest damage	7	38.9
	Construction does not require much money	1	5.6
	Structure can be used for many years	5	27.7
Jute sack	It is affordable	5	33.3
	It is portable	2	13.4
	Insect damage can easily be detected	5	33.3
	Occupy less space	3	20

PICS bag	It is moisture proof	3	43.0
	Insect proof and airtight	2	28.6
	It is portable	1	14.2
	Small quantities of grain can be stored	1	14.2
Store room/ House	Easy to keep grain	2	20
	Can be used for many years	3	30
	Has large capacity	5	50
Earthen pot	Less costly	1	33.3
	Less insect and rodent damage	1	33.3
	Efficient in storing small quantities of grain	1	33.3
Basket	It is cheaper	1	33.3
	Locally available	1	33.3
	It is portable	1	33.3

4.1.21 Reasons Why Farmers Stored Sorghum Grains

In table 5, the purpose farmers stored their sorghum grain are shown. Majority (31.6%) of the respondents purposely stored sorghum grains for daily consumption and as seeds for planting the following season, 25% stored for consumption, sale and as seeds for next season. Some (17.5%) stored sorghum for sale and consumption while 16.7% stored the grain purposely for consumption alone, 4.2% kept their produce only for sale, 2.5% also stored mainly for use as seeds to plant the following season. Few (2.5%) of the farmers kept some of the crops for cultural reasons such as funeral rituals. The crop for consumption purposes is used to prepare the local beer called *pito* and various dishes such as such *Tuo zaafi*, the most popular meal in the area and porridge. The crop is also fed to animals such as poultry and small ruminants, especially, goats and sheep.

Table 5: Purpose for storing sorghum grain by farmers in the district

Purpose	Frequency	Percentage
For consumption only	20	16.7
For sale only	5	4.2
Seeds for next season	3	2.5
Consumption and sale	21	17.5
Consumption and seeds for planting	38	31.6
Consumption, sale and seeds for next season	30	25
Cultural purposes	3	2.5
Total	120	100

4.1.22 Places Where Farmers Stored Their Produce

Almost all the respondents (98%) stored their sorghum at home while only 2% stored their harvested sorghum grain temporally in the farm. The grains stored in the farm are soon threshed for sale or consumption.

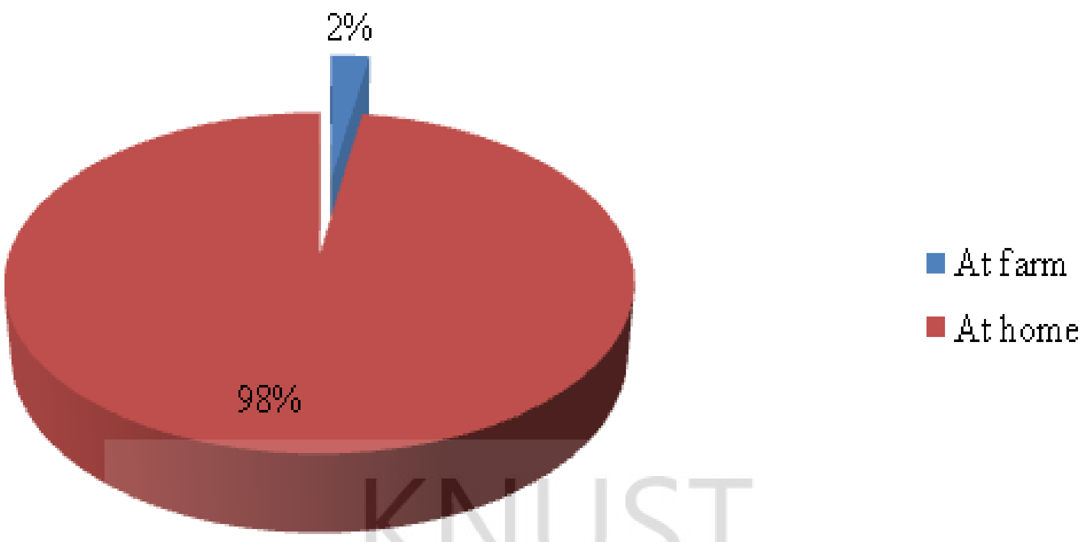

Figure 20: Places farmers store sorghum grains

4.1.23 Forms in Which Sorghum Grains are Stored

Many (60%) of the farmers stored their sorghum grain in an unthreshed form while the rest (40%) store the grains threshed.

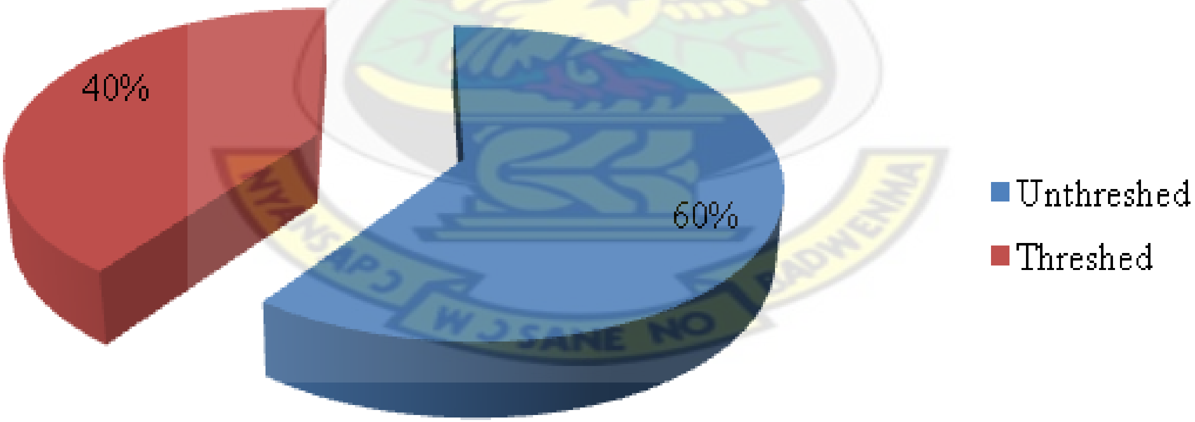

Figure 21: Forms in which sorghum grains are stored

4.1.24 Reasons for Storing Sorghum Threshed or Unthreshed

Table 6 shows the reasons farmers' stored sorghum grain in different forms. The table revealed that among the 72 farmers who stored sorghum in an unthreshed form, higher percentage (42.5%) of them were of the view that unthreshed grains stored better and had reduced insect infestation as compared to storing them threshed. A low percentage (12.5%) contended that the unthreshed grain storage reduces wastage hence was more economical while 2.5% agreed that it was easy to handle and manage; the rest (2.5%) of the respondents gave different reasons for storing the grain unthreshed ranging from cultural to religious reasons.

Forty eight (48) out of the one hundred and twenty (120) farmers who stored sorghum grains threshed (20.8%) also confirmed that it was easy to use grains when stored threshed as they could be readily used. Ten percent (10%) said they store better when threshed while 7.5% were of the perception that sorghum grains stored in threshed form was economical hence reduced wastage in their usage.

Table 6: Reasons for storing sorghum grain in different forms

Reasons	Threshed		Unthreshed	
	Frequency	Percent	Frequency	Percent
For easy usage or storage	25	20.8	3	2.5
Economical-reduces wastage	9	7.5	15	12.5
Stores better	12	10	51	42.5
Others	2	1.7	3	2.5
Total	48	40	72	60

4.1.25 Duration of Storage

Majority of the farmers in the area began to store sorghum grains in December and January and stored them for as long as one year depending on the farmers' circumstances. The survey generally revealed that many of the farmers in the area do not store sorghum grain beyond a year. Forty five percent (45%) of the farmers stored their grains between 7-12 months, 33.8% reported storing their grains for 4-6 months while 15% of them stored for the duration of 1-3 months. Only 6.2% of the respondents could store sorghum grains beyond a year (Figure 22).

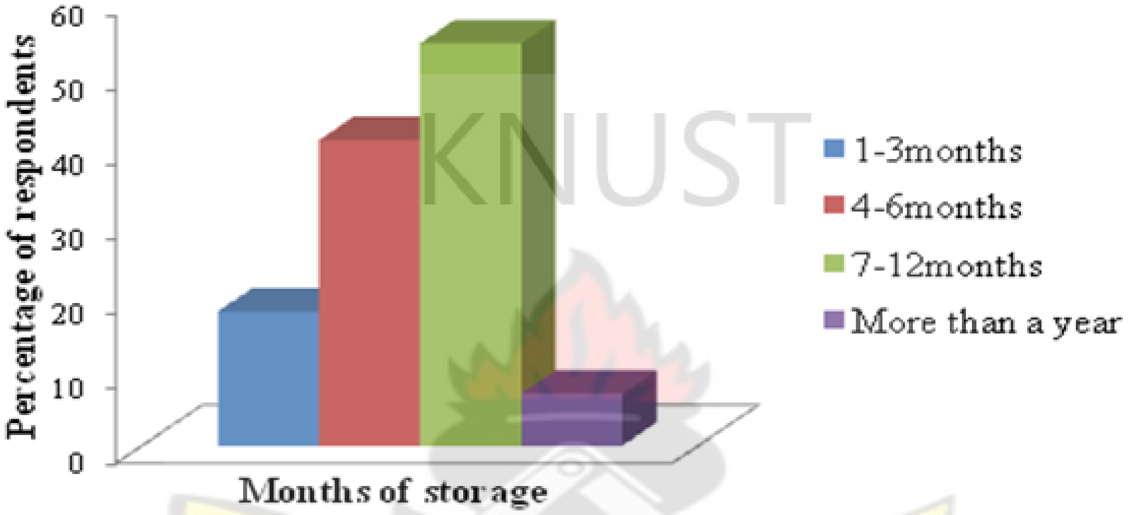

Figure 22: Duration farmers stored their sorghum grain

4.1.26 Time Stored Produce is Used or Sold

Greater proportion of the farmers (37.5%) used their stored grains any time it was necessary (Figure 23). Some 25% sold their produce when prices were high and 12.5% sold their produce when the farming season begins in order to get money for their farming activities. Only a few, constituting 2.5%, sold their produce immediately after harvesting while 22.5% of the farmers used their stored produce during funerals, ceremonies and other reasons.

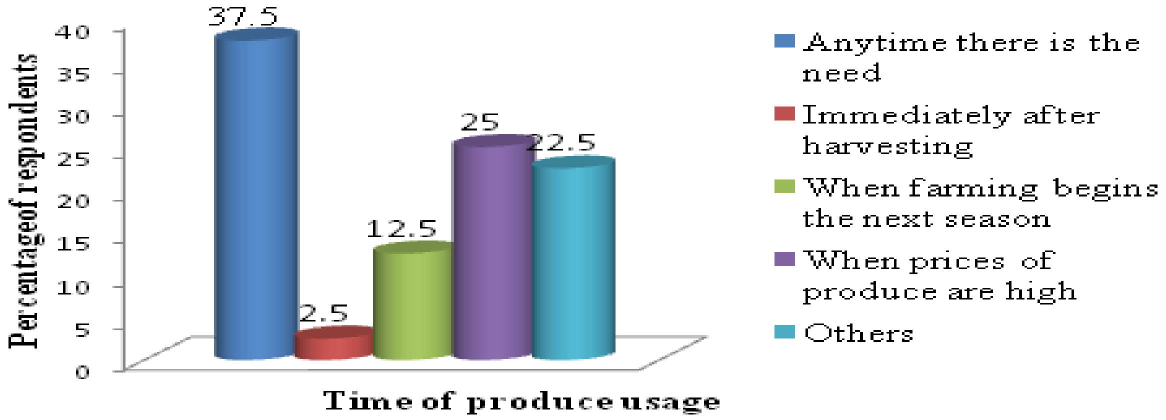

Figure 23: Time stored produce are used by farmers

4.1.27 Problems Faced by Farmers in the Storage of Sorghum

Table 7 below shows the challenges encountered by farmers while storing their sorghum grains. Forty five percent (45%) of the farmers faced the high incidence of insect infestation, destruction by rain and other climatic factors (17.5%), inadequate capital (15%), high cost of storage structures (8.3%), transportation difficulties (6.7%), 4.2% had destruction of structures by rodents whilst 3.3% reported not having any extension services on postharvest management.

Table 7: Problems faced by farmers in the storage of sorghum

Problem/constraint	Frequency	Percentage
High insect infestation	54	45
Destruction of structures by rain and other climatic factors	21	17.5
High cost of storage structures	10	8.3
Inadequate capital	18	15
Lack of extension services on postharvest management	4	3.3
Transportation difficulties	8	6.7

Destruction of structures by rodents	5	4.2
Total	120	100

4.2 EXPERIMENTAL RESULTS

4.2.1 Baseline Information

The sorghum grains were obtained from farmers immediately after harvesting, drying and threshing. They were stored in five most commonly farmers' storage structures in the area - barn, mud silo, Purdue Improved Crop Storage (PICS) bag, jute sack and polypropylene bag. Those stored in mud silo were not threshed (as it was the usual practice of farmers using those storage structures).

4.2.2 Relative Humidity (RH) of Storage Structures

The relationship between the ambient relative humidity and relative humidity inside the various storage structures (barn, mud silo, PICS bag, jute sack and polypropylene bag) over the storage period are given in Figure 24 below. It shows that during the first 90 days, the internal relative humidity was nearly the same in all the storage structures alongside the ambient relative humidity. From day 120 to 150 the ambient relative humidity increased slightly. The relative humidity inside all the storage structures was comparably lower than the ambient relative humidity within the first 150 days. However, the relative humidity in all the storage structures showed a gradual increasing trend from the beginning up to the end of the storage period in July. Initially, the relative humidity in the storage structures were 43.6%, 43.2%,45.1%, 44.2%,43.5% for mud silo, PICS bag, jute sack, polypropylene bag and barn, respectively. At the initial stage around January which is usually a dry season in the area, the relative humidity was generally low but begun to increase with the onset of rains from the 90 to the 210 days (7 months) storage period. So during the rainy season from April, the ambient relative humidity was higher as compared to the dry period. The relative humidity in PICS bag was lowest (from the beginning to the end) as compared to the other storage structures. On the other hand, the highest relative humidity among the storage structures at the end of the storage period was found in jute sack.

There was a mean ambient relative humidity of 54.6% compared to jute sack (53.3%), polypropylene bag (50.7%), barn (49.2%), mud silo (48.7%) and PICS bag (45.9%) over the entire period (Figure 25). Among the storage structures, PICS bag recorded the lowest mean relative humidity (45.9%) with jute sack recording the highest (53.3%) even close to that of the ambient relative humidity (54.6%) over the storage period. The difference in relative humidity between the initial and that of final in the 210 days among the storage structures were 3.8%, 14.4%, 14.7%, 20.0 and % 23.2% for PICS bag, mud silo, barn, polypropylene bag and jute bag respectively. There was lower variation (3.8%) in relative humidity between the initial and final in PICS bag compared to the rest of the storage structures. Polypropylene bag recorded the widest difference (23.2%) between the initial and final relative humidity among the structures. There was however no significant difference (p>0.05) in relative humidity among the various structures over the storage period (Appendix 7).

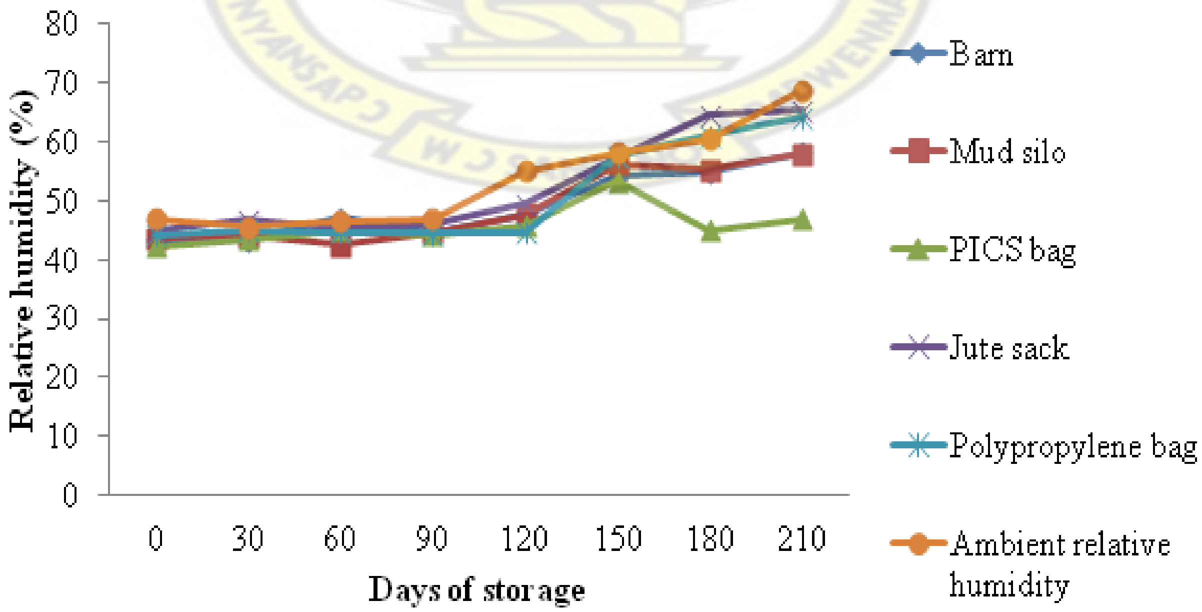

Figure 24: Relationship between ambient and relative humidity inside the storage structures

Figure 25: Mean relative humidity of sorghum grain storage structures

4.2.3 The Influence of Storage Structures Temperature on Sorghum Quality

Storage temperature has great effects on the keeping quality of grain. Initially the temperature of the grain inside the storage structures were 30.6°C, 30.9°C, 31.5°C, 31.5°C, 31.4°C for polypropylene bag, barn, mud silo, PICS bag and jute sack, respectively, while at the end of the storage period, the temperature was 32.9°C, 32.6°C, 32.8°C, 32.5°C and 32.9°C for polypropylene bag, barn, mud silo, PICS bag and jute sack, respectively.

The relationship between the ambient temperature and temperature inside the storage structures is given in Figure 26. It shows that during the first 30 days the internal (inside) temperature of the storage structures was nearly the same but lower than the ambient temperature. From the 60 days (February to March) which is a warm period of the year in the study area, there was an increase in the ambient temperature. It was also observed that the condition of the grain during this period was better as there were no insect infestation (from day 0 to 90). From the 60 to 90 days period the ambient temperature was higher than the temperatures of the storage structures. However, from day 90 to 180, the internal temperature of the storage structures became slightly higher than the ambient temperature. Also, all temperatures in the stored grain and environment went gradually and slightly higher after day 90 up to the end (210 day). A common phenomenon which occurred in all the storages structures was that, the temperature of the grain in all the storage structures increased after a certain period of time.

Polypropylene bag recorded slightly higher temperatures with mean temperature of 34.5°C whereas barn recorded the lowest mean temperature of 33.8°C compared to the rest of the storage structures (appendix 16). Temperature among the different storage structures was statistically not significant ($p>0.05$).

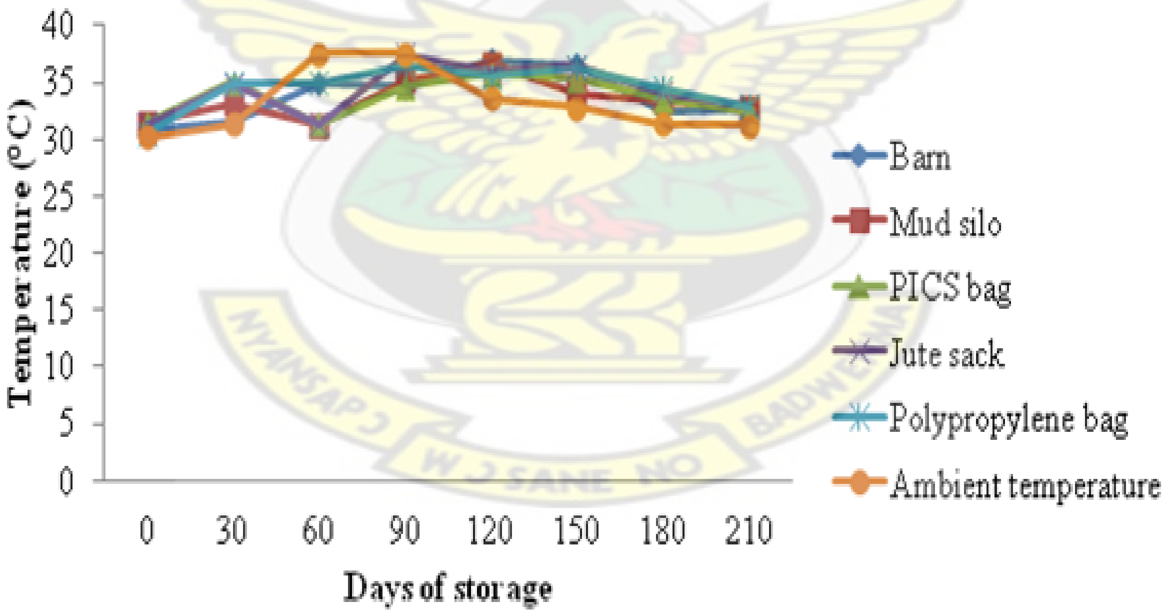

Figure 26: Relationship between ambient temperature and among internal temperatures of storage structures

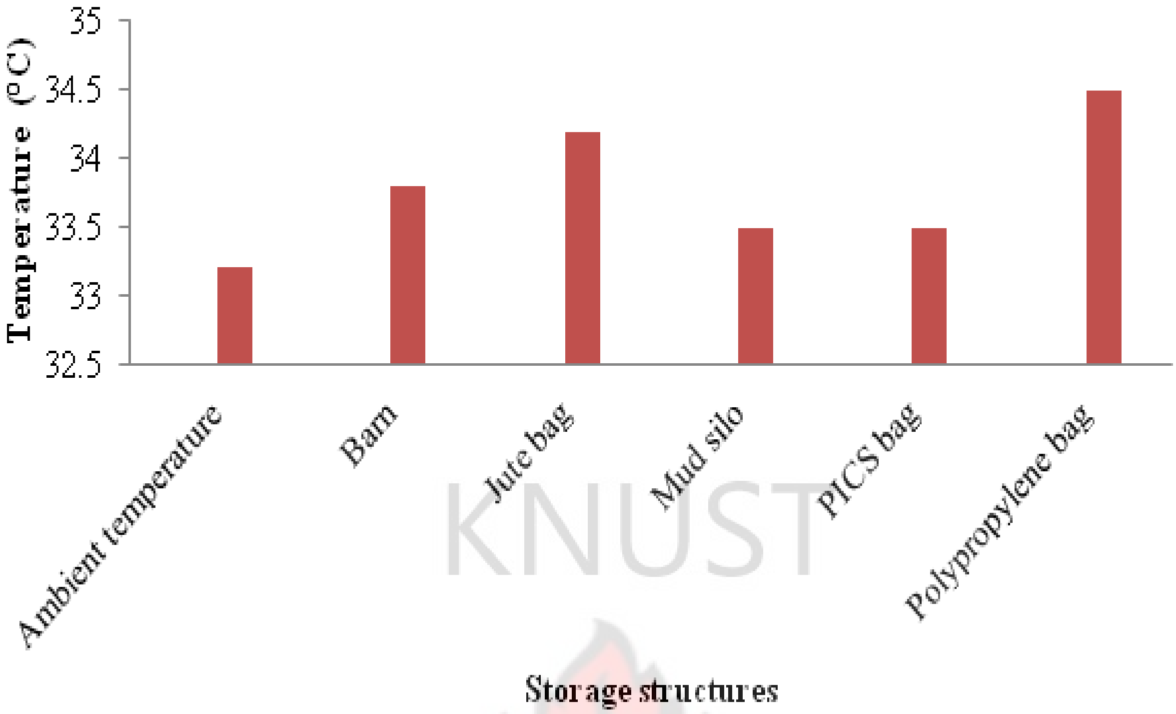

Figure 27: Mean temperatures of various storage structures

4.2.4 Moisture Content of Sorghum Grain in Storage Structures

The sorghum grain before storage had an initial mean moisture content of 12.2%. During storage, the moisture level fluctuated in all the storage structures (Figure 28). The moisture contents of the grain in the storage structures after the first 30 days had been consistently low in the PICS bag compared to the other storage structures. Also, the moisture level of the grain in barn after the 60 days consistently increased up to the last day. The moisture content of grain in all the storage structures slightly reduced from day 60 to 150 but increased between 180 to 210 days of storage. The moisture content of the grain in all the storage structures was within a safe moisture range of 10.1% to 12.9%. The moisture contents of grain in barn and polypropylene bag both increased from 12.2% to 12.9% at the end of the storage period, the moisture content in jute sack and mud silo both increased from 12.2% to 12.8%, barn increased from 12.2% to 12.9% while those in PICS bag decreased from 12.2% to 12.0%.

PICS bag recorded the lowest mean grain moisture level (11.44%) over the entire storage period while the barn had the highest mean moisture level (12.13%) during the storage period from January to July. There were no significant differences (p>0.05) among the moisture content of the grains stored in the various storage structures (Appendix 2.5).

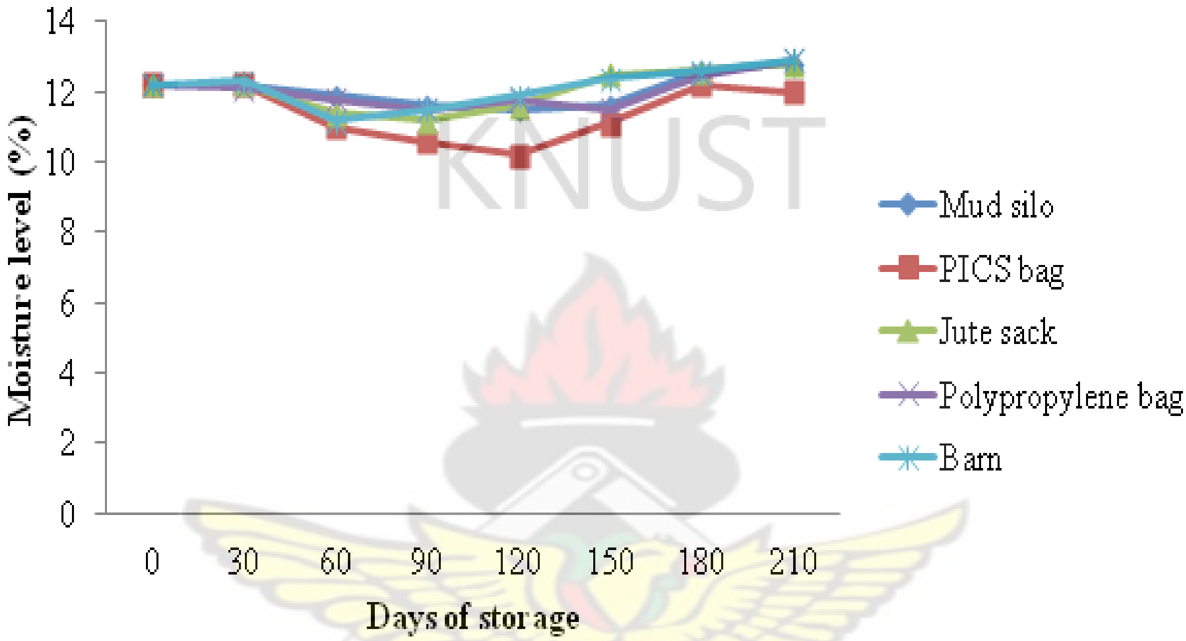

Figure 28: The relationship between the moisture content of sorghum in the storage structures

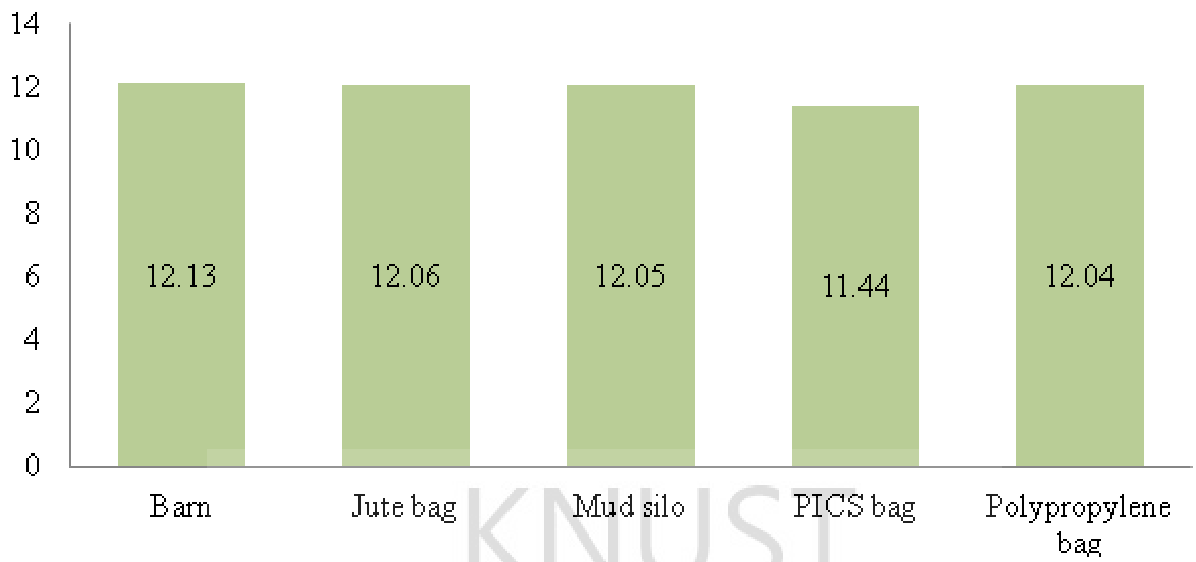

Figure 29: Percentage mean moisture content of sorghum stored in the storage structures

4.2.5 One Thousand (1000) Seed-Weight of Sorghum Stored in Storage Structures

There were significant differences ($p<0.05$) among the 1000 seed weight of sorghum grain stored under the different storage structures (Appendix 2.1). The 1000 seed weight of barn, jute bag (sack), mud silo, PICS bag and polypropylene (fertilizer) bag were 25.83 g, 26.06 g, 25.54 g, 2.50g and 24.56 g, respectively. However, there was no significant difference ($p>0.05$) among the 1000 seed weight of barn, mud silo and polypropylene bag. There was also no significant difference ($p>0.05$) between 1000 seed weight of grain sorghum stored in jute bag (sack) and PICS bag.

4.2.6 Germination (Viability) Test

Germination test was carried out on the sorghum seeds stored under the various structures every thirty (30) days interval to assess how effective they were in maintaining the viability of the seed grain over the seven month period (210 days). The baseline germination percentage was 94.4%. The germination test was conducted within a temperature range of 23-30°C. The outcome showed a gradual decline in germination over the period among all the storage structures (Figure 30). Germination was initially good for grain stored under all the different structures but began to decline gradually as time unfolds. There was no significant difference (p>0.05) in the germination percentages of grains stored in the different structures. However, as shown in Figure 31, sorghum grain stored in mud silo had 90% germination compared to sorghum stored in the other storage structures. This was slightly followed by sorghum stored in PICS bag (88.94%), polypropylene bag (88.87%), barn (88.17%) and jute bag (86.46%).

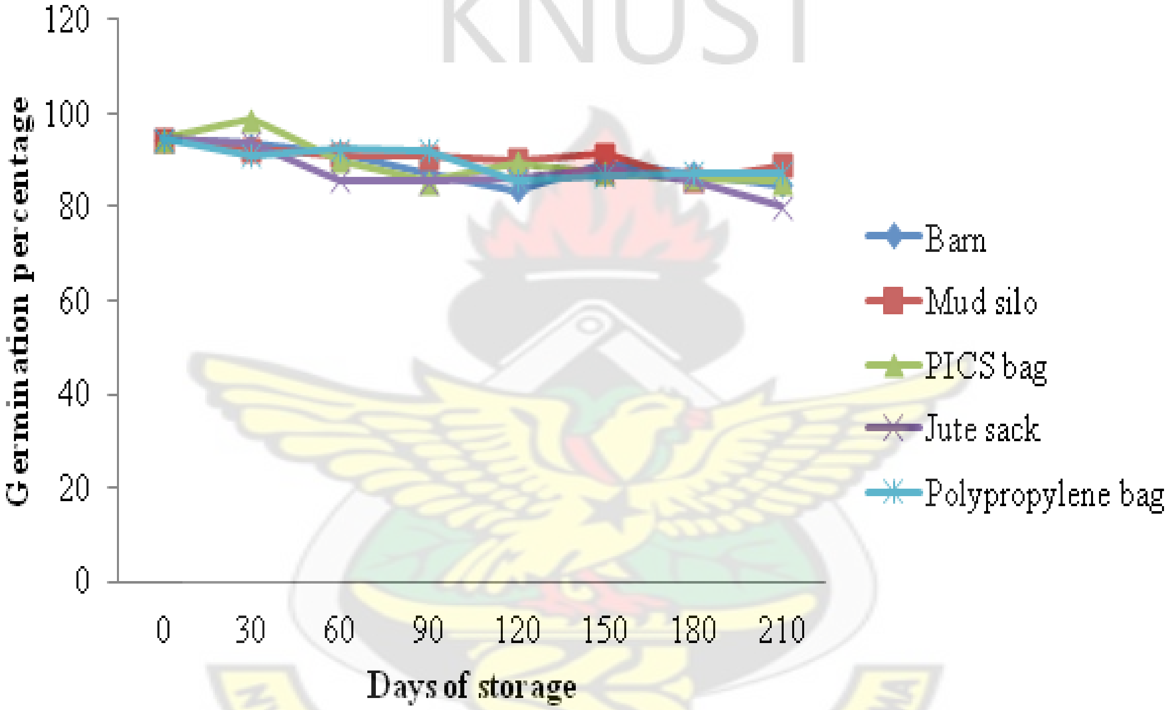

Figure 30: Variation in germination percentages of grain sorghum stored in the storage structures

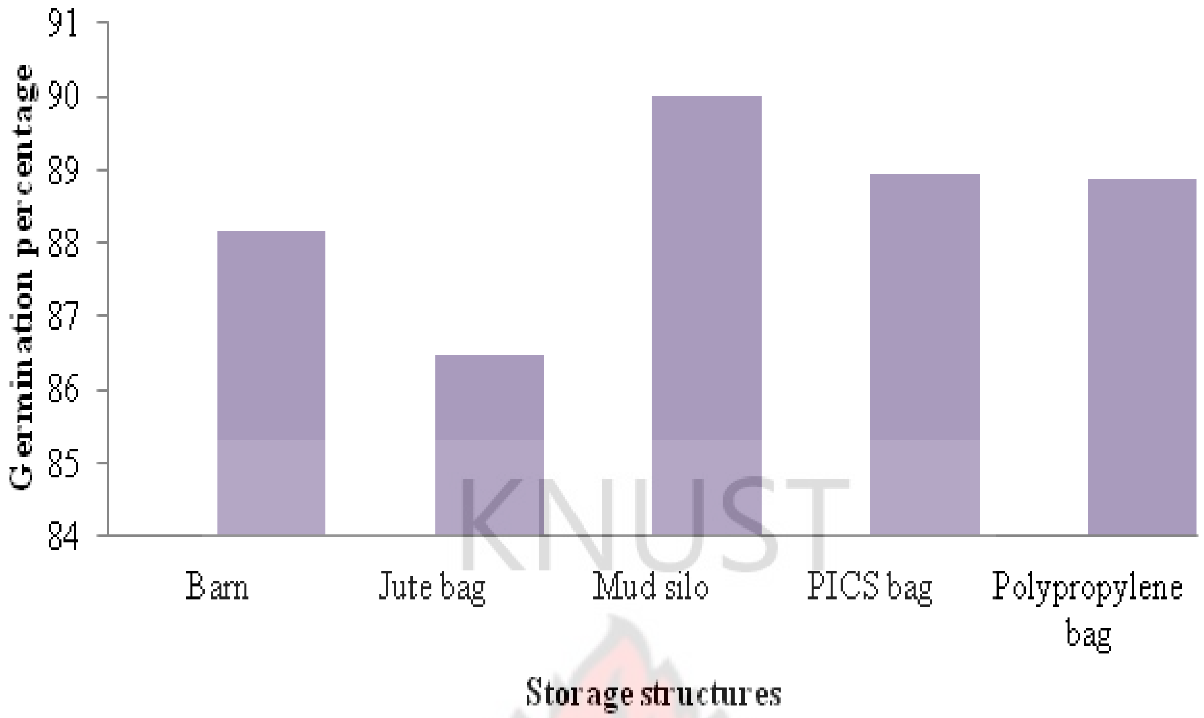

Figure 31: Mean germination of sorghum stored in different storage structures

4.2.7 Insect Infestation and Damage Levels

Insects are the most important pests that infest stored produce. The major insect species that attacked the stored sorghum grains in all the different storage structures was lesser grain borer (*Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae). They were found in all the storage structures. Both adult and larva damaged the grains by boring or chewing. There were also few termites found only in the barns. They consumed parts of the grains but their level of infestation was not significant. Figure 33 gives the total live and dead insects count of *Rhyzopertha dominica* during storage from a sample of 1 kg.

The duration affected the level of pest infestation during the storage. Insects infestation was first found on grain in barn and jute sack from 90 days of storage, mud silo and polypropylene bag at 120 days while in the PICS bag from day 150. The population of the insects (*Rhyzopertha dominica*) kept increasing with storage except in PICS bag where live insects population began to decline with increase in dead insects from day 180 to 210. Jute sack had the highest average insect population followed by polypropylene bag, mud silo barn and PICS bag recording the lowest insect numbers at the end of the 210 days (7 months) storage. There was no significant difference (p>0.05) in live insects and that of dead insect among the various storage structures over the period. Figure 32 shows an occurrence of live insects counted from 1 kg of grain samples.

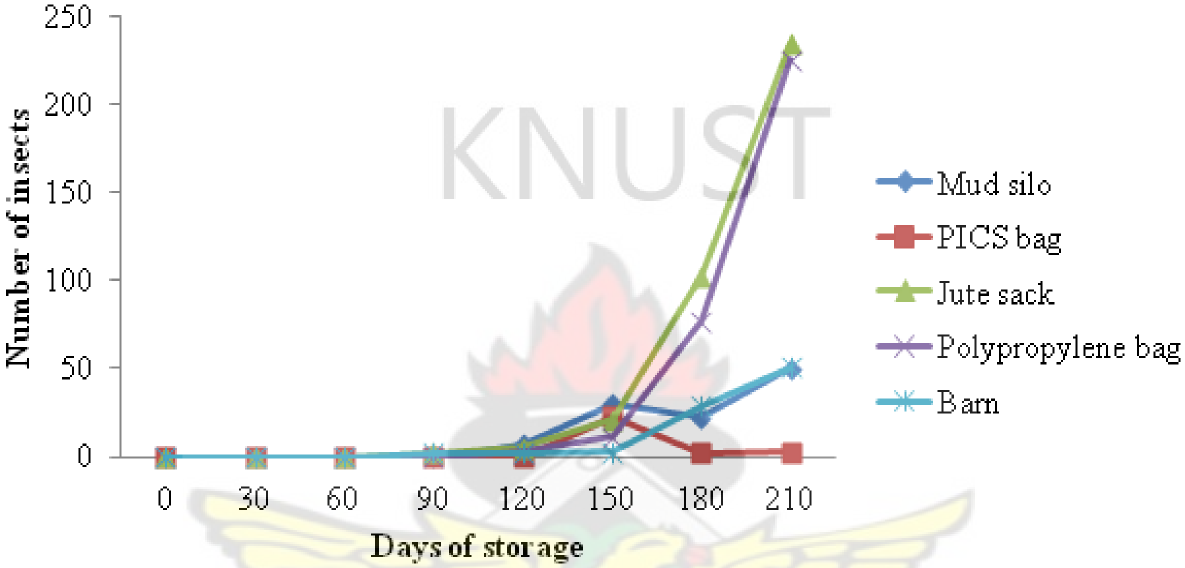

Figure 32: Live insects counted from 1 kg samples of the sorghum grain stored in the various storage structures

The result from Figure 33 indicated that jute sack recorded the highest number of live insect count (366), followed by polypropylene bag (317), mud silo (109) live insects, barn had (87) live insects while PICS bag (28) been the lowest or fewest live insect counted over the 210 days (seven month storage) period. With regards to dead insect count, there was no dead insect found in the mud silo and the barn. Polypropylene bag recorded the highest number of dead insects while PICS bag tend to record almost an equal number of dead insects (25) and live insects (28) over the period of storage. Figure 33 shows the dead and live insects count over the period of study.

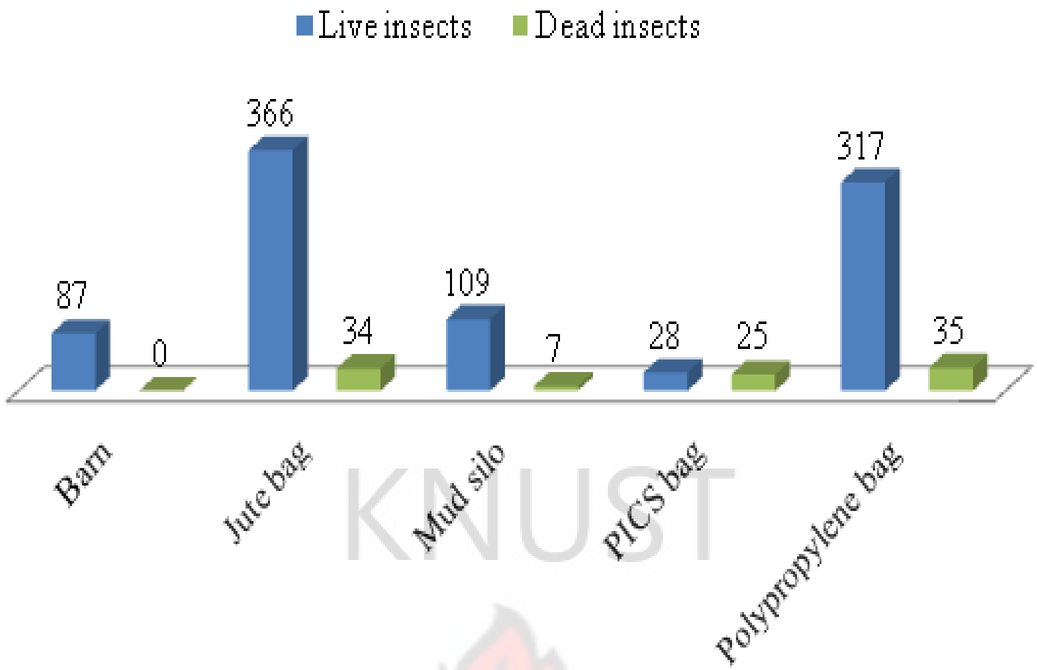

Figure 33: Dead and live insects counted from various storage structures over the 210 days (7 months) storage period

4.2.8 Purity Test

Purity test was carried out at the beginning and end of storage period to assess the purity of sorghum grain stored in the various structures. Grain samples tested before storage had a purity level of 97.24% pure seeds, 0.64% other seeds and 2.12 % inert matter as shown in table 8. It was observed that no significant changes had occurred in the grains in all the storage structures, between the initial and final samples of grain analysed. However, there was a general decrease in percentage of pure seeds and other seeds but with an increase in the inert matter. At the end of the storage period, mud silo with unthreshed grain tend to maintain high amount of pure seeds (97.6%) with the least inert matter (2.4%) and no any other seeds. Jute sack recorded the lowest pure seeds (94.3%) but with the highest inert matter (4.7%) and 1% of other seeds among the different structures. PICS bag had 96.3% pure seeds, 3.6% inert and traces (0.01%) of other seeds whilst polypropylene bag had 95% pure seeds, 4.6% inert matter and traces of other seeds. The barn also maintained 95.5% pure seeds, 4.4% other seeds and traces of other seeds (0.01%). Table 8 below shows the results of purity test of the sorghum grain stored.

Table 8: Purity test of stored sorghum grains (seeds)

Storage Structure	Initial Analysis of Samples			Final Analysis of Samples		
	Pure seeds (%)	Other seeds (%)	Inert matter (%)	Pure seeds (%)	Other seeds (%)	Inert matter (%)
Mud silo	97.24	0.64	2.12	97.6	0	2.4
Barn	97.24	0.64	2.12	95.5	0.01	4.4
PICS bag	97.24	0.64	2.12	96.3	0.01	3.6
Polypropylene bag	97.24	0.64	2.12	95	0.04	4.6
Jute sack	97.24	0.64	2.12	94.3	1	4.7
Mean	97.24	0.64	2.12	95.74	0.32	3.94

4.2.9 Grain Losses in the Storage Structures

The experiment assessed the extent of losses that emanated from the various structures caused by the insect - lesser grain borer (*Rhyzopertha dominica).* This was the main insect pest which damaged and caused considerable loss to the stored sorghum grain. The insect infestation and losses generally started in all the structures from 120 days of storage except that of the PICS bag which began after 150 days (See Figure 34). The barn had the initial lowest loss of 5.6% which went up to 14.4% at the end of the storage. Losses occurred much more in the jute sack compared to the other structures. There was an initial loss of 15.6% which increased to 26.8% at the end of the storage period.

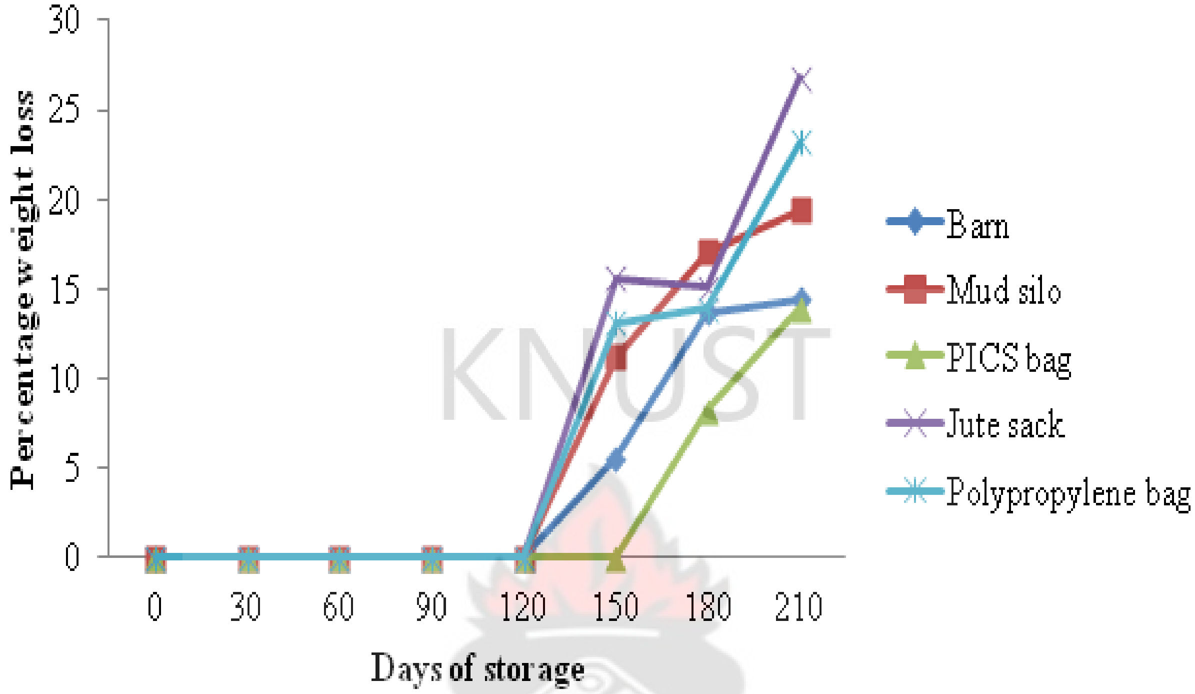

Figure 34: Weight loss caused by lesser grain borer (*Rhyzopertha dominica)*

Among the storage structures, it was observed that higher weight losses occurred from jute sack with PICS bag recording the lowest losses at the end of the storage period. There were average weight loss figures of 3.2%, 4.8%, 6.8%, 7.2% and 8.2% for PICS bag, barns, mud silo, polypropylene bag and jute sack, respectively. There was no significant difference (p>0.05) in weight loss caused by insects of grain sorghum stored under the different facilities. Figure 35 shows the percentage mean weight losses from the storage structures.

The storage structures over the storage period also recorded mean germination losses of 14.2%, 9.7%, 8.9%, 7.2% and 5.5% for jute sack, barn, PICS bag, polypropylene bag and mud silo, respectively. Sorghum grain in jute sack had the highest germination losses while mud silo recorded the least. This is shown in Figure 36.

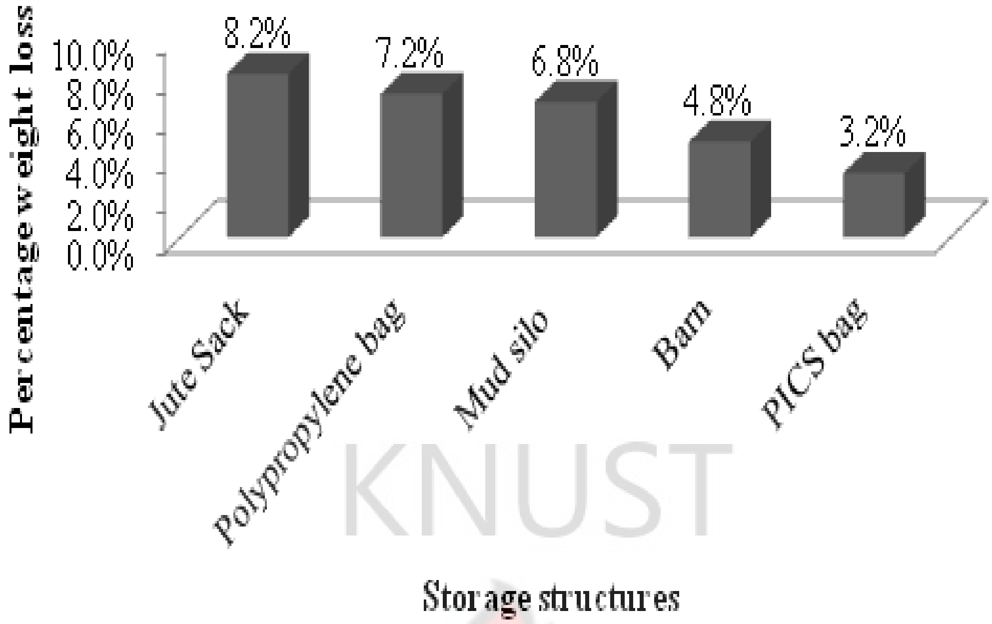

Figure 35: Percentage mean weight loss caused by insect over the storage period

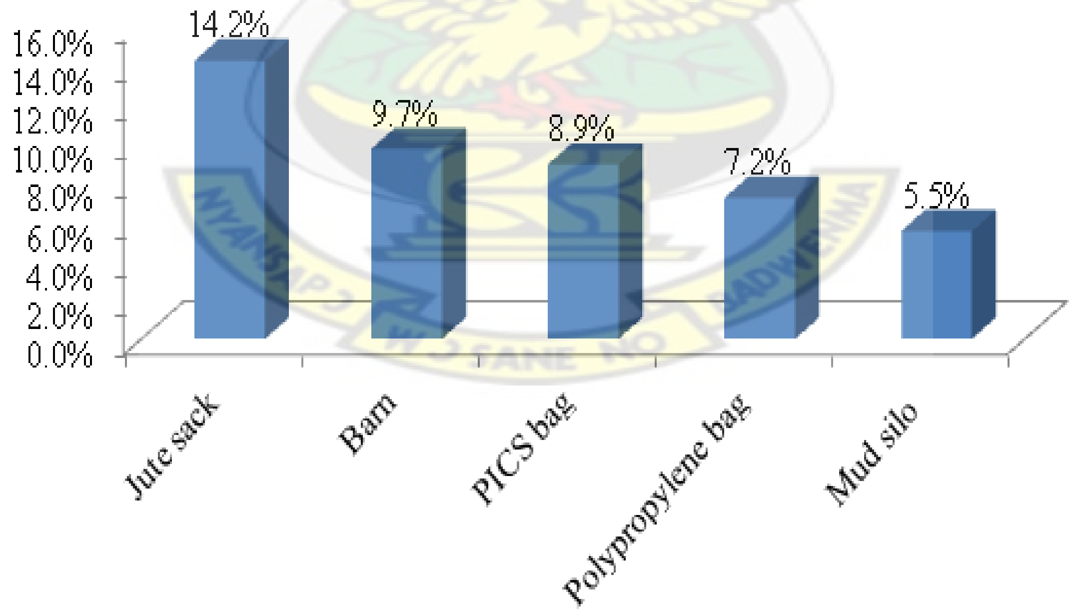

Figure 36: Germination losses of sorghum in various storage structures

Table 9: Comparative assessment of various parameters of sorghum in grain storage structures.

Storage Structure	Moisture content (%)	Relative humidity (%)	Internal temperature (°C)	Germination Percentage	1000 seed weight (g)	Insect Count	Weight loss
Barn	12.13a	49.19a	33.2a	88.17a	25.83b	2.879a	2.047a
Jute sack	12.06a	53.26	34.2a	86.46a	26.06a	5.205a	2.48a
Mud silo	12.05a	48.7a	32.83a	90.0a	25.54ab	3.333a	2.323a
PICS bag	11.44a	45.9a	33.7a	88.94a	25.0a	1.804a	1.699a
Poly. Bag	12.04a	50.74a	34.5a	88.87a	24.56a	4.263a	2.178a
Lsd (0.05)	0.806	7.92	3.209	3.881	0.5327	4.2	1.76
Cv (%)	6.3	14.4	8.6	4	1.9	107.8	73.3

Means sharing similar letters in columns are not significantly different

4.2.10 Correlation Analysis

Correlation coefficient (r) analysis was used to assess the relationships of the parameters that were taken on the sorghum stored in the various structures. It was observed that weight loss negatively correlated (r<-0.04) with both 1000 seed weight and germination but showed strong positive correlation with live insects, dead insects, moisture content and relative humidity (r>0.05). Relative humidity showed strong positive correlation (r>0.05) with live insects and negatively correlated with both 1000 seed weight and germination of grain (r<-0.05). Moisture content positively correlated with 1000 seed weight and also showed strong positive correlation with live insects (r>0.05). Live insects strongly correlated positively with dead insects (r>0.05) but negatively with both 1000 seed weight and germination.

Table 10: Correlation between various parameters taken for the appraisal of sorghum storage structures.

Parameters	1000 seed weight	Dead insects	Germination percentage	Live insects	Moisture content	Relative humidity	Weight loss
1000 seed weight							
Dead insects	-0.207						
Germination percentage	0.161	-0.44					
Live insects	-0.119	0.794*	-0.438				
Moisture content	0.314	0.353	0.02	0.503*			
Relative humidity	-0.217	0.6488*	-0.433	0.893*	0.459		
Weight loss	-0.143	0.727*	-0.395	0.808*	0.588*	0.866*	

* =Significant at 0.05 probability level

CHAPTER FIVE

5.0 DISCUSSION

Storage has been a major component in agriculture. Most agricultural produce after harvest are stored for future use. Thus, to ensure household food supplies, for sale or as seeds for planting. Grains are usually stored in various storage structures. Almost all the farmers contacted in the Wa West District stored their sorghum grains in one way or the other in various storage structures after harvesting.

5.1 SOCIO-DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

Gender plays a significant role in agriculture. Generally men dominate the agricultural sector especially in the Wa West District of Upper West Region of Ghana. It was revealed from the survey to obtain farmers' knowledge and perception that majority (77%) of the respondents were males while few (23%) were females. However, the Wa West District Assembly projected the population of the district to be 48.5% males and 51.5% females. However, women only played key roles when it came to the postharvest handling such as drying, threshing, winnowing, transportation, storage and marketing. Similar findings had been reported by Wortmann *et al.*, 2006; Utono *et al.*, 2013). Women who did not even own farms helped other farmers when it came to postharvest activities in the district. Women also played a major role in planting (sowing) and harvesting of crops in the area.

Greater proportions (44%) of the respondents were traditional believers with 26% being Muslims and 30% Christians. Many of the respondents (54.6%) in the area were illiterates. Most of the educated literates did not venture into agriculture but search for white colour jobs which are non-existent. Significant proportion representing 66.7% of the respondents were married with children. This was important as their families served as the major source of labour for farmers in the district. Women and children also helped in the crop production and postharvest handling activities.

The farmers produced varied food crops ranging from cereals (maize, sorghum, millet and rice), legumes (groundnuts, cowpea, bambara beans and soya beans), tubers (yam, cassava and sweet potato). It was realised from the survey that most of the farmers in the study area cultivated two or more crops in their farm(s) in a season with the reason to ensure food security in case of failure of one type of crop.

5.2 FARMERS' PERSPECTIVE ON SORGHUM GRAIN PRODUCTION

Majority of the farmers in the area grew local sorghum varieties such as kapiela, kakpong, kabile and kazie. Some were early maturing varieties (90-115 days), intermediate (120-135 days) and late-maturing varieties (140-180 days). Few farmers cultivated kapaala which was an early maturing improved variety. The local sorghum varieties had been cultivated by farmers for the past ten or more years while the improved ones cultivated were acquired by farmers from MoFA and Non Governmental Agencies. The main sources of seeds for planting were from the farmers own source as 75% of the farmers personally stored them with some few who bought or collected from friends and relatives. Many of the farmers (52.5%) had an estimated farm size of between 1-3 acres. Such sizes were not large enough to support any meaningful food crop production. This affected food security and income of farmers in the district. Farmers used duration of 3-7 months to produce sorghum depending on the cultivar as well as the start and end of rainfall in the area. Most farmers contacted considered time from clearing and gathering of stocks in their farms to harvesting as the production period.

Sorghum was harvested around November – December when rains had stopped. According to the farmers the crop was ready for harvesting when the seeds became exposed looking red or white depending on the type of sorghum and the entire plant began to dry. Then the crop was physiologically matured and could be harvested. The crop was harvested manually by hand with cutlasses and knives. The cutlasses were used to slash down the crop and the knives used to cut the panicle/head (see Appendix 4 plate 15). Farmers in the study area dried their produce before storage by exposing them to the sun. Nukenine (2010) reported that small scale farmers in African rely on sun drying to ensure that their crop is sufficiently dry for storage. After harvesting, the unthreshed grains were either collected at a clean spot or on raised platforms made with stocks and sticks in the farm or carried home and placed on top of mud houses for drying. The grains could be left for one to four weeks for which period they might have been dried naturally. However, farmers could not numerical determine the moisture level of the dried grain because they lack the necessary equipment, but only assumed by experience. Some bite the grain in between the front teeth to determine whether the grains were dried or not depending on the sound and feel of the grain in the mouth.

The grains were stored mostly for only family consumption and seeds for planting the next season with some few sales when there were some remains at the time prices were high and any time there was some cash need. This was similar to the reports by Adetunji (2007) that small scale farmers in Africa purposely store grains to ensure household food supplies (reserves) and seed for planting. Sorghum for consumption purposes is used to prepare the local beer called *pito* usually by women and various dishes such as such *Tuo zaafi*, the most popular meal in the area and porridge. The grain is also fed to animals such as poultry and small ruminants especially goats and sheep. The by-products of brewing pito is used to feed mostly pigs and to a lesser extent poultry, sheep and goats.

5.3 STORAGE ACTIVITIES (PRACTICES) FOR SORGHUM PRODUCERS

Farmers carried the produce home for storage before or after threshing by head load, bicycles, or motors. They were stored either threshed or unthreshed form. However, majority of the farmers (60%) stored their grains unthreshed with the rest (40%) storing theirs threshed. This finding was similar to what had been documented by NRI, (1999) that sorghum grain may be stored as unthreshed panicles or threshed before storage but many small-scale producers tend to store the grains unthreshed. Farmers gave various reasons for storing grains in various forms. Those who stored their sorghum unthreshed reported that such grains stores better, made it easy for monitoring of the usage of the grains for food, reduced wastage hence economical and the use of unthreshed grain to dress a corpse of a farmer in the palanquin when he/she dies especially among the Brifo tribe in the area. Farmers claimed threshed grains were more susceptible to pest attack, therefore required careful management and treatment with chemicals before storage. Those who stored their grains threshed said they were easier to store and use when the need arises. They also found it easy to manage or mix chemicals during storage among others.

Storage of sorghum was done around December-January by farmers in the area but the stored produce did not usually go beyond a year. Similar time of storing sorghum had been reported in Nigeria by Utono *et al*. (2013). Grains usually were loaded into the structures with a basin or fetched with a smaller container and poured into the structures especially the threshed grain. Others fetched with the hand which wasted time. Farmers repaired structures any time there was a fault but discarded if damage was severe. It was also revealed that farmers before storing new harvest in an old facility or newly built storage structures especially the barns and mud silos pre-heat them with fire to kill living creatures before storage. Some clean with brooms sprinkle inside the structures with synthetic chemicals or ash in an attempt to kill storage pests. Despite, insect infestation and damage still occurred during storage. The length of time grain is stored affects the level of pest infestation during storage (Owolade, *et al.*, 2011). The number of insects also varied by the type of storage structure used (Figures 32 and 33).

The survey findings also indicated that majority of the farmers (45%) could store their sorghum grain up to 210 days (7 months), 33.8% reported storing theirs for 4-6 months (120-180 days) while 15% of them stored for the duration of 1-3 months (30-90 days). Only few (6.2%) of the respondents could their store sorghum grains beyond a year. Most farmers in the area from the 6^{th} to 7^{th} month of the year usually run short of food stock. So there is usually some perpetual yearly contracted hunger among families called 'June July' by the literates.

5.4 SORGHUM STORAGE STRUCTURES

Varieties of storage structures were available for the storage of sorghum and were either open to air or airtight (hermetic) in the district. The survey revealed that the most common type of storage structures for storing sorghum in the district were mud silos (buor), barns (katanga), jute sacks, polypropylene bags, Purdue Improved Crop Storage (PICS) bags, Store rooms (houses), baskets, earthen pots and basins (mainly for few days storage). This finding could be backed by report from Motte *et al.* (1995) that ' the major storage techniques practiced by rural smallholder farmers in West Africa include jute bags, polypropylene bags, clay structures, woven baskets, raised platforms and open storage. The structures used by the farmers in the district were personally acquired and owned by the farmers. They were found in farmers' rooms, stores or in the open by farmers' settlements. This is confirmed by Hell *et al.* (2000) that farmers also stored grains in bags in their personal rooms.

It came out from the study that mud silos were the most preferred and commonly used structure by farmers as they were used by 35% of the respondents in the district. This was followed by the use of polypropylene bags (18.3%), barns (15%), jute sacks (12.5%), store rooms/houses (8.4%), PICS bags (5.83%), baskets (2.5%), pots and metal basins (2.5%) been the least.

Shaila (2011) reported that farmers concerns about storage structures was the prevention of grain from insects, rodents, adequate space as well as moisture damage and its ability to keep the produce safe for a reasonable period of time. Mud silos, traditional storage structure were the most preferred because they were perceived to be 'inexpensive to construct since construction materials were locally available, had large capacity, and had the ability to prevent insect infestation and rodent damage. It was also considered durable and could contain different kinds of grains in one structure in different compartments'. This finding is supported by Sundaramari (2009) that 'traditional storage structures protect the stored grains; do not cause health hazards apart from being eco-friendly, cheaper and locally available'. The mud silo however had the limitations of not being airtight and moisture proof.

Polypropylene bags were the second most preferred storage structure by 18.3% of the respondents after mud silos because they were perceived by farmers to be easy to handle, affordable and small quantities of grain could be stored well though they had the disadvantage of not being pest and moisture proof.

Barns were also preferably used by 15% of the respondents for their merits of being spacious; prevent insect and other pest damage, not expensive to build and their durability. Their use was however constrained by the gradual decline of experts in their construction.

The next kind of storage structure farmers preferred was the jute sacks. Some farmers (12.5%) preferred to use jute sacks because they feel they were affordable, portable, easy to handle, occupy less space and ease to detect insect or rodents damage. They were however not airtight, rodent, insect and moisture proof thereby exposing the stored produce to insect and rodent damage and further losses.

Store rooms/houses were used by 8.4% of the respondents to store sorghum in some parts of the district especially in the Dorimon zone/cluster. Farmers after harvesting first carried the unthreshed grain to their stores or houses at home and stored for a number of 1-3months and after which they were threshed and stored in bags and other containers for use. The stores rooms had the advantage of been spacious, durable and easy to keep grain. However, grains stored in rooms were exposed to all sorts of pests.

Purdue Improved Crop Storage (PICS) bags were preferably used by 5.83% of the respondents because they were insect and moisture proof, airtight, portable and capable of storing small quantities of grain. Their use was constraint by their unpopularity in the area since they were still on promotion by MoFA in the area coupled with their high cost as compared to other structures like polypropylene bags and jute bags. The price per PICS bag was Ghc 5 compared to Ghc 1.40p, Ghc 3.0 for polypropylene bag and jute sack, respectively.

Earthen pots have decline in their use in recent times in the area, however some 2.5% of the farmers were still glued to them for the fact they were less costly, rodent and insect proof, efficient in storing small quantities of grain as seeds.

Baskets were predominantly used by Brifos and some Dagaabas in the district to keep their produce. They were perceived by the farmers to be cheap, portable and locally available. Most of the structures farmers used had capacities of 50 kg and above. Some farmers confirmed their structures could contain up to 1000 kg (10 bags). Structures with large capacities gave farmers the opportunity to store more of the sorghum grain after harvest. The type of storage structures used to store grains was also related to the quantity of yield farmers had and the purpose of storage. Thus the higher the yield obtained, the larger the type of storage structure used. This assessing can be supported by the report of Udoh *et al.* (2000) that the commodity stored is related to the production statistics and the technique of storage.

5.5 CONSTRAINTS IN THE STORAGE OF SORGHUM

Farmers complained of high insect pest infestation as the major problem that confronted them in the storage of sorghum in Wa West District with majority (45%) of the respondents attested to this. This could be attributed to the fact that, the farmers' storage structures and storage technologies were not effective. The farmers reported that, their stored sorghum was infested with various kinds of insects. These insects destroyed the produce turning some them into powder. Apart from this, farmers encountered the problem of structural failure (17.5%), resulting from the effects of climatic factors such as rain and wind. Some of storage structures were fully or partially exposed to the mercy of natural factors such as rainfall and wind. So, torrential rainfall and strong winds often collapse the buildings and the storage structures.

The finding also revealed that farmers' inadequacy in terms of capital to acquire storage structures and chemicals (15%) was a setback in the storage of sorghum. Most of the farmers in the area lived below the poverty line. As a result they often find difficult if not impossible to acquire storage facilities to store their produce after harvest. Even those structures that are locally made, farmers were charged by the experts to build them. Farmers complained that the experts charge higher prices to build storage structures since the expertise were scarce.

More than eight percent (8.3%) of the farmers complained of high cost of storage structures (8.3%). During discussion with farmers, it came out that the storage facilities were costly and most of them not cost effective. It equally cost to purchase the jute sack, polypropylene bag, PICS bag, baskets and the pots.

Some percentage (6.7%) of the farmers found it difficult to transport their produce from the farm to where they store their produce. Motor kings, motorbikes, bicycles and head loads were the various means of transporting grains in the study area. Farmers who had motor king, motorbike or bicycle used them to carry their produce home or to storage facilities. Those who did not personally own motor king, motorbike or bicycle hired the services of motor king to carry their produce. Those that use bicycles and their heads to carry their grain complained they were very difficult especially when the farm was far. These modes of transport (bicycles and heads) were considered not very effective and efficient. These also waste time and energy. At times farmers carry their produce for days making them to become tired and weak leading to other health problems.

Furthermore, 4.2 % of the farmers faced the problem of destruction of structures and grains by living organisms such as rodents (mice, and rats), termites and ants. There were similar reports by Adejumo and Raji (2007) that mice and termites posed a serious threat to the structures storage. The storage structures and the grains attracted rodents and other creatures which came to hide, destroyed them and also made the surroundings dirty and unattractive. They created holes on storage structures thereby reducing their efficiency and lifespan.

Over three percent (3.3%) reported not having any extension service on postharvest management of crop produce. It was observed that Extension Officers in the area only concentrated on the production aspects of crops neglecting the postharvest management of the produce.

The findings were also in line with the reports by Golob *et al*. (1995), where they identified the major postharvest problems in Northern Ghana to relates to storage issues such as high insect infestation of stored produce, destruction of produce by rodents, limited market for sorghum, high cost of storage materials, poor threshing technologies, poor storage facilities/conditions, poor transportation, inadequate capital and access to credit and lack of extension services regarding postharvest management.

5.6 EFFECTS OF STORAGE STRUCTURES ON THE MOISTURE CONTENT, RELATIVE HUMIDITY, TEMPERATURE, PURITY, 1000 SEED WEIGHT AND GERMINATION OF STORED SORGHUM GRAINS

5.6.1 Moisture Content

Low temperatures, relative humidity, and moisture contents are favourable for maintaining the quality of the stored produce (Anon., 2011). Moisture content is noted to be one of the most important factors that affect the quality of stored grains (Sisman and Ergin, 2011) and the most important factor determining seed longevity during storage (Qaisrani, 2000). The moisture content was monitored over the period to assess the variation and moisture levels of grain sorghum stored in the different storage structures. The grains before storage had an initial mean moisture content of 12.2%. The moisture contents of grain in the various storage structures over the period were not significantly different from one another. The moisture contents of the grain in the storage structures after the first 30 days had been consistently low in the PICS bag compared to the other storage structures while the moisture level in barn after the 60 days consistently increased up to the last day. The moisture content of grains in all the storage structures slightly reduced from 60 to 150 days in storage but increased after 180 to 210 days. When grains are wet there is an increase in biological activity in the structure (CIRAD, 2002). The moisture content of the grain in all the storage structures was within a safe moisture range from 10.1% to 12.9%. The moisture contents of the grain in barn and polypropylene bag both increased from 12.2% to 12.9% at the end of the storage period, the moisture content in jute sack and mud silo increased from 12.2% to 12.8% while those in PICS bag decreased from 12.2% to 12.0%. PICS bag recorded the lowest mean grain moisture level (11.44%) over the entire storage period while the barn had the highest mean moisture level (12.13%) during the storage period from January to July. The variation in moisture content could be due partly to changes in climatic factors such as the rainfall, temperature, relative humidity and sunshine due to seasonal changes and the activities of insects during storage. It is generally accepted that climatic condition leads to physical changes in stored grain through the movement of moisture which leads to deterioration (Sawant *et al.*, 2012).

Rainfall was observed to have had a great influence in the moisture level of the stored produce and was evident during the raining season when moisture level of grain in the structures began to increase as a result of the grains absorbing moisture from the atmosphere. PICS (triple -layer) bag which kept the grains at lower mean moisture content over the entire period exhibited high potential for long term storage. This might be due to its air-tight nature. The International Rice Research Institute (IRRI) studies in a many Asian countries, comparing commercial and locally manufactured hermetic sealed storage systems with traditional storage systems showed that sealed systems prevent the uptake of moisture by the grain from the outside atmosphere, reduce the number of live insects, prolong the viability of seed, and maintain grain quality (Rickman and Aquino, 2004).

5.6.2 Relative Humidity

The relative humidity in PICS bag was comparably lower (from the beginning to the end) compared to the other storage structures. This might be due its air-tight nature, lower numbers and activities of insects. On the other hand, the highest relative humidity among the storage structures was found in jute sack. This could be due to their porous nature making the environmental relative humidity to directly influence it. Initially, the relative humidity in the storage structures were 43.6%, 43.2%,45.1%, 44.2%, 43.5% for mud silo, PICS bag, jute sack, polypropylene bag and barn, respectively. After the first 90 days the relative humidity increased. This might have being due to the onset of rains. So during the rainy season from April, the ambient relative humidity became higher compared to the dry period. Therefore relative humidity from 120-210 days (during raining season) showed an increasing trend. The increase in relative humidity could also be due to the presence and activities of insects in the various storage structures. There was a mean ambient relative humidity of 54.6% compared to jute sack (53.3), polypropylene bag (50.7%), barn (49.2%), mud silo (48.7%) and PICS bag (45.9%) over the entire period.

Among the storage structures, PICS bag tend to record the lowest mean relative humidity (45.9%), with jute sack recording the highest (53.3%) even close to the ambient relative humidity of (54.6%) over the storage period.

The difference in relative humidity between the initial and that of final among the storage structures were 3.8%, 14.4%, 14.7%, 20.0 and % 23.2% for PICS bag, mud silo, barn, polypropylene bag and jute bag respectively. There was lower variation (3.8%) in relative humidity between the initial and final in PICS bag compared to the rest of the storage structures while polypropylene bag recorded the widest difference (23.2%) between the initial and final relative humidity among the structures. There was however no significant difference ($p>0.05$) in relative humidity among the various structures over the period (Appendix 7).

5.6.3 Temperature

Storage temperature had great effects on the keeping quality of the grain. Initially the temperature of the grain inside the storage structures were 30.6°C, 30.9°C, 31.5°C, 31.5°C, 34.4°C for polypropylene bag, barn, mud silo, PICS bag and jute sack, respectively, while at the end the storage period, the temperature were 29.8°C, 29.5°C, 29.7°C, 29. 4°C and 28.9°C for polypropylene bag, barn, mud silo, PICS bag and jute sack respectively. During the first 30 days the temperatures of grain in all the structures was nearly the same and lower than the ambient temperature. From the 60th to the 90th day (February to March) the warm period of year in the study area had set in resulting in increased ambient temperatures. The condition equally influenced the temperature of some the storage structures. It was observed that for the first 90 days the condition of the grain during this period was good as there were no cases of insect infestation. After the 90 days month onwards a common phenomenon of temperature upsurge occurred in the grain in all the storage structures. So, the temperatures inside the storage structures were higher than the ambient temperature. This might have been due to the infestation of insects and heat released during the respiration of the grain sorghum. The grain is a living entity; it also respired and released heat. Polypropylene bag recorded the highest mean temperature (34.5°C) while barn recorded the lowest (33.8°C) over the storage period. Temperature between the different storage structures was statistically not significant ($p>0.05$).

5.6.4 Purity Test

The purity test of the initial and final samples compared revealed that the final samples had an increase in inert matter but decrease in pure and other seeds. This might be due to insect damage, soil or mud from storage structures. The increase in inert matter and the decrease in pure seeds recorded may represent financial loss in terms of the material used as food, the consequent loss in plant population (Ahmed and Alama, 2010) and a decrease in grain quality. Purity analysis between the initial and the final samples of the grain revealed a general decrease in pure seeds and other seeds but an increase in inert matter. This could have resulted from the eating of the grains by insects during storage. The insects consumed the embryo first which contained the protein and other nutrients thereby lowering the nutrients level of the stored grain. The frass or dust produced through the activities of the insects feeding could be considered unfit for human consumption because of their unattractive taste, colour and the possible presence of the eggs and other by-products of the insects. At the end of the storage period jute sack recorded high percentage of inert matter (4.7%) with mud silo recording the lowest (2.4%).

5.6.5 1000 Seed Weight

There were significant differences ($p<0.05$) among the 1000 seed weight of grain sorghum stored under different storage structures (Appendix 2.1). The mean 1000 seed weight of grain sorghum stored in jute sack was highest (26.06 g) and lowest was found in polypropylene bags (24.56 g). There were significant differences between grains stored in barns (threshed) and that of mud silo (unthreshed). However, there were no significant differences ($p>0.05$) among the 1000 seed weight of grain in jute bags (sacks), PICS bags and polypropylene bags.

5.6.6 Germination Test

Farmers in the study area used part of the grain stored for consumption as seeds for planting in the following season. To assess how farmers' storage systems could ensure good plant stand, germination test was carried out on the sorghum stored under the various structures every month to assess how effective they were in maintaining the viability of the seed grain stored in them over the 210 days (seven months) period. The germination test was conducted within a temperature range of 23-30°C. The outcome showed a gradual decline in germination over the period among all the storage structures (Figure 30). Germination was initially good for grain stored under all the different structures but began to decline gradually. The decline in germination could have been due to insect activities, deterioration of grains and the influence of storage environmental factors such as temperature, relative humidity and moisture. There have been reports by Sawant *et al.* (2012) that moisture content, temperature and relative humidity of storage structures had effects on the germination (viability) of seeds. There was no significant difference ($p>0.05$) in the germination percentages of grains stored in the different structures. However, unthreshed sorghum stored in mud silo tends to maintain an overall mean of 90% germination compared to sorghum stored in the other storage structures. Suggesting that mud silo was more efficient in maintaining the viability of the stored sorghum. This was slightly followed by sorghum stored in PICS bag (88.94%); polypropylene bag (88.87%), barn (88.17%) with jute bag (86.46%) been the least.

The efficiency of the mud silo which is traditionally made therefore affirms the report by Kanwar and Sharma (2006) in their study on traditional grain storage structures in Himachal Pradesh that ‘‘for the storage of seeds, farm families still prefer some traditional storage structures over improved ones because farmers perceived that seed stored in modern storage structures which are air-tight had low germination rate in comparison to traditional structures with the reason that modern storage structures which are air-tight do not maintain consistent temperature’’. Unthreshed grain stored in mud silos showed better germination than the rest of the storage structures.

5.7 STORAGE DURATION AND ITS EFFECTS ON INSECT PEST INFESTATION IN SORGHUM STORAGE STRUCTURES

After harvesting sorghum from October through to December in the Wa West District, majority of the farmers begin to store their grains in December- January, and store for as long as one year, depending on the farmers' circumstances. Many (31.6%) of the farmers in the district stored sorghum grains for daily consumption and as seeds for planting the following season, 25% stored for consumption, sale and as seeds for next season. More than seventeen percent (17.5%) stored for sale and consumption while 16.7% stored the grain purposely for consumption, 4.2% kept their produce only for sale, 2.5% also stored mainly for use as seeds to plant the following season. Few of the farmers (2.5%) kept some of their grains for cultural reasons such as funeral rituals.

It was generally revealed that many of the farmers in the area could not store their sorghum grain beyond a year. Forty five percent (45%) of the farmers stored their grains between 7-12 months, 33.8% reported storing their grains for 4-6 months while 15% of them stored for the duration of 1-3 months. Only 6.2% of the respondents could store sorghum grains for more than a year. This was mostly due to low yield, poor storage structures and management as well as the situation of the farmer.

In the field experimental study, there was occurrence of insect infestation on the stored produce in all the different storage structures. The dominant insect species that attacked the stored sorghum in the various structures was lesser grain borer *(Rhyzopertha dominica).* A similar finding has been reported by Ratnadass *et al.* (1994); Utono *et al.* (2013). Few cases of termites were found especially in the barn. They perforated the structures, bored or ate the grains. Lesser grain borers (*Rhyzopertha dominica)* tolerates higher temperatures, and is able to attack very dry grain (Sinha, 1974). The infestation of *Rhyzopertha dominica* started from the day 90 in the barn and polypropylene bag and 120 days time in all the storage structures except the PICS bag which occurred from the 150 days. The number of insect pest found - lesser grain borer (*Rhyzopertha dominica*) increases as the storage time extended in all the storage structures except that of the PICS bag where the insects numbers reduced as the duration of storage increased. This might have been due to the air-tight nature of the structure which provided an environment unsuitable for the multiplication of the insect pests. The barn, polypropylene bag, jute sack and mud silo provided a conducive environment for the proliferation of the insect pests. There was increase in insect population, damages and resultant losses of grains in storage over the time. At the end of the storage period, jute sack recorded the highest cumulative number of live insect count (366), followed by polypropylene bag (317), mud silo with 109 live insects, barn had 87 live insects while PICS bag (28) been the lowest or fewest live insect population. With regards to dead insect count, there was no dead insect found in the mud silo and the barn. Polypropylene bag recorded the highest number of dead insects while PICS bag tend to record almost an equal number of dead insects (25) and live insects (28) over the period of storage. There was however no significant difference in that of live insects and dead insect among the various storage structures over the period.

The study revealed that PICS bag was effective in keeping down insect population in storage. This was followed by barn, mud silo, polypropylene bag and jute sack been the worse. Therefore, PICS bag was comparably better in keeping down the level of insect infestation among all the structures while jute sack was less effective against insect attack. This could be due to its porous nature. This finding affirms the reports by Jones *et al.,* (2011) that PICS bags are effective against storage pests and therefore show superior profitability and potential in Ghana, Malawi, Tanzania and Mozambique. These results still conforms with Mahama (2012) when he stored cowpea in PICS bag (triple bag), barn, polypropylene sack and a pot where PICS bag tend to offer better protection against insects (bruchids), than the rest of the structures.

5.8 GRAIN LOSSES FROM STORAGE STRUCTURES

Food security of farmers depends on the success to grow and store the staple food that the families need with a minimum loss of quantity and quality, using effective and appropriate methods that can be afforded (Blum and Bekele, 2002). The use and maintenance of storage structures is the key to minimizing losses. Grain losses due to insect pests affect the livelihood of farmers in Wa West district. Lesser grain borers *(Rhyzopertha dominica)* had been the dominant insect species that infested stored sorghum in the study area. They were responsible for losses of sorghum grain stored by farmers in the storage structures such as the barns, mud silos, polypropylene bags, jute sacks and PICS bags (triple-layer bags). Similar findings had been reported by Ratnadass *et al.* (1994) where grain sorghum stored in bags recorded losses more than 6%, and later as high as 15.9% and also a monthly grain losses of 2.4% up to 8.9% in granary by *Rhyzopertha dominica*. It was observed from the study that losses were further influenced by the storage time and population of insects involved. Therefore, losses and damage increased as the number of insects and duration of storage increased in all the structures. A similar finding has been reported by Tuluker and Howse (1994) and also by Haile (2006) where grain damage increased with the extension of the storage period in the treatment of control, sand and taff. Damages and losses caused by the insects were seen from the 120 days (fifth month) of storage except that of the PICS bag which started from the 150 days time (sixth month). It was also observed that grain weight losses increased with increase in storage period. This was attributed to the increase in damages and population of live insects. The percentage mean grain weight losses caused by the insect (*Rhyzopertha dominica*) were 8.2%, 7.2%, 6.8%, 4.8%, and 3.2% for jute sack, polypropylene bag, mud silo, barn and PICS bag, respectively. This implied that lesser grain borer (*Rhyzopertha dominica*) could cause higher losses or complete damage of grain in the various storage structures if they were to be kept for a year or more. The activities of the insects (boring/eating) could also lower the nutrient content of grain stored.

The results showed that PICS bag (triple bag) was more efficient in protecting sorghum grain against *Rhyzopertha dominica* damage and subsequent losses than the use of jute sack, polypropylene bag, mud silo and barn. This might be due to the air-tight condition of the PICS bag (triple bag) which allows carbon dioxide level to accumulate inside the bag making it not conducive for the survival and proliferation of insects. This finding corroborates the report of PICS (2010) who stated that the triple bag technology allows less air exchange with the outside world. In the absence of the PICS bag (triple bag), barn storage could be the next preferred choice in minimizing *Rhyzopertha dominica* damage. The results also indicated that the proportion of loss caused by storage pests is related to the type of storage structure used. The losses in germination of sorghum in the various storage structures were 14.2%, 9.7%. 8.9%, 7.2% and 5.5% for jute sack, barn, PICS bag, polypropylene bag and mud silo respectively. Thus, there were greater germination losses in jute sack followed by barn, PICS bag, polypropylene bag and mud silo.

In conclusion, indigenous grain storage structures may not offer effective protection against *Rhyzopertha dominica*. However, the current promotion of the use of resistant varieties, PICS bags and possibly metal silos, alongside appropriate synthetic chemicals in storage are alternative approaches to reducing losses.

5.9 RELATIONSHIP AMONG THE QUALITY PARAMETERS OF SORGHUM IN STORAGE STRUCTURES

The correlation coefficient (r) among the parameters taken from sorghum stored in the various structures was evaluated. This was to find out the relationships that existed with regards to the qualities of sorghum stored in the various storage structures. The parameters include: moisture content of stored produce, temperature of storage structures, relative humidity of storage structures, 1000 seed weight, live insects and dead insects count and weight loss. It was observed that weight loss positively and strongly related to the number of live insects responsible for loss (r =0.808). This implies that the more the insects population the more the damage and losses. Therefore, insects were contributing factor to the loss of grain in the storage structures. Weight loss caused by insects also strongly and positively correlated with relative humidity of storage structures (r = 0.866), implying the higher the relative humidity the higher the weight loss. Therefore, structures with high relative humidity resulted in higher losses as was found in jute sack. Moisture content also positively correlated with weight loss (r = 0.588). Meaning an increase in moisture content also increased the losses by insects. Therefore, the higher the moisture content of the stored produce in the structures the greater the activities of the insects leading to higher losses by insects (*Rhyzopertha dominica*). Live and dead insects both negatively correlated with germination percentage (r = -0.438 and r = -0.44), respectively. Therefore, when live insects increased, the germination of seeds decreased. Similar finding has been reported by Mahmood *et al.* (2011) where mites' population negatively correlated with germination at both initial and final stages of an experiment. Negative correlation between insects (mites) population and germination was reported by Bashir *et al.* (2009) which revealed that with increase in mite population the germination of seeds reduced. Seed weight had a positive correlation with germination of seeds (r = 0.155). Therefore, the heavier the seeds in the various structures the better the germination. So storage structures that were able to maintain good seed weight had a better chance in maintaining the viability of the seeds of the sorghum. Such was the case in mud silos. Therefore, the higher the relative humidity, moisture content and insect population of grain in the storage structures the higher the weight loss. Relative humidity had negative correlation with 1000 seed weighed (r = -0.217). However, there was a positive correlation on the relative humidity of the various structures with dead insects, live insects and moisture content. This implied that when relative humidity increased, it resulted in increased live and dead insects and a concomitant increase in moisture content. Live and dead insects were also strongly positively correlated.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The study brought to the fore the major storage structures used by farmers to store sorghum grain in Wa West District. These were mud silos (buor), barns (katanga), polypropylene (fertilizer) bags, jute sacks, store rooms (houses), Purdue Improved Crop Storage (PICS) bags, baskets, basins and pots. Based on the result from the study, it occurred that mud silos were the most preferred and commonly used storage structure by farmers in the district. This was followed by the use of polypropylene bags, barns, jute sacks, store rooms/houses, PICS bag, baskets, pots and metal basins been the least. These structures were preferably used by farmers based on their cultural and socio-economic reasons. Mud silos were the most common and preferred structures used by farmers to store their sorghum grain in the area because they were perceived to be inexpensive to construct since construction materials were locally available, had large capacity and the ability to prevent insect infestation as well as rodent damage. They were also considered durable and could contain different kinds of grain in one structure in different compartments'. They however had the limitations of not being airtight and moisture proof. On the other hand, earthen pot and woven basket were the least preferred structures used. However farmers attributed certain reasons for their preferred usage. Earthen pots were perceived by farmers by to be less costly, rodent and insect proof, efficient in storing small quantities of grain as seeds. Baskets were perceived by the farmers to be cheap, portable and locally available.

The storage and use of sorghum grain storage structures were constraint by high incidence of insect pest infestation, structural failure resulting from effects of climatic factors (rain and wind), destruction of grain and structures by living creatures (rodents, termites and ants), inadequate capital to acquire storage structures and chemicals, transportation difficulties and lack of extension services on postharvest management of produce.

There were no clear cut differences in the parameters measured (temperature, relative humidity, moisture content, insect count, germination, weight loss, purity analysis) among the grain stored in various storage structures over the storage period except some little differences in seed weight.

In terms of insect count, the insect – lesser grain borer *(Rhyzopertha dominica*) was the main insect which infested and damaged grain. The insect caused considerable loss to the grain. Greater weight losses occurred in the jute sack making it considered highly ineffective in keeping the quality of the produce. This could be due to its porous nature which allows for the proliferation of insects into the structure. Therefore, lesser grain borer (*Rhyzopertha dominica*), if not handled with prudent postharvest management techniques, could cause a lot of damage to sorghum in storage if they are to be kept for a long period of time.

As the storage time extended, there was a decrease in the quality of the grain resulting from increased insect population and damage, reduction in germination as a result of deterioration of the grain and increased weight losses due to the storage structures inability to keep the produce in good condition. Comparably, there was greater germination losses of grain in jute sack with the least found in mud silo. Hence, mud silo maintained the best germination percentage.

It was found from the study that weight loss caused by insects, strongly and positively correlated with relative humidity, moisture content and insect population. Therefore relative humidity, moisture content and insect population influenced the weight loss of sorghum stored in the various storage structures. It was also observed that weight loss resulted in decreased germination of grain stored in the various storage structures.

PICS bag recorded the lowest mean relative humidity with jute sack recording the highest over the storage period. There was however no significant difference in relative humidity among the various structures over the storage period. The moisture contents of grain in the various storage structures over the period were not significantly different from one another. PICS bag recorded the lowest mean grain moisture level over the entire storage period while the barn had the highest mean moisture level over the storage period. The temperature of the storage structures increased when there was increase in atmospheric temperature and when insect infested the grains in the storage structures due to heat released during the respiration of the grain sorghum and insects. Polypropylene bag recorded the highest mean temperature while barn recorded the lowest over the storage period. Temperature between the different storage structures was statistically not significant.

The purity test carried out on the grain samples at the beginning and end of storage compared generally revealed that the final samples had an increase in inert matter but decrease in pure and other seeds. Jute sack recorded high percentage of inert matter with mud silo recording the lowest.

The findings from the study also revealed that, among the storage structures, PICS (triple-layer) bag tend to be more effective in maintaining the quality and quantity of the grain under storage. It also exhibited high potential for long term storage. This was evident from the study that PICS bag kept the grains at mean lower moisture content over the entire period, recorded the lowest insect population, lowest mean relative humidity, lowest average loss of grains in the storage structures. So, PICS (triple layer) bag was comparably better in keeping down the level of insect infestation among the storage structures while jute sack recorded the highest average live insect population over the storage period hence less effective in protecting the grain against insect attack.

Therefore, in terms of protection against insect infestation and losses, PICS bag stood out and proved to be more effective. Jute sack was the worst hence less effective in maintaining grain quality. For germination of seeds, unthreshed grain stored in mud silos proved to be more effective and comparably better than the grain stored in the PICS bag, jute sack and the rest of the storage structures. For the purpose of seeds for planting, storing in mud silos unthreshed will be better.

6.2 RECOMMENDATIONS

The findings of this study added to our knowledge on issues with regards to the storage structures used by farmers to store sorghum grain in Wa West District in the Upper West Region of Ghana after harvesting the crop. Therefore the following are worth recommending based on the outcome of the study:

- This study should be repeated and the period extended up to a year (12 months).
- There was also the need to improve mud silos and barns by lining the inside walls, the floors and concrete reinforcement as well as improve covering to make them airtight.
- Sorghum grain stored in PICS (triple-layer) bag could be the storage option for farmers living in the area since it was available and moderately affordable.
- For the purpose of storing sorghum grain as seeds for planting, storing in mud silos unthreshed will be better.

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APPENDICES

Appendix 1: Sample Questionnaire

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECCHNOLOGY, KUMASI

DEPARTMENT OF HORTICULTURE

A questionnaire designed to help collect information from farmers about sorghum production storage and storage structures in Wa West District in the Upper West Region of Ghana

All information provided will be treated confidentially. Please be objective as possible.

Town...

Demographic Characteristics of Respondents

1. Sex of respondent: A. Male [ ] B. Female [ ]

2. Age of respondent:

A. 10-19 [ ] B. 20-29 [ ] C.30-39 [ ] D. 40-49 [ ] E.50-59 [ ] F.60-69 [ ]

Others...

3. Marital status: A. Single [ ] B. Married [ ] C. Divorced [ ] D. Widowed [ ]

4. Religious background: A. Christian [ ] B. Muslim [ ] C. Traditionalist [ ]

5. Educational background: A. None [ ] B. Non-formal education [ ] C. Primary [ ]

D. MSLC/JHS [ ] E.SHS/Voc. [ ] F. Tertiary [ ]

6. What other work do you do apart from farming?

....

Principal Sorghum Grain Production

7. What variety of sorghum do you grow? A. Local [ ] B. Improved/hybrid [ ]

8. Where do you get your seed for production? A. Self storage [ ] B. Buying [ ]

C. Friends [ ] D. Others...

9. How large is your farm?

A. less than an acre [ ] B. 1-3 acres [ ] C . 4-5 acres [ ] D. 6-8 acres [ ] E. 9-10 acres [ ] F. More than 10 acres [ ] E. Others (specify)..

10. What do you use to plough/ till the land for producing your sorghum?

A. Tractor only [ ] B. Hoe only [ ] C. Both tractor and a hoe [ ]

D. Others (specify)..

11. What has been your main source of labour for producing your sorghum?

A. Family [ ] B. Hired [ ] C. Both [ ] D. Others (specify).......................................

12. How long is the production period?

A. 2 months [ ] B.3 months [ ] C. 4 months D. 5 months [ ] E. 6 months [ ]

F.7- 12 months [ ]

13. Do you apply fertilizer to your crops?

A. Yes [ ] B. No [ ]

14. If yes to 13, what kind of fertilizer?

A. inorganic/chemical fertilizer [ ] B. Organic fertilizer/manure [ ] C. Both [ ]

15. At what time of the year do you harvest your sorghum?

A. Sept-Oct. [ ] B. Sept-Nov. [ ] C. Sept-Dec. [ ] D. Oct-Nov.[ ] E. Oct-Dec. [ ]

F. Nov- Dec.[ ]

16. How do you determine the sorghum is ready for harvesting?

....

17. What tool(s) do you use to harvest the sorghum?

....

18. What other crop(s) do you cultivate? ....

Storage Practices for Sorghum Producers

19. Do you store your sorghum grains?

A. Yes [ ] B. No [ ]

If yes, why do you store the grains? ....

20. Where do you store your produce?

A. At the farm [ ] B. At home [ ]

21. Do you store immediately after harvesting?

A. Yes [ ] B. No [ ]

Why? ....

22. In what form do you store your sorghum grain?

A. Unthreshed/Unshelled [ ] B. Threshed/Shelled [ ].

Why? ....

23. Do you apply some chemicals to your produce before storing or at storage?

A. Yes [ ] B. No [ ]

24. If yes to 23, what kind of chemical?

A. Synthetic [ ] B. Herbs [ ] C. Both [ ] D. Others (specify..

25. What other treatment do you give to your produce before storing?

Specify: ....

26. How long do you store your sorghum grain?

A. 1-3 months [ ] B. 4-6 months [ ] C. 7-12 months [ ] D. More than a year [ ]

E. Others (specify)...

27. At what time (of the year) do you use or sell your stored produce?

....

28. What is/are your main purpose(s) for storing the produce?

A. For home consumption [ ] B. For sale [ ] C. As seeds [ ] D. Others..................

29. What are the use(s) of your sorghum grain?

A. Preparing daily meals B. Feeding animals C. Brewing pito D. Others

(Specify)..

30. What are the major problem(s) you encounter in the storage of your produce?

A. Insect damage [ ] B. Rodents destruction [ ]

C. Destruction of the structures by rain and other climatic factors [ ]

D. Others (specify)..

Storage Structures/Facilities

31. What kind of structure do you store your sorghum grain?

A. Barn [ ] B. Mud silo [ ] C. Jute bag (sack) [ ] D. Store rooms/house [ ]

E. Shed [ ] F. Cribs [ ] G. Basket [ ] H. Polypropylene bag [ ] I. Pot [ ]

J. Purdue Improved Crop Storage (PICS) bags [ ]

K. Others (specify)..

32. Which is your most preferred storage structure?...

33. Why do you prefer it to other storage structures?

a...

b...

c...

34. Are there some disadvantages or limitations associated with use of your storage structure? Yes [ ] No [ ]

If yes, what are they? ....

35. How do you obtain the structure to store your sorghum grain?

A. Self constructed [ ] B. You bought it [ ] C. Borrowed it [ ]

36. At what time of the year is/are the storage structure(s) made/ constructed?

A. Dry season [ ] B. Wet season [ ] C. Any time of the year [ ] D. I don't know [ ]

37. What treatment do you give to the storage structure before you store grain sorghum?

....

38. What quantity of grains can be stored in the structure/facility?

A. less than a bag [ ] B. 1-2 bags [ ] C. 3-5 bags [ ] D. 6-10 bags [ ] E .Others (specify)..

39. How long can your storage structure keep your grains safe for consumption or sale?

....

40. How will you grade the efficiency/effectiveness of the storage structure you use?

A. 0-9 [ ] B.10-19 [ ] C. 20-29 [ ] D. 31-39 [ ] E. 40-49 [ ]

F. 50-59 [ ] G. 60-69 [ ] H. 70-79 [ ] I. 80-100 [ ].

41. Do you maintain your storage structure? A. Yes [ ] B. No [ ]

42. If yes to 41, how often do you maintain it?

A. Yearly [ ] B. Every two years [ ] C. Others (specify)..

43. Do you need some improvement on the construction materials?

A. Yes [ ] B. No [ ]

44. How much does it cost to construct or obtain the storage structure?

....

45. What pest(s) destroy the storage structure?

....

46. What problem(s) do you face in the use of your storage structure?

....

THANK YOU

Appendix 2: Analysis of Variance (ANOVA) Tables

1. ANOVA of 1000 seed weight (g) of grain stored in storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	6.9040	1.7260	7.50	<.001
Residual	30	6.9057	0.2302		
Total	34	13.8097			

2. ANOVA of live insects counted from the various storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	52.02	13.01	0.88	0.488
Residual	30	444.28	14.81		
Total	34	496.20			

3. ANOVA of dead insects counted from the various storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	5.129	1.282	0.98	0.435
Residual	30	39.427	1.314		
Total	34	44.556			

4. ANOVA of germination percentage of grain stored in storage structures

Source of variation	df	ss	ms	Vr	Fpr
Storage structure	4	48.05	12.01	0.95	0.449
Residual	30	379.26	12.64		
Total	34	427.32			

5. ANOVA of moisture content of grain stored in storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	4.2989	1.0747	1.97	0.125
Residual	30	16.3686	0.5456		
Total	34	20.6674			

6. ANOVA of relative humidity of storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	246.49	61.62	1.17	0.343
Residual	30	1577.28	52.58		
Total	34	1823.7			

7. ANOVA of internal temperature of grain storage structures environment

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	2.699	0.675	0.08	0.988
Residual	30	59.177	8.639		
Total	34	261.876			

8. ANOVA of weight loss caused by insects from the different storage structures

Source of variation	df	ss	ms	vr	Fpr
Storage structure	4	114.94	28.74	0.39	0.811
Residual	30	2184.36	72.81		
Total	34	299.30			

Appendix 3: Results of Experiment

Table 1: Moisture content (%) of grain sorghum stored in storage structures over the period

Storage Structures	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210	Mean
Barn	12.2	12.3	11.2	11.5	11.9	12.4	12.6	12.9	12.13
Mud silo	12.2	12.2	11.9	11.6	11.5	11.6	12.6	12.9	12.06
PICS bag	12.2	12.2	11.0	10.6	10.2	11.1	12.2	11.6	11.44
Poly. Bag	12.2	12.1	11.8	11.5	11.8	11.5	12.5	12.9	12.04
Jute bag (sack)	12.2	12.1	11.4	11.2	11.6	12.5	12.6	12.8	12.06

Table 2: Germination percentages of grain sorghum stored under various storage structures as seed source

Storage Structures	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210
Barn	93.3	91.5	87.3	83.5	89.5	87.4	84.7	88.17
Mud silo	92.4	91.0	90.8	90.0	91.2	85.7	88.9	90.0
PICS bag	98.7	89.9	85.4	89.4	87.4	86.3	85.5	88.94

Jute bag (sack)	93.8	85.8	85.4	86.0	88.2	85.8	80.2	86.46
Polypropylene bag	90.9	92.3	92.2	85.6	86.7	87.2	87.2	88.87
Mean	93.8	89.3	88.2	86.9	88.1	87.3	85.3	88.49

Table 3: Insect counted from samples of 1 kg of sorghum grain stored in the various storage structures over the storage period

Storage Structures	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210
Mud silo	0(0)	0(0)	0(0)	0(0)	7(0)	30(1)	22 (3)	50(3)
Barn	0(0)	0(0)	0(0)	2(0)	2(0)	3(0)	29 (0)	51(0)
PICS bag	0(0)	0(0)	0(0)	0(0)	0(3)	23(3)	2 (6)	3(16)
Jute bag (sack)	0(0)	0(0)	0(0)	2(0)	5(0)	21(4)	103 (8)	235(22)
Poly. Bag	0(0)	0(0)	0(0)	0(0)	3(0)	11(0)	77 (9)	226(26)

Numbers outside the brackets are live insect counted while those inside the brackets are dead insect counted

Table 4: Percentage weight losses caused by lesser grain borer (*Rhyzopertha dominica)* on the sorghum grain stored in the different storage structures

Storage Structure	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210	Cumulative loss	Average loss
Barn	0	0	0	0	0	5.6	13.7	14.4	33.7	4.8
Mud silo	0	0	0	0	0	11.2	17.1	19.4	47.7	6.8

PICS bag	0	0	0	0	0	0	8.2	13.9	22.1	3.2
Jute sack	0	0	0	0	0	15.6	15.1	26.8	57.5	8.2
Poly. Bag	0	0	0	0	0	13.1	13.9	23.2	50.2	7.2

Table 5: Ambient and internal relative humidity of the storage structures

Storage Structures	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210
Ambient relative humidity	47	45.6	46.5	46.9	55	58.1	68.5	68.9
Mud silo	43.6	44.1	42.6	44.6	47.7	53.8	55.2	58
PICS bag	43.2	43.4	45.1	44.3	45.8	53.4	45.0	47
Jute sack	45.1	46.7	45.5	46.0	49.5	58.6	66.4	68.3
Polypropylene bag	44.2	45.1	44.6	44.5	44.6	57.6	61.1	64.2
Barn	43.5	43.2	47.2	44.7	47. 7	54.1	54.9	58.2

Table 6: Ambient and internal temperature (°C) of the storage structures over the storage period

Storage Structures	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150	Day 180	Day 210
Ambient Temp.	30.2	31.3	37.6	37.6	33.6	32.8	31.4	31.2

Mud silo	31.5	33.2	31.2	35.2	36.6	34.1	33.4	32.8
PICS bags	31.5	35.1	31.4	34.6	35.7	35.3	33.5	32.5
Jute bag (sacks)	31.4	34.8	31.3	37.4	36.1	36.4	34.1	32.9
Polypropylene bag	30.6	35.0	35.0	36.5	35.5	36.3	34.5	32.9
Barn	30..9	31.6	35.0	34.6	37	36.5	32.5	32.6

Table 7: Hundred (100) grain weights (g) of damaged and undamaged seeds at the time insects caused damaged to grains in storage structures

	Weight of 100 grain (g)					
	Day 150		**Day 180**		**Day 210**	
	Undamaged	**Damage**	**Undamaged**	**Damage**	**Undamaged**	**Damaged**
Jute sack	2.53	1.74	2.55	1.75	2.58	1.16
Mud silo	2.46	1.91	2.51	1.65	2.52	1.54
Barn	2.49	2.21	2.52	1.83	2.50	1.78
Polypropylene bag	2.44	1.80	2.45	1.77	2.48	1.33
PICS bag	2.51	1.98	2.51	2.10	2.52	1.82

Appendix 4: Data Collection Tools and Materials

Plate 1: Sorghum grain

Plate 2: Moisture tester & Hygrometer

Plate 3: Weighing of 1000 seeds of sorghum

Plate 4: Threshed grain inside barn

Plate 5: Grain in Purdue Improved Crop Storage (PICS) bag

Plate 6: Threshed sorghum grain in jute sacks

Plate 7: Sorghum grain in polypropylene (fertilizer) bag

Plate 8: A barn

Plate 9: Cluster of mud silos

Plate 10: Unthreshed grain inside a mud silo

Plate 11: Counting of seeds for weighing

Plate 12: Germination test of sorghum grain stored in storage structures

Plate 13: Lesser grain borers *(Rhyzopertha dominica)* found after sieving stored sorghum grain

Plate 14: Stored sorghum damaged by lesser grain borer (*Rhyzopertha dominica*)

Plate 15: Harvesting of sorghum