KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI.

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DEPARTMENT OF AGRICULTURAL ENGINEERING

PERFORMANCE EVALUATION OF THREE YAM STORAGE STRUCTURES IN FIASO IN THE TECHIMAN MUNICIPALITY, GHANA.

BY

MUSTAPHA GHANIYU MWINIBALONNO

NOVEMBER, 2015.

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BSc. (Hons.) Agricultural Engineering

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DECLARATION

I hereby declare that, except for specific references which have been duly acknowledged, this project is the result of my own work and it has not been submitted for any other degree elsewhere.

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DEDICATION

This thesis is dedicated to the Almighty Allah, the most gracious the forgiver of sins who has brought me this far and to my dear lovely wife, Abubakari Zuleihat who stood by me thick and thin during my studies.

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ABSTRACT

The study was conducted in Fiaso, a yam farming community in the Techiman Municipality of the Brong Ahafo region of Ghana where two new yam barns were constructed. These structures differ by way of shape (rectangular and circular). The general objective of the study was to evaluate the performance of two yam varieties namely Pona and Denteh, stored in the newly constructed storage structures. A control treatment was included in the study by selecting an existing storage structure in the community. Storage conditions and parameters monitored included temperature, relative humidity, weight loss, sprouting and tuber rot. The study was done between February and June 2015.

From the study, it was observed that ambient temperatures ranged from 15.4 ^{o}C to 46.3 ^{o}C. The rectangular storage structure recorded minimum and maximum internal temperatures of 18.2 ^{o}C and 38.4 ^{o}C respectively whilst the circular storage structure recorded 18.7 ^{o}C and 35.9 ^{o}C respectively. The existing local storage structure recorded minimum and maximum temperatures of 18.3 ^{o}C and 39.6 ^{o}C respectively.

It was observed that the minimum relative humidity recorded for ambient, rectangular, circular and existing local storage structures were 11%, 17.3%, 18.5% and 16.7% respectively. Maximum relative humidity for the ambient, rectangular, circular and existing local storage structures were 99.5%, 89.2%, 89.9% and 90% respectively. Rectangular, circular and the existing local storage structures recorded 54.9%, 55.5% and 58.7% weight loss for the Pona respectively and 40.4%, 32.4 and 35.1% for Denteh respectively during the storage period of 17 weeks.

Sprouting index for circular, rectangular and the existing local storage structures were observed to be 45.2%, 46.5% and 59.2% for Pona respectively as against 53.1%, 48.7% and 57.5% for Denteh respectively.

During the study, rot in Pona was observed to be the lowest in the rectangular storage structure with 37.5% against 50% and 56.3% for the circular and the existing local storage structures respectively. For Denteh, there was no tuber rot observed in the circular storage structure. However, the rectangular and the existing local storage structures recorded 6.3% and 8.3% respectively for Denteh.

The newly constructed storage structures performed well in almost all aspects of the parameters monitored and therefore can be recommended as an improved storage structures over the local method in the study area.

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CHAPTER ONE

1.0 INTRODUCTION

Yam belongs to the genus Dioscorea which has over 600 species but only about 6 of which are cultivated for human consumption while a few non edible ones are cultivated for industrial raw materials (Mijinyawa and Alaba, 2013). It originated in the Far East and spread Westwards (Osunde, 2008). According to IITA report, this thick tropical-vine tuber is popular in Africa, the West Indies, and parts of Asia, South and Central America. By virtue of its excellent palatability, yam is a high value crop (IITA, 2004), widespread throughout the world (Kordylas, 1990) and forms about 10% of the total roots and tubers produced in the world (FAO, 2002). Yam is the second most important tropical root crop in West Africa after cassava (Opara, 1999). West Africa accounts for 94% of world production with Nigeria being the largest major producer (IITA, 2007).

According to Yamoah and Aidoo (2014) cited in FAOSTAT (2012), Ghana accounts for 94% of the world exportation of yam making her the leader in the export of the produce in the West Africa.

Yam play a prominent role in a variety of human food diet and livestock feed in many of the areas where it is cultivated (Lancaster and Coursey, 1984; Opara, 1999; IITA, 2008). Yam has socio economic and cultural values in many parts of the world, these being manifested in celebration of traditional ceremonies to usher in the new yam season (Opara, 1999). In Ghana, yam festival is celebrated by the people of Brong Ahafo region and the Ewes (from the Volta region)

The most popular and preferred form of consuming yam is the tuber form boiled, pounded, roasted or fried yam. Better financial returns are obtained by selling the tubers rather than as processed yam flour even though other yam value addition techniques are encouraged.

Despite its numerous importance, yam belongs to the neglected crops and many constraints limit its production most especially storage. High losses are associated with the yam production process from harvesting to storage. Considerable amount of yam is lost during storage when the right structures and storage conditions are not met. It is estimated that as high as 50-60% of the stored produce is lost (Vernier, 1998).

1.1 Problem Statement

Yam is one of the preferred staple foods in West Africa. The annual vegetative cycle of yam necessitates a long period to make it available all year round.

The major problems in yam tuber storage are sprouting, respiration and transpiration, which cause weight and quality losses (Osunde and Orhevba, 2009).

Although farmers have been known to practice indigenous storage of farm produce, these have been known to be less effective compared to modern storage methods. According to Omoruyi and Orhue (1991); Tyler (1982) and Mughogho (1989), produce stored under the traditional system usually do not keep long and farmers usually suffer great losses. Thus, there is need for the extension service to actively pursue and communicate knowledge of improved storage methods to farmers since effective storage plays an important role in stabilising food supply at the household level by smoothing the seasonal food production. Postharvest losses hinder maximisation of net returns by farmers and traders as these losses render a substantial quantity of produce unusable or unmarketable. The type of storage system used contributes significantly to these losses. Farmers and traders in yam producing communities are faced with postharvest losses during storage. This lowers the income generation by these farmers and subsequently affects their standards of living. The construction of improved yam storage systems could help in addressing the post harvest losses encountered by farmers and traders in Fiaso in the Techiman Municipality. Due to the perishability of the crop, the tubers cannot be kept for more than a few weeks after harvesting. 50% of the crops may be lost within 6 months due to rot or sprouting if no stabilisation processes are used and this explains the volatility in fresh yam prices over the years (Vernier, 1998). Thus farmers prefer not to store most of their yams after harvest. This is a similar case of most farmers in Fiaso, a major yam farming community in the Techiman Municipality as farmers are faced with all sorts of challenges in the storage of yam tubers. They therefore tend to sell the produce immediately after harvest even when market prices are not encouraging.

In general, methods of storage vary from delayed harvesting, storage in simple piles or trenches to storage in buildings specially designed for that purpose and application of sophisticated modern techniques (Igbeka, 1984).

Causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot, rodent attack, etc. Sprouting, transpiration and respiration are physiological activities which depend on the storage environment.

This work looks at the storage of two local yam varieties namely Pona and Denteh in three yam storage structures (two newly constructed structures and an existing local storage structure) aimed at encouraging yam farmers and traders to store their produce.

1.2 Objectives of the Study

1.2.1 Main objective

The main objective of this work was to compare the storage characteristics of Pona and Denteh yam varieties in three storage structures over a period of 17 weeks.

1.2.2 Specific objectives

The specific objectives are to:

1. Measure the relative humidity and temperature of the storage structures including the surrounding conditions.
2. Monitor the physical rot/deterioration and insect or rodent attack on the tubers.
3. Estimate of storage weight losses in the newly constructed storage structures and the local structure.
4. Estimate the sprouting rate of Pona and Denteh yam varieties in the three storage structures.

1.3 Significance of study

1. The project will help identify better forms of yam storage in the district to maximize farmers and traders income and improve upon their lives. The project seeks to explore forms of yam storage and this could better inform stakeholders on better ways or systems of yam storage.
2. The study will also help identify yam cultivars that can be stored adequately for long. The two yam varieties under study namely Pona and Denteh will be evaluated and the one that most appropriately stores for long will help inform farmers and other yam stakeholders the particular cultivar to select for storage.

   Furthermore, the duration of the storage can also be estimated under the storage structures.
3. The performance of the structures in terms of storage conditions on rot and weight loss can encourage the use of traditional materials in the construction of yam barns. These storage structures are mainly constructed using locally available materials to basically encourage farmers and other stakeholders to be comfortable adapting to the usage and construction of the storage structures.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Brief history of yam

In West Africa, domestication has been a traditional farmers practice (Scarcelli *et. al.,* 2005). White yam (Dioscorea rotundata) according to Agbaje *et al.* (2005) can be traced to the indegines of Africa where it is the most predominantly grown and favoured yam specie. Yellow yam (Dioscorea cayenensis) can also be traced to West Africa and much similar in morphology to that of the white yam in physical appearance.

Guinea yams (Dioscorea cayenensis-rotundata; D. rotundata. and D. cayenensis.) have been described as resulting from a process of domestication of wild yams of the section Enantiophyllum by African farmers (Mignouna and Dansi, 2003).

The bitter leaves used as a description of the bitter yam (Dioscorea dumetorum) also known as trifoliate yam originated from Africa.

2.2 Varieties of yams

There are about 600 known species of yams throughout the world, however, the varieties for human consumption are derived largely from the most economically essential species.

The white yam tuber in description is cylindrical in shape, the skin being smooth and brown. It normally has a white flesh but also firm and it is also noted that, large quantities of white yam varieties exist with variations in their method of farming and post-harvest features (Mignouna and Dansi, 2003).

The yellow yam (Dioscorea cayenensis) derives its name precisely from the yellow flesh it presents and is similar to the white yam. Except for other morphological features, the yellow yam's period of vegetation is much longer and also has s shorter dormancy period than the white yam according to Mignouna and Dansi (2003).

Yam production, depending on the cultivar or variety takes six (6) to ten (10) months and is dormant or remains in the dormant state for a period of two (2) to four (4) months. Production state is normally in the wet season and the dormant stage in the dry season constituting the two phases. Annual rainfall distribution of over 1,500mm uniformly across the growing season is an important and key factor to successful maximum yam production (yield) in the wet season.

According to Mignouna and Dansi (2003), Dioscorea rotundata and D. cayenensis are the most popular and economically important yams in West and Central Africa where they are indigenous, while D. alata is the most widely distributed species globally.

2.3 General characteristics of the Yam tuber

The produce, yam (Dioscorea spp.), is a multi-species, polyploidy and vegetatively propagated tuber crop that is cultivated widely in the tropics and subtropics. Its shape and number vary largely between species. White yam (D. rotundata) tubers are usually large and cylindrical in shape with white flesh. D. alata (water yam) tubers have variable shape, the majority being cylindrical according to Aseidu-Larbi (2010) cited in FAO (2002).

Based on the cultivar, colours of yam may range from off-white, purple including pink with the skin of the tuber ranging between off-white and dark brown (IITA, 2004). Variations in size and shape may be attributed to environmental and genetic factors. An average weight of 3 to 5kg with a cylindrical shape is generally the yield of a normal growing season yam tuber for most varieties. Tubers of yam grow from a corn-like structure on mounds at the base of the vine. Sporadically these corn-like structures remain to the tuber even after harvest where sprouts develop at the end of the dormant stage of the yam. As the corn-like structure detaches from the yam tuber, sprouting is initiated close to the very point where the corn-like structure was attached (Huber, 1998). The water yam tuber is usually cylindrical in shape; however it can be very variable. The normal flesh of the water yam is very white with a very "watery" (slippery) feel in texture. It is an important food in Africa, the Caribbean, and especially Melanesia where it has considerable social and cultural importance (Lebot *et al.*, 2005).

Bitter yam (Dioscorea dumetorum), referred to as trifoliate yam because of the nature of the leaves originated from Africa where wild varieties also exist. One unique characteristic of the bitter yam is the flavour that comes along with the flesh of the yam. It has a bitter flavour. It is also worth noting that once harvested the flesh of the bitter yam gets toughened or hardened if not cooked soon enough with certain wild cultivars being extremely poisonous (Lebot *et al.*, 2005).

2.4 Nutritional Value of Yams

The detailed nutritional value of yam in its raw form or state is illustrated in Table 2.1. Yams are an excellent source of carbohydrate, energy, vitamins (especially vitamin C), minerals and protein. Some cultivars of yam tuber have been found to contain protein levels of 3.2 – 13.9% of dry weight. A yam meal could supply 100% of the energy and protein, 13% of the calcium and 80% of the iron requirement of an adult male (Knoth, 1993).

The chemical composition of yam is characterised by a high moisture content and dry matter. The dry matter is composed mainly of carbohydrate, vitamins as well as protein and minerals. Nutrient content varies with species and cooking procedure. Having the peels intact during cooking helps retain vitamins (Osagie, 1992).

Yam is an essential source of calories and several other nutrients in the diet of many people in Ghana. The crude protein content of white yam was found to be between 6.40– 9.64 g/100g according to Mbome-Lape and Treche (1994) and Agbor-Egbe and Treche (1995) cited by Dramani (2013).

Table 2.1: Nutritional value of yam (Nutrient in 100 g of edible portion)

Nutrient	Unit	Value per 100g
Water	G	69.6
Energy	Kcal	118
Protein	G	1.53
Total lipid (fat)	G	0.17
Carbohydrate, by difference	G	27.88
Fiber, total dietary	G	4.1
Sugars, total	G	0.5
Calcium, Ca	Mg	17
Iron, Fe	Mg	0.54
Magnesium, Mg	Mg	21
Phosphorus, P	Mg	55
Potassium, K	Mg	816
Sodium, Na	Mg	9
Zinc, Zn	Mg	0.24
Vitamin C, total ascorbic acid	Mg	17.1
Thiamin	Mg	0.112
Riboflavin	Mg	0.032
Niacin	Mg	0.552
Vitamin B-6	Mg	0.293
Folate, DFE	µg	23
Vitamin B-12	µg	0
Vitamin A, RAE	µg	7
Vitamin A, IU	IU	138
Vitamin E (alpha-tocopherol)	Mg	0.35
Vitamin D (D2 + D3)	µg	0
Vitamin D	IU	0
Vitamin K (phylloquinone)	µg	2.3
Fatty acids, total saturated	G	0.037
Fatty acids, total monounsaturated	G	0.006
Fatty acids, total polyunsaturated	G	0.076
Cholesterol	Mg	0
Caffeine	Mg	0

Source: USDA Nutrient Database

2.5 YAM PRODUCTION

2.5.1 Yam production in Ghana

Table 2.2 represents the production of yam in Ghana in 2012. A number of varieties of white yams are cultivated throughout the country but predominantly in the Northern and Brong Ahafo Regions, and the northern part of the Volta Region (Dramani, 2013). Some of the varieties of white yam (Dioscorea rotundata) are Pona, Dente, and Asana. Pona is the highly preferred variety due to its high yielding, early maturing, and sweetness (high sugar content) but is highly perishable (MIDA, 2010). In Ghana, major areas for commercial yam production Atebubu, Techiman, Wenchi, Kintampo in the Brong Ahafo region; Yendi, Tamale, Bole in the Northern region; Ejura, Mampong in the Ashanti region; Wa in the Upper West region and Kete-Krachi in the Volta region (Twumasi, 1986).

Table 2.2: Yam production in Ghana

REGION	YAM (tonnes)
Western	93,861
Central	16,664
Eastern	709,722
Volta	463,559
Ashanti	476,172
Brong Ahafo	2,319,583
Northern	2,038,196
Upper East	521,112
TOTAL	**6,638,867**

Source: MoFA, 2012.

2.5.2 Production in Africa

Yam is an important source of carbohydrate to the inhabitants of the tropical and subtropical Africa, Central and Southern America, parts of Asia, the Caribbean and Pacific Islands (Coursey, 1967). Table 2.3 represents the production of yam in Africa. Out of 600 yam species grown throughout the world, 3 main species are predominantly grown in West Africa. These are white yam, yellow yam, and water yam according to Nweke *et. al*., (1991).

Nigeria is the leading producer of yam followed by Ghana. According to Mijinyawa and Alaba (2013) cited in IITA (2008), Ghana is the leading exporter of yam with an annual export of about 12,000 tonnes.

Table 2.3: Yam production in Africa

Country	Yam Production	% of World Total
Nigeria	40,500,000 m/t	64.2%
Ghana	7,074,574 m/t	11.2%
Côte d'Ivoire	5,731,719 m/t	9.09%
Benin	3,177,265 m/t	5.03%
Ethiopia	1,191,809 m/t	1.89%

Sources: FAOSTAT (2015).

2.6 OPERATIONS IN YAM PRODUCTION

2.6.1 Production

Yam production starts with the construction of yam mounds or ridges and the seed tubers or portions of tubers planted into them (mounds/ridges) as illustrated in Figure 2.1 at the beginning of the rainy season. These mounds are constructed in the traditional settings manually which makes the production laborious. A number of factors determine the yield a farmer gets at the end of a growing season. Some of which include the variety, how yam setts are planted, the size of the constructed mounds. Intercropping with cereals or vegetables is generally practiced by peasant farmers in West and central Africa as a means of maximizing land use. According to Aduening and Amponsah (2000), yam production is suitable and economical for intercropping. Yam setts are perishable and transportation also is done in bulk. This therefore compel some farmers to set a quantity usually 30% of his/her harvest for the next season's production

Figure 2.1: Yam mounds Source:

Field data, 2015.

2.6.2 Harvesting

Harvesting of yam in West Africa is done basically using traditional equipment such as sticks, diggers, spades, etc according to Onwueme (1978). Preference is mostly given to wood base equipment to metallic tools since the metallic tools can easily inflict damage to the tubers even with the greatest care. Wood base equipment however requires constant replacement. The process in yam harvesting is extremely labour intensive as well as physically demanding. Frequent standing, bending, squatting and maybe sitting is required in the harvesting of every 2 to 10kg of yam depending on the mound size or the tuber size. Proper precaution must be taken into consideration not to inflict any damage to the tubers as this will subsequently affect the storage (Onwueyme, 1978). Peasant or small scale farmers who intercrop have extra work to do as harvesting becomes a bit more difficult (Opara, 2003).

2. 6.3 Curing

Stored yams will keep longer if they are cured before they are placed in the store. Curing helps heal wounds and toughen the skins. Curing carried out immediately after harvesting and transportation to the storage area is highly recommended. Curing requires high temperatures and high humidity and is done under a cover which traps selfgenerated heat and moisture. Temperatures under this cover should be between 32-40^{o}C. One day of curing is enough if the temperature is near 40^{o}C and the relative humidity is

95%. But 2 to 4 days are needed when temperatures and relative humidity are lower (FAO, 1998).

One way to cure yams is to make a stack on the ground as illustrated in Figure 2.2. The stack of yams should be put in a lightly shaded area. Stacked yams may be covered with grass or mats and a canvas tarpaulin placed over the whole stack. The canvas should cover the grass or mats, but care should to taken to ensure the canvas does not touch the yams. As an alternative, a simple wooden frame can be built and the canvas draped like a tent over the piled yams. Again, the canvas should not touch the yams. It is not recommended to use plastic sheets for curing since the plastic will make the yams too hot. If there is no canvas tarpaulin, then several layers of sacks or mats can be used (Wilson, 1987).

Figure 2.2: Curing of yam

2.6.4 Storage

Respiration in yam is inevitable since they are living organisms even after harvest according to Dramani (2013) cited in Alhassan (1994).

Successful storage of yams requires:

- initially selecting sound and healthy yam
- effective curing, if possible the application of fungicides;
- sufficient aeration to minimize the heat generated by respiration of the tubers;
- frequent monitoring during storage and separation of rotting yams and any sprouts that may develop;
- Protection against direct sun rays and rainfall (FAO, 1998).

The storage of yam at low temperature reduces the respiration rates sufficiently (Kumar, 2014). However, temperatures below 12 °C cause damage through chilling, causing a breakdown of internal tissues, increasing water loss and yam's susceptibility to decay. When tubers are still in cold storage, the symptoms of chilling injury are not always obvious. The injury becomes noticeable as soon as the tubers are restored to ambient temperatures (FAO, 1998).

Sprouting in tubers rapidly increases the respiration rates within them, and accelerates the rate at which its food value decreases. Certain cultivars of yam store better than others. Storage losses for yams are very high in Africa, with insects alone causing over 25% harvest loss within 4 months (Oke, 1990).

2.6.4.1 Importance of yam storage

Post-harvest food losses are one of the important sources of food insecurity in Africa. According to AMCOST (2006), pre- and postharvest food crop loss among African countries is estimated at about 10%, which is higher than the global average.

The storage of yam by farmers and traders cannot be overemphasised. Many farmers and traders are faced with problem of storing their produce for a period of time after harvest. Some of the significance of storage of yam in Ghana are:

1. It enables farmers to increase the net profit when good prices set in. Mostly during harvest of yam, supply tends to increase thereby reducing the cost of the perishable crop. However, when farmers and traders are able to store their produce for sometime, the market value of the produce appreciates with time and this increases the net income of the farmers and traders.
2. Successful storage of yam for a period of time tends to give the farmer food for his family until new yam is planted. Farmers do not have foodstuff (yam) for family

consumption few months after harvest since they are challenged with the storage of the produce. Successful storage of yam for a period of 3 to 4months can help supply the yam farmer and trader food for their family until new yam

sets in.

3. Additionally, yam seeds for a new planting season are obtained when effective storage of yam is done.

2.6.4.2 Factors Influencing Yam Storage

Effective yam storage requires the selection of healthy, sound tubers, carrying out effective curing procedure and if possible the application of fungicide. Excess heat within the storage structure should be removed to slow down the rate of respiration. Regular inspection or monitoring may also be carried out to detect the presence of destructive rodents as well as eliminate direct sun rays and rain (Umogbai, 2013).

Tubers of yam may most effectively be stored in environments that are cool but dry and well aerated. This will increase the shelf or storage life. Irrespective of varietal difference, ware, seed and commercial yams have very similar internal storage requirements. Temperatures ranging from 12 ^{o}C to 16 ^{o}C are recommended for effective storage of fresh tubers of yam in ambient and/or refrigerated environments. Temperatures of 15 ^{o}C or 16 ^{o}C with relative humidity of 70 to 80 % are as well recommended for cured yams (Cooke *et al.*, 1988; Opara, 1999).

Most edible yams species reach maturity in 8 to 11 months after planting. As a seasonal crop, harvested yam tubers are stored to meet the demand during the off-season period. Adequate aeration, reduction of temperature, protection from direct sunlight and flood, and regular inspection of produce are the basic requirements for successful and long term storage of yam tubers (Wilson, 1980; Lancaster and Coursey, 1984; Orhevba and Osunde, 2006). Ventilation prevents the condensation of moisture on the surface of tubers and helps in the removal of heat as a result of respiration. Low temperatures are necessary for the reduction of storage losses resulting from respiration, sprouting and rotting. Additionally, regular inspection is very vital in combating sprouting and tuber rots as well as monitoring of the incidence of rodents, etc. Storage conditions for yam should be such that they will considerably slow down the process of sprouting as this will significantly increase the respiration rate within the produce leading to the shrivel and deterioration of the yams. The shelf or storage can be considerably improved under such environment (Plucknett, 1979; Passam *et al.,* 1978; Opara, 1999).

Microorganisms thrive in conditions where they can survive and therefore such conditions must not be established as much as possible. Moisture, temperature, relative humidity and soil type according to Kay (1973) are major factors which influence the development and growth of these microorganisms.

Effective yam storage requires the control of moisture within the storage environment to a suitable level so it does not trigger other factors. Additionally, the soil type may be considered in instances of underground storage.

Considerable variations exist in storing different varieties of yam. *D. alata* is extremely difficult to keep for long than *D. rotundata*. Under high storage temperatures (160 ^{o}C and above) and relative humidity (85% and above) sprouting and decay occur in water yams (*D. alata*) as compared to *D. rotundata* (white yam) (Maduewese and Onyike, 1981).

However, at high temperatures and lower humidity the case is the same since water yam has high moisture or water content compared to the *D. rotundata*. Water yam will therefore require lower temperatures and humidity to be stored effectively. For instance, burying water yam inside the ground and covering properly with earth can help it last for few weeks until is ready for use (Maduewese and Onyike, 1981).

2.7 Post-Harvest Losses of Yam

Yam is a perishable produce (Alhassan, 1994). Large quantities of yams are lost annually to the disadvantage of producers, and traders and other yam stakeholders. According to Dramani (2013) cited in Asiedu and Alieu (2010), the bulkiness of yam tuber, its chemical composition and moderately high water content predispose it to degradation during long-term storage. Storage losses incurred during storage of yam could be classified into quantitative and qualitative losses (Asiedu and Alieu, 2010). Quantitative losses of yam include weight loss which is mostly due to moisture loss through transpiration. Qualitative losses include dry matter losses (loss of nutrient content as a result of sprouting and respiration) and loss of nutritive quality. Robertson and Lupien (2008) noted that weight loss after 3 months of storage ranges between 10-20% and 50% after 6 months of storage.

2.8 Causes of Post-Harvest Losses of Yam

The storage of fresh yam tubers has been confronted with a major problem over the years. Physiological and pathological factors contribute to yam losses in storage (Ravi and Aked, 1996; Kader, 2005; Imeh *et al.*, 2012).

According to Marcotte *et al.*, (2005); Osunde (2008); Imeh *et al.*, (2012) physiological activities in yam that lead to postharvest losses are transpiration and respiration which in turn contribute to weight loss and sprouting.

Pathogenic causes of postharvest yam deterioration include moulding and bacterial infection (Green and Simons, 1994 and Dumont, 1995). Physiological activities taking place in yam tubers in storage may bring about some changes in their internal composition, resulting in loss of nutritional qualities (Serge and Agbor-Egbe, 1996; Afoakwa and Sefa-Dedeh, 2001; Osunde, 2008), can cause 10% losses within 3 months and up to 25% losses in 5 months (Robertson and

Lupien, 2008). According to Ezeh (1995), significant causes of postharvest losses, are weight loss, insect attack, microbial infection and sprouting. Sprout development is a major cause of storage losses (Osunde, 2008).

2.9 Losses in yam production

Yam, as a perishable crop, deteriorates after harvest and the loss due to this may be attributed to the following reasons:

1. mechanical damage,
2. physiological changes within the yam
3. Infections due to decay organisms as well as pest infestations.

The above mentioned factors may cause losses throughout the entire production process, i.e. starting from produce maturity to harvesting, transportation and storage (FAO, 1998). Pre-harvest factors contribute largely to the considerable postharvest losses experienced in yam production. These factors consist of cultural practices, field pests' attacks, disease organism infections, environmental and genetic factors (FAO, 1998).

2.9.1 Mechanical Damage

According to FAO (1998), mechanical damage to the skin can be the starting point of deterioration in yam. Mature yam tubers have their skins serving as barrier against most potential destructive bacteria and fungi which results in the rotting or deterioration of tissues. This prevents the tubers from long storage or reduces the healthy storage period.

Any form of breakage to this barrier will constitute the first point of entry to bacteria or destructive organism and can further stimulate physiological deterioration and dehydration. Post harvest rot/deterioration of tubers of yam is significant through the different processes which include handling, storage and marketing among others (FAO, 1998).

Different degrees of mechanical damage exist during yam handling from small bruises to large cuts which initiate deterioration. Also operations starting even before harvesting to harvesting and subsequently operations involving handling where the produce is graded, packed and transported may all increase the physical damage of the produce if proper care is not taken. Damage to yam which is not immediately noticeable may lead to physiological rot/deterioration and serve as the entry point of pathogens ((FAO, 1998).

2.9.2 Physiological Factors

Physiological factors include the following:

1. Respiration
2. Transpiration
3. Damage by high temperatures (FAO, 1998).

2.9.2.1 Respiration

Yams as perishable crops respire as living organisms. This respiration process eventually results in the oxidation (burning) of the starch contained in the cells of the tuber, which converts it into water, carbon dioxide and heat energy. During this transformation of the starch the dry matter of the tuber is reduced (Diop, 1998). In order to have respiration occur freely, oxygen supply is required. This result in CO_2 with heat removed from the surrounding. Reduced oxygen supple with inadequate removal of CO_2 may result in death of the tissue of the produce (FAO, 1998).

2.9.2.2 Factors affecting the respiration rate

During the physiological development of yam through growth, harvesting, storage and subsequent planting as seed, the tuber as a living organism goes through various forms for which the respiration rate is affected. These factors include:

1. Physiological age of the yam,
2. As to whether sprouting has initiated or still in dormant stage,
3. Any form of mechanical damage
4. Storage conditions, most especially the temperature.

Generally, the respiration rate of yam is relatively high during or at harvest followed curtly by subsequent decrease during storage. The rate increases again once sprouting is initiated according to Burton (1966).

2.9.2.3 Effect of storage temperature on respiration

Temperature as the degree hotness or coldness is the single primary factor affecting respiration rate in yam. Extremely high temperatures may result in the formation of black heart, a disorder that is caused by central cells asphyxiation (Booth and Proctor, 1972). This disorder happens when internal temperatures of the yam is exposed to the rays of the sun between 45-50^{o}C (Coursey, 1967). The rate of respiration in yam is observed to slow down as temperatures reduce to 5^{o}C (Coursey *et al.,* 1966).

The metabolic activities of yam are tremendously reduced as temperatures get low. Oke, 1990 reports that temperatures within the range of 10^{o}C to 12^{o}C can cause damages related to chilling, subsequently increasing the water loss and also the susceptibility of the tuber to decay.

2.10 Dormancy and sprouting

Vegetative propagation is the method of reproduction exhibited by yam as other tubers. Yam normally goes into the dormant phase as a means of responding to unfavourable weather conditions at the tail end of its growth period. The commencement of this phase is considered as the physiological maturity of the tubers, also known as wilting point. Dormancy period in yam is the period of rest (Craufurd *et. al.*, 2000) or period where there is a reduction in the endogenous metabolic activities during which the tuber of yam exhibits no or very minimal intrinsic or bud growth, even though the potential to retain future growth is still within the produce. Dormancy is considered a species as well as a varietal trait or characteristic (FAO, 1998). It is affected by other factor including temperature which is the principal factor. Dormancy is also affected by factors such as moisture, oxygen content as well as the carbon dioxide content of the environment (storage). The physical damage and in some cases, the disease of the yam occasionally have principal effect (FAO, 1998).

2.10.1 Effects of Sprouting on the Quality of Yam

Yam is a living organism and therefore continues to respire even after harvest. Energy (carbohydrate) stored in the tubers is used up for the continuation of this process. Carbon dioxide and water are released into the atmosphere during the process. Increased respiration is the consequence of sprouting. According to Afoakwa and Sefa-Dedeh (2001), sprouted yams that are meant for consumption are unacceptable since the process result in loss of sugar, carbohydrate, and other nutrient contents in the yam tubers. As the carbohydrate level of the tuber reduces, the smaller it becomes in terms of size, and less the price of the yam (Ravi and Aked, 1996). The income level of yam exporters and farmers in Ghana is greatly affected. Sprouting is accelerated by respiration (Ravi and Aked, 1996).

When sprouts are removed regularly on monthly intervals, it helps reduce the amount of weight loss and at the same time increases useful storage life (Osunde *et al.,* 2003). Monthly removal of sprouts reduces tuber weight loss within 5-month storage period by 11% in D. rotundata and D. alata tubers (Osunde *et al.*, 2003).

2.10.2 Effects of Dormancy on Yam Storability

Dormancy is an indication of a state of rest when metabolic activities such as respiration, starch and sugar metabolism, and enzymatic activity are low or indicate the presence of endogenous growth inhibiting substances (Elsie, 2011). That is, dormancy is a period when fresh tubers of yam are unable to sprout.

Dormancy period of yam if enhanced will be largely beneficial to both farmers and marketers or yam traders. This is so since the onset of sprouting in yams that are meant for the market seriously affect their market value. Sprouting occurs in yams within temperature of 25 and 30 ^{0}C (Osunde, 2008). According to Asiedu and Alieu (2010), a higher temperature of 35^{0}C was found to cause about 85% sprouting of yam tubers after 95 days of storage and low temperatures between 15 to 16^{0}C were found to extend dormancy but temperature below 10^{0}C causes chilling injury (Osunde, 2008).

2.11 Pathological factors

Most living organisms including tubers of yam are prone to attacks by microorganisms.

Direct postharvest losses are hugely caused by these destructive organisms (microorganisms, fungi, etc) which are present in the air, soil and on decaying materials (plants). The physical state or condition of the produce mostly determines the level of destruction by these microorganisms since the factors such as wounds inflicted on the produce serves as entry points for these destructive organisms (FAO, 1998).

2.11.1 Effect of Pathogens on Quality of Yam

Rotting in yam is caused by pathogens (microbes) such as fungi, bacteria, and nematodes. Yam rot is mostly caused by pathogenic fungi. According to Okigbo and Ikediugwu (2002) and Aidoo (2007), the fungi in this category include Aspergillus flavus, Aspergillus niger, Botryodiplodia theobromae, Fusarium oxysporum, Fusarium solani, Penicillium chrysogenum, Rhizoctonia spp., Rhizopus nodosus Penicillium oxalicum, and Trichoderma viride. Normally, fungi that do cause rot are lesion pathogens. Thus, they depend on the lesions or wounds to enable them penetrate the tubers to cause rot (Okigbo and Emoghene, 2004).

Yam tuber rot can be grouped into three namely, dry, watery, and soft rot (Aidoo, 2007 and Lebo, 2009). Dry rot is usually not observed externally. The flavour and physical nature of the tuber is greatly affected when rotting sets in and renders the produce uneconomical. Bacteria though cause rot as moulds, their effect is uneconomical.

Numerous species of mould fungi infest yam tubers (Jonathan *et al.*, 2011).

2.12 Pests and insects attacks

Postharvest losses caused by pests include rodents (animals), insects, nematodes etc.

Insects damage yams in two ways:

- by drilling holes in them, reducing the quantity and quality of the yam and also the germination prospects;
- By damaging the epidermis providing entry source for moulds and bacteria to penetrate the yam (FAO, 1998).

2.13 STORAGE STRUCTURES

2.13.1 Factors to consider in constructing storage structures

When building the storage structure for yam, several factors should be taken into consideration for effective or successful storage of the produce. Some of these factors are:

- adequate shade
- protection from rain
- good ventilation
- security against animals, rats, thieves

2.13.2 Types of Storage Structures

The intended final use of yam produce is a principal factor in the determinant of the type of storage system to be used. The structures used for the storage of yam tubers are numerous. Some of the storage structures include trench or clamp silos, underground pits, barns of various designs, shelves in specially constructed or improvised sheds, raised huts, and assorted platforms. The popularity of these structures varies from one region to another, and the choice made depends on the volume to be stored and what the farmer can afford (Mijinyawa and Alaba, 2013). Yams for planting are usually stored fresh with those meant for consumption either kept fresh or processed into chips and stored dry.

Storage structures for yam can be grouped into two namely:

1. Traditional storage structures
2. Improved storage structures

2.13.3 Traditional storage structures

Several low-cost traditional storage systems are being used and practiced by yam producers. The commonest among them are ground storage where the tubers are left on the ground till their intended use, leaving produce under trees, yam barns, underground storage systems, for instance pits and ditches, mud structures, thatch huts and cribs. Construction of these structures takes different shapes and sizes depending on the producer's capability and farming practice. Local materials such as wood, palm fronds, mud, etc are employed in the construction of these storage systems (Osuji, 1985; Cooke *et al.*, 1988; FAO, 2004).

Figure 2.3 is a typical traditional yam barn in Ghana. This produce is stored in this structure and by the complete closure of the structure, high temperatures result in the deterioration of the yam. Generally, the tubers are left on the floor or palm fronts or materials are placed on the floor before the produce is place. Farmers or traders are forced to reconstruct these storage structures everytime tubers are to be stored since very little consideration is taken before construction. Tubers are exposed to the mercy of rodents in these structures.

Figure 2.3: Rectangular traditional storage barn

Source: Field data, 2014.

A number of significant challenges face the traditional storage systems of yam. Some farmers leave their produce in the ground after harvest. This method when adopted prevents the farmer from comfortably using the land for any productive use. Furthermore, tubers of yam are at the mercy of rodents and other insects which eventually hasten the deterioration of the produce.

When farmers store their produce under trees, the produce become open to damage by rodents and also serves as the habitat of reptiles and other dangerous animals. Tubers under these structures such as Figures 2.4A and B are exposed to direct rainfall and the trouble of dismantling the heaps to inspect tubers for rotting and sprouting tubers are among the disadvantages of this system of yam storage (Osuji, 1985; Satimehin, 1987; Umogbai and Satimehin, 2004).

Flooding, fungal attack, decay, etc are some of the challenges associated with underground and mud storage structures. Also, choosing to store yams under palm fronts and guinea corn talks risk exposing the tubers to fire outbreaks (Osuji, 1985; Satimehin, 1987; Umogbai and Satimehin, 2004).

A

Figure 2.4A: Round/Circular traditional storage barn.

Source: Field data, 2014.

Figures 2.4A and 2.4B illustrates another type of traditional yam storage structure where the local material is just built around a tree and the produce or tubers of yam placed on the floor. The peasant farmer explains that it is the aeration that will help in the effective storage of the produce. However, there are well ventilated weather-proof, insect and rodent proof strong shelters for storage of yam tubers. The high financial cost of these structures discourages the local farmers from constructing such improved storage structures (Umogbai and Satemehin, 2004).

B

Figure 2.4B: Round/Circular traditional storage barns

Source: Field data, 2014.

2.13.4 Improved storage structures

In attempts at reducing postharvest losses and long storage, the yam barn presents the best results in comparison to other storage systems in West Africa. Improved technologies tend to provide protection and increase the useful shelf life of the produce in the structures. Without totally changing the type of storage, some measures to the construction can be carried out which can lead to a considerable improvement of the barn (Knoth, 1993).

Over the years, several improved yam storage structures have been introduced.

Traditional storage structures are monitored and challenges associated with them are addressed to qualify them as improved storage structures. For instance, the introduction of rodent guards to an existing traditional structure as shown in Figure 2.5 and 2.6 can significantly reduce the loss of yam through rodents. Mostly improved technologies are based on the availability of local materials to facilitate the construction of these structures at a relatively low cost (Knoth, 1993).

Figure 2.5: Circular improved storage barn

Source: field data, 2015

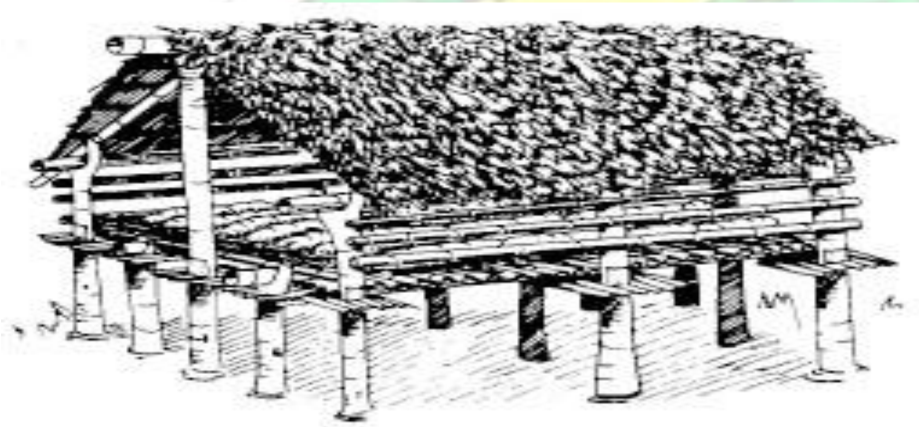

Figure 2.6: Improve raised yam platform

Source: Wilson, 1987.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Project site

This project work was sited at Fiaso, a predominantly yam farming community in the Techiman municipality of the Brong Ahafo region of Ghana.

3.2 MATERIALS

3.2.1 Project Storage structures

Two differently shaped yam storage structures were constructed in the community (Fiaso). The storage structures are rectangular and circular in shape as illustrated in figures 3.1 and 3.2 respectively with the same construction materials. These construction materials were selected based on their availability in the area. Furthermore, low cost but efficient materials were sourced for the construction.

Figure 3.1: Rectangular storage structure

Source: Field data, 2015.

Figure 3.2: Circular storage structures

Source: Field data, 2015.

A third storage structure (existing local storage structure) represented in Figure 3.3 was included in the work but selected from the community and sited close to the constructed storage structures. Storage practices were conducted to fall in line with the farmers practices in this storage structure. That is, the tubers were heaped on the floor just as farmers do in this storage structure. The materials used in the construction of the local storage structure included Wawa, Borassus, and aluminium roofing sheets.

Figure 3.3: Existing local storage structure.

Source: Field data, 2015.

In the construction of the new storage structures, the following materials were used:

- Borassus
- Wawa boards
- Wire mesh
- Aluminium roofing sheets
- Ropes
- Thatch
- Padlocks
- Nails

Borassus were chosen for construction of the frame of the structures since they have high strength and are very durable. Also, resistance to severe weather conditions in addition to resistance to termite attack are among some reasons for their selection.

The Wawa boards were used in the creation of shelves for the careful placement of the produce for storage. Additional shelves were also constructed and placed in the storage structure to increase the volume of produce that can be contained.

The wire mesh is used at the openings (windows) for the prevention of birds and other pests and for easy and constant passage of air. This is essential since ventilation is key to the storage of perishable produce like yam. These air vents are strategically located at the top of the structures.

The aluminium roofing sheets are used in the construction of rodent guards. This is done to forestall the activities of rodents inside the storage structures. Suitable sizes are cut and nailed round the frames of the structure which are buried in the ground to support the storage systems. This material is selected for its smooth or slippery nature which tends to drastically reduce the friction between feet of rodents and the material. Rodents therefore find it difficult if not impossible, up climb to the barn.

Thatch is used for the roofing of the structures. This is extremely cheap and very cost effective. It is suitable for yam storage since heat absorption in the inside of the structure is minimal. These roofing materials are fastened to the top of the structure by means of the ropes.

Security of the stored yam is guaranteed by the provision of a door with a reliable padlock.

The following equipment/materials were used in the attainment of the project objectives:

- Yam tubers
- Spring balance
- Tinytag data logger
- Tape measure
- Weighing bag

3.2.2 Sourcing of yam tubers

The yam tubers used for this study were Pona and Denteh which are among some of the commonly cultivated varieties among the farmers in the area of study. The sourcing/selection of tubers was carefully done to ensure that no mechanical damage was inflicted on the tubers. The tubers were cleaned by trimming off roots attachment and only healthy tubers were sampled for storage.

3.3 METHOD

3.4 Sampling method

Yam tubers were labelled (Figure 3.5) for easy identification. These tubers were put into replications and the replications put into groups. Each replication was made up of 12 healthy tubers and each group is made up of four (4) replications. This brought the total number of tubers for each variety of yams to 48 for each storage structure. A total of 288 tubers were used for data collection.

Simple random sampling technique was employed for the selection of four replications to be used as samples for the study.

Weight of the tubers was taken before stocking on the shelves and the subsequent weights on monthly basis taken to determine the weight loss over the period using the spring balance.

Figure 3.5: Researcher labelling sampled tubers

Source: Field data, 2015.

3.5 MEASUREMENT OF PARAMETERS

3.5.1 Weight loss

Weight loss of tubers were recorded as indicated in Figure 3.4 before the commencement of the project and the subsequent weight loss determined on monthly basis with the help of the spring balance. In other words, a replication is weighed and this is recorded as the initial weight at the beginning of the month. The same sample (replication) is weighed at the end of the month and this is recorded as the final weight. The difference between the initial weight and the final weight gives the weight loss over the period (for that month).

Figure 3.4: Weighing procedure of samples

These same replications are weighed each month to determine the weight loss over the period.

3.5.2 Temperature and relative humidity

Internal and external temperature of the atmosphere is taken on hourly basis with the help of the Tinytag data logger. This equipment has the capacity to record automatically the temperature and relative humidity of its surrounding environment. The Tinytag data loggers were calibrated to take temperature and relative humidity readings on an hourly basis. However, for the purpose of this research, the maximum and minimum daily temperatures and relative humidity were used for analysis.

These loggers are installed in all storage structures as well as outside the structures to record values.

Measure of the dimensions of the storage structures is done by use of the tape measure.

3.5.3 Experimental Design

The experimental design used was the RCBD (Randomized Complete Block Design), a 3x2 factorial design with four replications. Three storage structures (Rectangular storage structure, circular storage structure and an existing local storage structure) were applied on two cultivars of yam, Pona and Denteh. A total of 288 tubers were used for the research work. 48 tubers of each variety of Pona and Denteh for all three structures: rectangular and circular structure and the existing local storage structure.

3.5.4Analysis of data

The analysis of the data was done using GenStat Release 9.2 with the means separated at LSD of 5%. The research parameters analysed were the temperature, relative humidity, weight loss, frequency of sprouting and the rot/deterioration.

3.5.5 Transformation of field data

The field data on frequency of sprouting as well as that of rot were transformed by means of square root transformation method followed by the analysis. As a result, Tables 4.1 to 4.5 in Chapter Four (Results and Discussions) are the transformed means with the untransformed means at the appendices.

3.6 Sprouting and Rot/Deterioration Index

The sprouted tubers in the storage structures were determined using the relation in equation 1.

Sprouting index $= \frac{number\ of\ sprouted\ tubers}{total\ number\ of\ tubers} \times 100$ ------------------------ equation (1)

Also, the number of rotten tubers in the storage structures was determined as follows

Rot index$= \frac{number\ of\ rotten\ tubers}{total\ number\ of\ tubers} \times 100$ ---------------------------------- equation (2)

(Opara, 1999).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter deals with the results or findings from the research work i.e. the data collected and the interpretation of the collated data. The interpretation is done using graphs alongside tables.

4.1 Temperature

The daily minimum and maximum temperatures of the three storage structures were recorded and compiled into weekly average.

4.1.1 Minimum average temperatures

Figure 4.1 illustrates the minimum average temperatures recorded within the three storage structures and the ambient environment. Higher minimum average temperatures were observed within the three storage structures compared to the ambient (outside) temperatures. Within the newly constructed storage structures, the circular structure recorded the highest minimum average temperature of 24.4 ^oC followed by the existing local and circular storage structures with average minimum temperatures of 24.2 ^oC and 23.9 ^oC respectively. A lower ambient temperature of 15.4 ^oC was observed around the storage structure. This observation is due to the fact that within the storage structures, the respiration of the tubers of yam increased the internal temperatures of the structures which is not the case under the ambient environment.

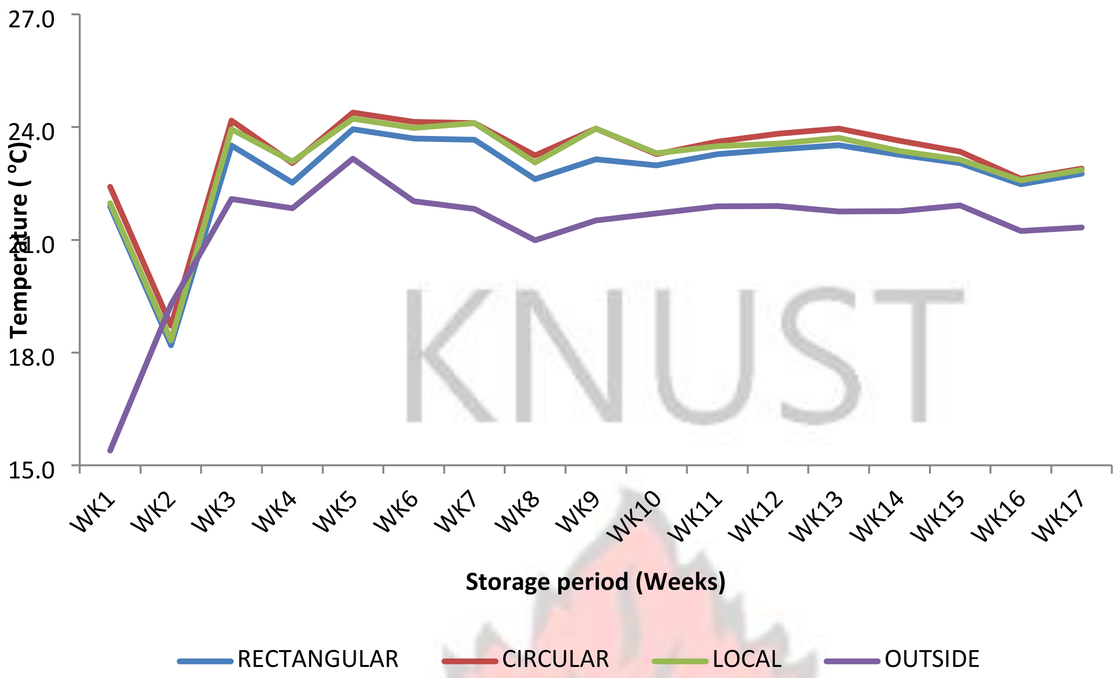

Figure 4.1 Average minimum temperatures recorded over storage period

4.1.2 Average maximum temperatures

Tinytag data logger recorded average maximum temperatures for the three storage structures and the ambient environment as illustrated in figure 4.2. The internal maximum temperature of the three storage structures indicated that the existing local storage structure recorded the highest average maximum temperatures of 39.6 °C followed by the rectangular storage and the circular storage structures with average

maximum temperatures of 38.4 °C and 35.9 °C respectively . This could be attributed to the type of roofing system used which was a case of the metallic roofing sheet. As a good conductor of heat, the metallic roofing sheet absorbs much heat during the day and therefore increases the internal temperature of the structure. The ambient temperatures recorded as high as 46.3 °C in the second week of data collection.

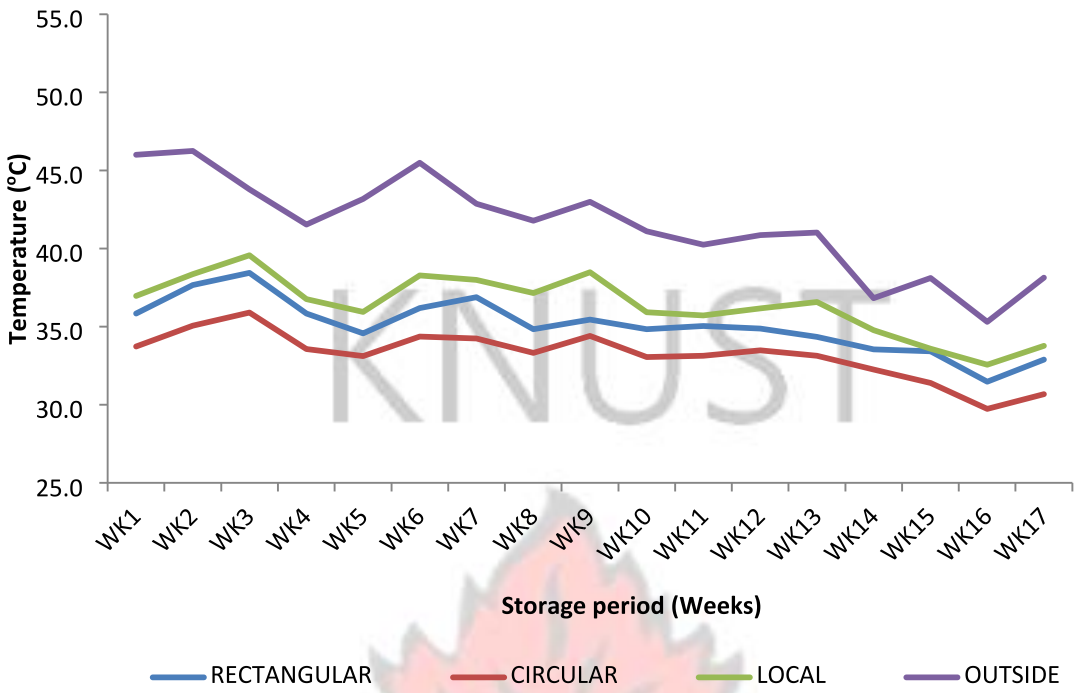

Figure 4.2 Average maximum temperatures against storage period

4.2 Relative humidity

The internal relative humidity of the three structures was recorded with the aid of the Tinytag data logger. Similarly as in the case of the temperatures, the minimum and maximum average relative humidity readings were tabulated.

4.2.1 Average minimum relative humidity

Tinytag weekly average readings revealed that the internal minimum relative humidity of the existing local structure recorded the lowest of 16.7% compared with the rectangular storage structure and the circular storage structure of 17.0% and 18.5% respectively as shown in figure 4.3. This could be explained since the removal of moisture in the air by the heated environment in the existing local storage structure could result in the lowering of the moisture content of the structure resulting in the low relative humidity recordings.

The relative humidity of the ambient environment recorded was the lowest (11.0%) in 15th week during the storage period.

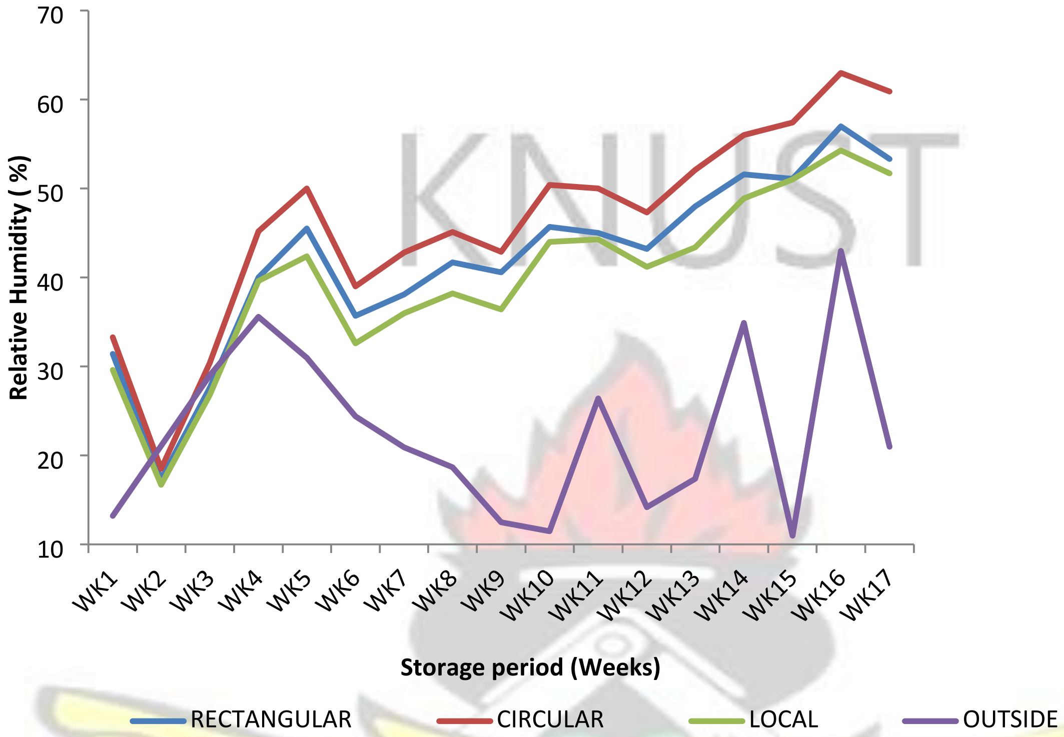

Figure 4.3 Average minimum relative humidity against storage period

4.2.2 Average maximum relative humidity

Illustration of average maximum relative humidity is found in figure 4.4 where the existing local structure recorded the highest weekly average maximum relative humidity readings of 90% compared with the rectangular storage structure and the circular storage structure of 89.9% and 89.2% respectively. The higher relative humidity recording within the existing local storage structure may be that, condensation of the heated air increases the moisture content in the atmosphere and consequently increase the relative humidity. As the moisture of the environment increases, the relative humidity of the environment increases. The ambient environment recorded a relative humidity of 99.9% in the 12th week of the storage period.

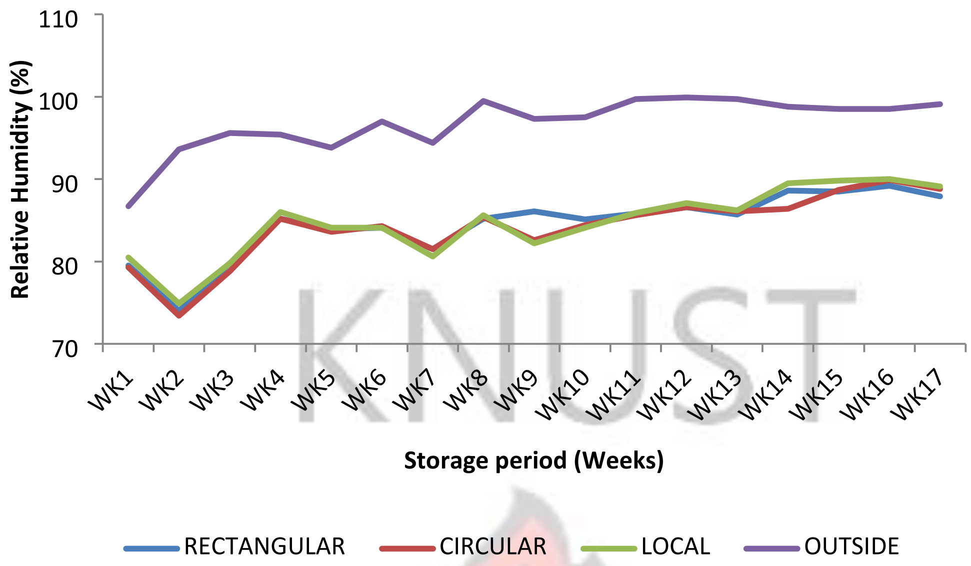

Figure 4.4 Average maximum relative humidity against storage period

4.3 Weight loss

4.3.1 Interaction of Structure/Variety on weight loss

Significant ($P > 0.05$) effect of structure/variety was recorded among the newly constructed storage structures on weight loss as illustrated in Figure 4.5. However, the newly constructed structures (rectangular storage and circular storage structures), recorded lower weight loss than the existing local storage structure except for Denteh variety in which the local structure recorded lower weight loss than the rectangular. The circular and local storage structures both recorded a weight loss of 4.1 kg whilst the rectangular storage structure of 5.2 kg for Denteh. The circular storage structure recorded the least weight loss of 10.1 kg whilst the rectangular and local storage structures recorded 10.5 kg and 11.1 kg of weight loss respectively for Pona. High temperature recordings in the existing local structure resulted in the high weight loss due to rot for

Pona and the increased rate of sprouting resulted in the weight loss in the case of Denteh.

According to Ofor *et al.*, (2010), excessively high temperatures may induce black heart, a disorder caused by the asphyxiation of the central cells; and it is thought to occur in yams, where it has been shown that the internal temperature of tubers exposed to the sun may reach 45-50^{0}C (Coursey, 1967). The respiration rate of yam tubers during storage has been observed to decrease with decreasing temperature over the range 30 to 50^{0}C (Coursey *et al.*, 1966).

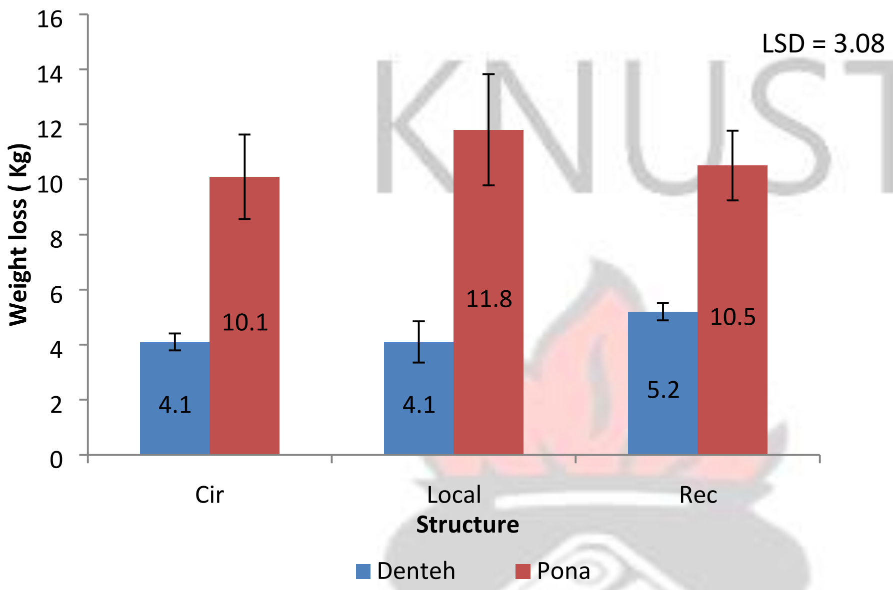

Figure 4.5 Interaction of structure/variety on weight loss

4.3.2 Interaction of varieties on weight loss

Significant effect ($P < 0.05$) on weight loss was observed in the varieties (Denteh and Pona) as shown in Table 4.1. Denteh recorded the least weight loss of 4.5kg whilst Pona recorded a mean weight loss of 10.8kg. During the storage period, Pona recorded a high weight loss due to high rot. The recorded weight loss observed on Denteh was due to sprouting of the yams. The sprouting effect was prominent in the Denteh variety and this resulted in physical shrinkage in the size of the tubers. Sprouting within the Pona variety was not prominent and did not contribute significantly to the weight loss and the tubers did not show much shrinkage in terms of physical appearance.

Table 4.1: Interaction of varieties on weight loss

Variety	Mean weight loss (kg)

	1 Month after storage	2 Month	Month3	Month4	Total weight loss
Denteh	0.6	2.2	0.5	1.2	4.5
Pona	1.1	4.1	1.7	3.9	10.8
LSD	0.4	1.08	0.93	0.93	3.08

4.3.3 Interaction of storage structures on weight loss

There was no significant (P > 0.05) structure interaction among the treatment structures on weight loss as indicated in Table 4.2. The circular storage structure recorded the lowest mean weight loss of 7.1kg compared to the mean weight loss of 7.9kg recorded for both the rectangular storage structure and existing local storage structure. According to Mijinyawa and Alaba (2013), weight loss in stored yam tubers is attributed to three factors. These are moisture loss through transpiration, respiration and sprouting which exhaust the food stored in the yam. Among the three factors, moisture loss is reported to contribute the highest percentage on weight loss even though such loss may not be in terms of the edible portion of the tuber.

During the storage period, it was observed that weight loss in all storage structures increased from the first month to the second and also from the third month to the fourth month as indicated in Table 4.2. This is the case since rot/deterioration of the Pona tubers increased in the second and fourth month of storage. Also sprouting increased in the second and fourth month during the storage period on Denteh resulting in the weight loss of the tubers. Temperatures within the storage structures increase marginally in the second and fourth month averagely to about 37^{o}C from temperatures of 33 ^{o}C thereby contributing to this observation of increased sprouting in the second and fourth month.

Table 4.2: Interaction of storage structures on weight loss

Structure	Mean weight loss (kg)				
	1 Month after storage	Month 2	Month 3	Month 4	Total weight. Loss
Circular	0.8	3	1	2.3	7.1
Local	1.1	3.4	1.1	2.4	7.9
Rectangular	0.7	3.2	1.1	2.9	7.9
LSD	0.49	1.32	1.13	1.14	2.18

As shown in Table 4.2, the newly constructed storage structures has the least mean weight loss of 0.8 and 0.7 compared to 1.1 mean weight loss observed for local storage structure even though this was significant. This could be attributed to mainly the high humidity recordings for the local storage structure increasing the respiration rate and sprouting rate within that structure. This contributed to the loss in weight within the first month and similar observation were made in subsequent months.

4.4 Sprouting

4.4.1 Interactions of structure/varieties on sprouting

Structure and variety interaction on sprouting is presented in Figure 4.6. There was no significant ($P > 0.05$) structure/variety interaction among the treatment structures on the frequency of sprouting. However, the treatment structures (rectangular storage and circular storage structures) recorded the lowest total sprouting frequency than the control (existing local storage structure). The rectangular and circular storage structures recorded total frequency of sprouting of 4.5 and 4.6 respectively against the existing local storage structure which recorded total frequency of sprouting of 4.9. High values on sprouting were recorded for both varieties of tubers in the existing local storage structure compared to both rectangular and circular storage structures. With the Denteh, mean frequency of sprouting of 4.8, 5.0 and 5.2 were recorded for the rectangular, circular and existing local storage structure respectively. The circular, rectangular and existing local storage structure recorded 4.2, 4.3 and 4.7 mean frequency of sprouting respectively for Pona.

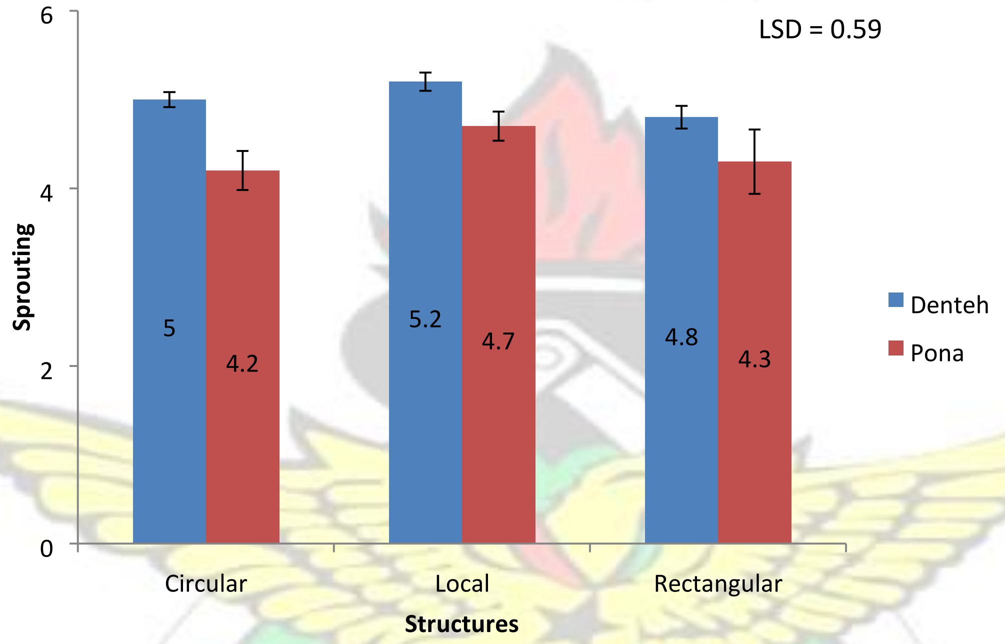

Figure 4.6 interactions of structure/varieties on sprouting

From the study, it was observed that sprouting index for circular, rectangular and the existing local storage structures were 45.2%, 46.5% and 59.2% for Pona respectively as against 53.1%, 48.7% and 57.5% for Denteh respectively. According to Ofor *et al.*, (2010), tubers in storage structures could have 100% sprouting index after four months. According to Booth (1974), an increase of temperature to a particular maximum results in an increase in sprouting

4.4.2 Structure interaction on sprouting

Structure interaction on sprouting is illustrated in Table 4.3. Sprouting was observed to increase from the first month to the second month and also from the third month to the fourth month. This is so because tubers that did not sprout in the first and third month, added to the total number of sprouts at the end of the second and fourth month respectively. That is, cumulative sprouting resulted in the higher frequency of the sprouting in the second and fourth months.

Table 4.3: Structure interaction on sprouting

Structure	Mean frequency of sprouting				
	1 Month after storage	Month 2	Month 3	Month 4	Total frequency of sprouting
Circular	1.7	2.6	2	2.6	4.6
Local	1.7	3	2	2.8	4.9
Rectangular	1.9	2	2	2.8	4.5
LSD	0.41	0.39	0.37	0.51	0.41

The frequency of sprouting within the newly constructed rectangular storage structure increased marginally from 1.9 to 2.2 compared to that of the local structure from 1.7 to 3. This observation can be explained with reference to the high temperatures and relative humidity recordings within the local storage structure which had recorded average temperature readings of about 35 ^{o}C with relative humidity of 87%. This observation explains the similar results for the other months.

4.4.3 Variety interactions on sprouting

Significant effect (P < 0.05) on frequency of sprouting was observed on the varieties studied as illustrated in figure 4.7. The Pona variety recorded the lowest mean frequency of sprouting of 4.4 compared to that of Denteh variety which recoded 5.0. High temperatures and relative humidity recorded in these storage structures resulted in the high sprouting.

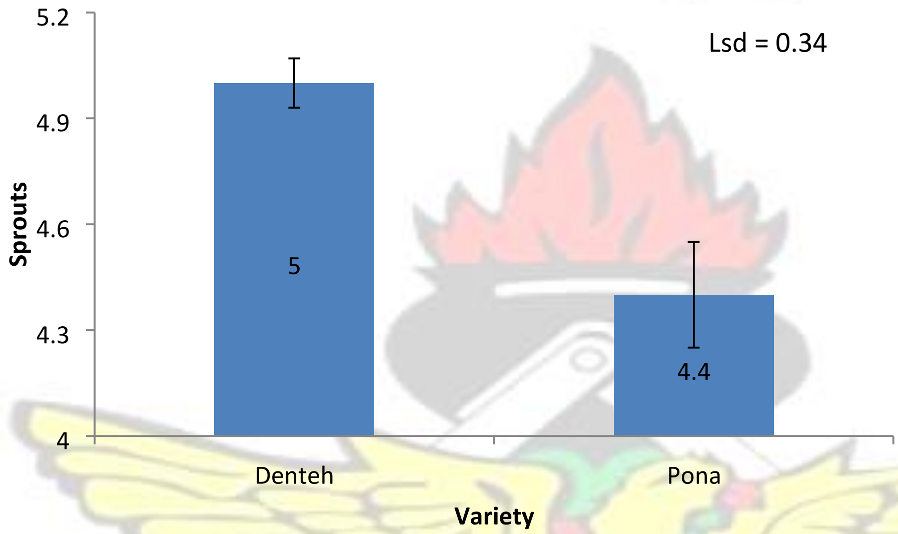

Figure 4.7 Variety interactions on sprouting

4.5 Rot

4.5.1 Structure/variety interactions on rot

Structure/variety interaction on rot/deterioration presented in figure 4.8 indicates significant (P < 0.05) structure variety interaction among the storage structures. During the storage period, it was observed that, there was no tuber rot in the circular structure on the Denteh variety. However, the Denteh variety recorded mean rot of 0.4 and 0.7 for the rectangular and existing local structure respectively. The treatment structures (rectangular and circular storage structures) recorded mean rot of 2.1 and 2.4 respectively for the Pona yam variety. The control treatment structure (existing local storage structure) recorded the highest tuber rot of 2.6 compared to the treatment storage structures (rectangular and circular storage structures). This increased tuber rot in the existing local storage structure compared to the newly constructed storage structures can be attributed to the high temperatures experienced in the local structure. According to Dramani (2013), pathogens (microbes) such as fungi, bacteria, and nematodes cause postharvest losses of yam tubers through rot. High temperatures increase the respiration rate of the produce thereby increasing the deterioration rate of the produce. Pona contains a lot of moisture which increases the respiration rate during high temperatures resulting in the high rot of that variety. According to Dramani (2013) cited in Aidoo (2007) and Lebo (2009), tuber rot can be classified into three namely dry, watery and soft rot. This high rot recorded for Pona therefore implies that, longer storage of Pona will result in loss of the produce which reduces its market value.

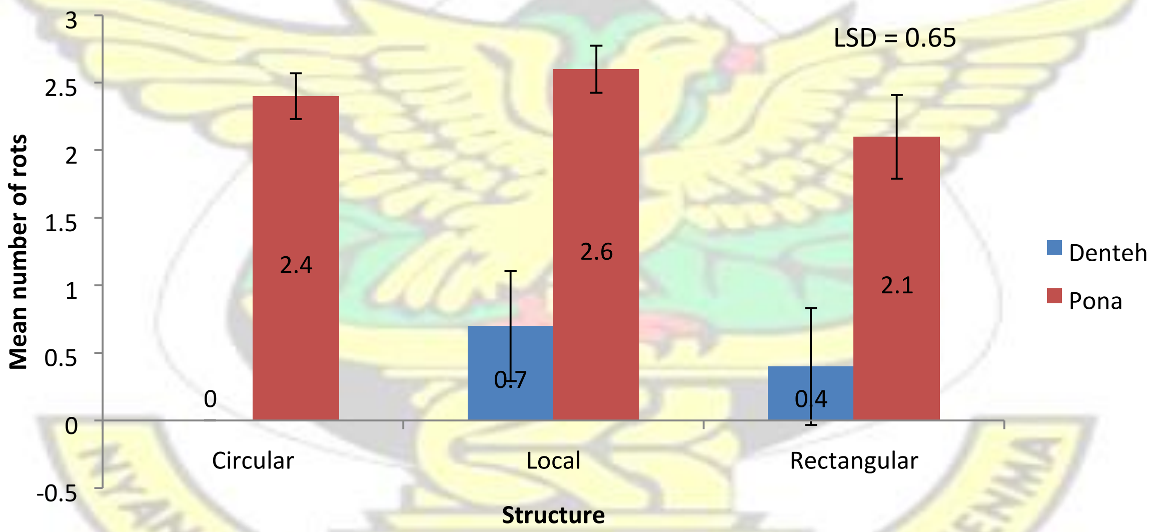

Figure 4.8 Structure/variety interactions on rot

4.5.2 Structures interaction on rot

There was significant ($P < 0.05$) structures interaction during storage period in the fourth month for tuber rot as shown in Table 4.4. However there was no significant ($p > 0.05$) structure interaction during the first three months for tuber rot. Aeration and conducive humidity conditions within the storage structures made tubers to exhibit long storage without significant rot/deterioration rate. The rate of respiration once reduced, reduces the rate of metabolic activities which subsequently affects the rate of rottening or deterioration by pathogenic fungi according to Dramani (2013).

Table 4.4: Structure interaction on rot

Structure	Mean number of rot				
	1 Month after storage	Month 2	Month 3	Month 4	Total rots
Circular	0	0.3	0.6	1.0	1.2
Local	0	0.6	0.7	1.3	1.7
Rectangular	0.1	0.5	0.6	0.8	1.2
Lsd	0.22	0.49	0.46	0.42	0.46

Within the first month of storage, there wasn't significant loss of tubers due to rot for all structures as virtually no rot was recorded. However, the existing local storage structure increasely recorded high tuber rot from the second through to the fourth month as shown in Table 4.4. The circular and rectangular storage structures recorded average less mean number of rots compared to the existing structure. This could be attributed to the metallic roofing system used resulting in the internal temperature of the structure going as high as 38^{o}C.

4.5.3 Variety interaction on rot

During the study period, it was observed that significant ($p<0.05$) effect of variety on rot was recorded throughout the entire period as shown in Table 4.5. Denteh recorded the lowest mean total rot of 0.4 against Pona which recorded a mean total rot of 2.4 as shown in table 4.5. Pona which is susceptible to deterioration upon the introduction to least unfavourable conditions tends not to last long in storage. However, temperature and relative humidity within the storage structures being conducive could allow produce to be stored for the storage period. Even though Pona variety started deteriorating from before month one of storage, this wasn't significant within the structures as indicated in Table 4.5 and therefore makes the treatment structures conductive for storage even for Pona.

Table 4.5: Variety interaction on rot

Variety	Mean number of rots				
	1 Month after storage	Month 2	Month 3	Month 4	Total tuber rots
Denteh	0	0	0.1	0.3	0.4
Pona	0.1	0.9	1.1	1.7	2.4
Lsd	0.18	0.4	0.37	0.35	0.38

Denteh did not experience any rot for the first two months of storage but this wasn't the case of Pona which recorded mean rot of 0.1 and 0.9 for the first and second months respectively. As the temperatures increase in the structures within the storage structures, metabolic activities increases thereby increasing the respiration within the Pona variety. The Pona experience much rot than the Denteh possible because of the higher sugar content of the produce. This prevents the produce from being stored for long compared to the Denteh.

According to Enyiukwu *et al.*, (2014) cited in Nahunnaro (2008), rots are exacerbated by high ambient temperatures and relative humidity. Pona deteriorates or rots easily when exposed to high temperatures and relative humidity which explains the high rot of Pona in the storage structures.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

During the period of the study, it was observed that the fairly average low temperature recording of 24.4^{o}C coupled with relative humidity recordings of 89.2% for the newly constructed storage structures were significant contributory factors to better performance of the yams with regard to the rot especially. This was significant to the extent that there was no rot in the circular storage structure with Denteh variety implying that conditions in the circular storage structure were conducive for storing Denteh.

Similarly the high temperature recording of 39.6 ^{o}C could be the reason for the high rot in the local storage structure since these high temperatures results in an increased respiration causing it to deteriorate with time.

High relative humidity recording of 90% coupled with the high temperatures contributed to the high sprouting recorded in the existing local storage structure compared to the newly constructed storage structures.

The data from the study showed that, the rectangular storage structure had average minimum and maximum relative humidity of 17.3% and 89.2% respectively. Average minimum and maximum temperatures of 18.2 ^{o}C and 38.4 ^{o}C respectively were also recorded. In the circular storage structure, average minimum and maximum relative humidity of 18.5% and 89.9% respectively were also recorded over the storage period with average minimum and maximum temperatures of 18.7 ^{o}C and 35.9 ^{o}C respectively. The average ambient relative humidity recorded minimum and maximum values of 11% and 99.5% respectively with temperatures between 15.4 ^{o}C and 46.7 ^{o}C.

The circular storage structure recorded 32% and 55.5% weight loss for Denteh and Pona respectively with the rectangular storage structure recording 40.4% and 54.9% for Denteh and Pona respectively against the existing local storage structure with 35.1% and 58.1% for Denteh and Pona respectively.

The circular storage structure recorded 45.2% and 53.1% cumulative sprouting index for Pona and Denteh respectively with the rectangular storage structure recording 46.5% and 48.7% for Pona and Denteh respectively against the existing local storage structure with 59.2% and 57.2% for Pona and Denteh respectively.

The tubers were regularly inspected for physical rot and it was observed at the end of the study that no tuber rot was observed for Denteh in the circular storage structure 50% Pona got rotten rot. However, the rectangular storage structure recorded 37.5% and 6.3% for Pona and Denteh respectively with the existing local storage structure recording 56.3% and 8.3% for Pona and Denteh respectively.

The study revealed that there was no significant difference in terms of most of the parameters monitored except rot between the treatment structures (circular and rectangular storage structures) and the control (existing storage structure) structure. However the newly constructed structures performed creditably well in the storage of Pona and Denteh in Fiaso in the Techiman Municipal of the Brong Ahafo region of Ghana.

5.2 RECOMMENDATIONS

Further research should consider loading the storage structures to maximum capacity to determine the capacity and holding strength of these structures.

Future research should involve more than two varieties of yam for study to assess the performance of the storage structures as most yam farmers produce more than two varieties in a growing season.

Also modification of the structures by the inclusion of more ventilation vents both at the top and bottom of the structure should be considered for effective ventilation as this result in further improvement of storage conditions and consequently the storage life of the produce.

The siting of storage structures at the farms should be considered since most farmers do on-farm storage. Very few farmers transport their produce to the homes and therefore construction at the farms should be considered.

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APPENDICE

Appendix 1: Field data

WEIGHT LOSSES

RECTANGULAR STORAGE STRUCTURE

YAM VARIETY	SAMPLE	INITIAL WEIGHT (Kg)	1ST MONTH (Kg)	2ND MONTH (Kg)	3RD MONTH (Kg)	4TH MONTH (Kg)	ACC WT LOSS (Kg)	FINAL WT (Kg)
PONA	R_1G_1	16.5	14.5	10.5	9.0	6.5	10	6.5
	R_2G_2	18.0	15.0	12.5	11.0	8.5	9.5	8.5
	R_3G_3	20.0	19.5	17.0	16.0	13.0	7.0	13.0
	R_4G_4	18.5	18.0	17.0	13.0	10.5	8.0	10.5
DENTEH	R_1G_1	11.5	10.5	8.5	7.0	5.5	5.5	5.5
	R_2G_2	15.5	13.5	10.5	8.5	6.5	9.0	6.5
	R_3G_3	13.0	12.0	10.5	10.0	8.5	4.5	8.5
	R_4G_4	13.5	12.5	10.0	9.5	8.0	5.5	8.0

CIRCULAR STORAGE STRUCTURE

YAM VARIETY	SAMPLE	INITIAL WEIGHT (Kg)	1ST MONTH (Kg)	2ND MONTH (Kg)	3RD MONTH (Kg)	4TH MONTH (Kg)	ACC WT LOSS (Kg)	FINAL WT (Kg)
PONA	R_1G_1	19.0	18.0	15.0	14.5	9.5	9.5	9.5
	R_2G_2	17.5	16.0	10.0	9.5	7.5	10.0	7.5
	R_3G_3	18.0	16.5	15.0	13.5	11.5	6.5	11.5
	R_4G_4	14.5	12.5	11.0	10.0	8.5	6.0	8.5
DENTEH	R_1G_1	14.0	12.5	10.0	9.0	7.5	6.5	7.5
	R_2G_2	15.5	13.5	11.0	10.5	8.0	7.5	8.0
	R_3G_3	14.0	12.5	10.0	9.0	7.5	6.5	7.5
	R_4G_4	12.5	12.0	9.0	8.5	7.0	5.5	7.0

EXISTING LOCAL STORAGE STRUCTURE

YAM VARIETY	SAMPLE	INITIAL WEIGHT (Kg)	1ST MONTH (Kg)	2ND MONTH (Kg)	3RD MONTH (Kg)	4TH MONTH (Kg)	ACC WT LOSS (Kg)	FINAL WT (Kg)
PONA	R_1G_1	20.0	17.5	13.0	11.5	6.5	13.5	6.5
	R_2G_2	19.5	16.5	14.5	10.0	5.5	14.0	5.5
	R_3G_3	18.0	15.5	13.5	9.5	6.5	11.5	6.5
	R_4G_4	19.5	15.5	12.0	9.0	6.5	13.0	6.5
DENTEH	R_1G_1	17.5	15.5	12.5	8.5	6.0	11.5	6.0
	R_2G_2	18.5	15.0	11.5	9.0	6.0	12.5	6.0
	R_3G_3	17.5	14.0	11.5	9.0	6.5	11.0	6.0
	R_4G_4	16.0	14.5	12.0	10.0	5.0	11.0	5.0

SPROUTS

RECTANGULAR STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL SPROUTS
PONA	R_1G_1	1	6	2	2	11
	R_2G_2	5	3	2	7	17
	R_3G_3	4	5	5	11	25
	R_4G_4	1	5	7	8	21
DENTEH	R_1G_1	5	1	5	10	21
	R_2G_2	6	5	3	10	24
	R_3G_3	4	3	5	9	21
	R_4G_4	7	7	3	9	26

CIRCULAR STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL SPROUTS
PONA	R_1G_1	3	6	5	8	22
	R_2G_2	2	7	4	1	14
	R_3G_3	1	5	3	6	15
	R_4G_4	3	6	5	5	19
DENTEH	R_1G_1	4	8	3	10	25
	R_2G_2	4	9	4	8	25
	R_3G_3	5	7	4	12	28
	R_4G_4	3	7	5	9	24

EXISTING LOCAL STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL SPROUTS
PONA	R_1G_1	2	8	3	7	20
	R_2G_2	3	6	4	6	19
	R_3G_3	4	8	6	8	26
	R_4G_4	3	10	4	5	22
DENTEH	R_1G_1	4	8	3	10	25
	R_2G_2	3	10	5	9	27
	R_3G_3	2	11	5	12	30
	R_4G_4	3	11	3	9	26

ROT

RECTANGULAR STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL ROTS
PONA	R_1G_1	1	2	0	5	8
	R_2G_2	0	2	2	1	5
	R_3G_3	0	0	1	1	2
	R_4G_4	0	1	1	1	3
DENTEH	R_1G_1	0	0	2	1	3
	R_2G_2	0	0	0	0	0
	R_3G_3	0	0	0	0	0
	R_4G_4	0	0	0	0	0

CIRCULAR STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL ROTS
PONA	R_1G_1	0	0	1	5	6
	R_2G_2	0	3	2	3	8
	R_3G_3	0	1	1	2	4
	R_4G_4	0	0	1	5	6
DENTEH	R_1G_1	0	0	0	0	0
	R_2G_2	0	0	0	0	0
	R_3G_3	0	0	0	0	0
	R_4G_4	0	0	0	0	0

EXISTING LOCAL STRUCTURE

YAM VARIETY	SAMPLE	1ST MONTH	2ND MONTH	3RD MONTH	4TH MONTH	TOTAL ROTS
PONA	R_1G_1	0	2	2	4	8
	R_2G_2	0	1	2	5	9
	R_3G_3	0	1	2	2	5
	R_4G_4	0	2	1	3	6
DENTEH	R_1G_1	0	0	0	2	2
	R_2G_2	0	0	0	2	2
	R_3G_3	0	0	0	0	0
	R_4G_4	0	0	0	0	0

Appendix II: Anova tables

Analysis of variance

Variate: %1st_MTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.8646	0.2882	1.35	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.5833	0.2917	1.37	0.285
VARIETY	1	1.2604	1.2604	5.91	0.028
STRUCTURE.VARIETY	2	1.3333	0.6667	3.13	0.073
Residual	15	3.1979	0.2132		
Total	23	7.2396			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 4 0.9 s.e. 0.4

Tables of means

Variate: %1st_MTH

Grand mean 0.9

STRUCTURE	Cir	Local	Rec
	0.8	1.1	0.7

VARIETY	Denteh	Pona
	0.6	1.1

STRUCTUREVARIETY	Denteh	Pona
Cir	0.8	0.9
Local	0.5	1.6
Rec	0.6	0.8

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

s.e.d. 0.23 0.19 0.33

Least significant differences of means (5% level)

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

l.s.d. 0.49 0.40 0.70 Stratum standard errors and coefficients of variation

Variate: %1st_MTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.22	25.7
SAMPLE.*Units*	15	0.46	54.1

Analysis of variance

Variate: %2nd_MTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	11.865	3.955	2.59	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.562	0.281	0.18	0.834
VARIETY	1	21.094	21.094	13.79	0.002
STRUCTURE.VARIETY	2	13.938	6.969	4.56	0.028
Residual	15	22.948	1.530		
Total	23	70.406			

Message: the following units have large residuals.

SAMPLE R3G3 *units* 5	-2.0	s.e.	1.0
SAMPLE R4G4 *units* 1	-2.2	s.e.	1.0

Tables of means

Variate: %2nd_MTH

Grand mean 3.2

STRUCTURE	Cir	Local	Rec
	3.0	3.4	3.2

VARIETY	Denteh	Pona
	2.2	4.1

STRUCTUREVARIETY	Denteh	Pona
Cir	2.8	3.2
Local	1.4	5.4
Rec	2.6	3.8

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE
VARIETY rep. 8 12 4 d.f. 15 15 15			
s.e.d.	0.62	0.50	0.87

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE
VARIETY rep. 8 12 4 d.f. 15 15 15			
l.s.d.	1.32	1.08	1.86

Stratum standard errors and coefficients of variation

Variate: %2nd_MTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.81	25.5
SAMPLE.*Units*	15	1.24	38.8

Analysis of variance

Variate: %3rd_MTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	1.917	0.639	0.57	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.083	0.042	0.04	0.964
VARIETY	1	9.375	9.375	8.29	0.011
STRUCTURE.VARIETY	2	1.000	0.500	0.44	0.651
Residual	15	16.958	1.131		
Total	23	29.333			

Message: the following units have large residuals.

SAMPLE R2G2 *units* 3	2.5	s.e.	0.8
SAMPLE R4G4 *units* 1	1.9	s.e.	0.8

Tables of means

Variate: %3rd_MTH

Grand mean 1.1

STRUCTURE	Cir	Local	Rec
	1.0	1.1	1.1

VARIETY	Denteh	Pona
	0.5	1.7

STRUCTUREVARIETY	Denteh	Pona
Cir	0.1	1.9
Local	0.8	1.5
Rec	0.5	1.8

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE
VARIETY rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.53	0.43	0.75

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE
VARIETY rep.	8	12	4
d.f.	15	15	15
l.s.d.	1.13	0.93	1.60

Stratum standard errors and coefficients of variation

Variate: %3rd_MTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.33	30.1
SAMPLE.*Units*	15	1.06	98.1

Analysis of variance

Variate: %4th_MTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	10.531	3.510	3.07	
SAMPLE.*Units* stratum					
STRUCTURE	2	1.521	0.760	0.66	0.529
VARIETY	1	44.010	44.010	38.48	<.001
STRUCTURE.VARIETY	2	3.521	1.760	1.54	0.247

Residual	15	17.156	1.144
Total	23	76.740	

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 2.4 s.e. 0.8

Tables of means

Variate: %4th_MTH

Grand mean 2.5

STRUCTURE	Cir	Local	Rec
	2.3	2.4	2.9

VARIETY	Denteh	Pona
	1.2	3.9

STRUCTUREVARIETY	Denteh	Pona
Cir	0.5	4.1
Local	1.5	3.2
Rec	1.5	4.2

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.53	0.44	0.76

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	1.14	0.93	1.61

Stratum standard errors and coefficients of variation

Variate: %4th_MTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.76	30.3
SAMPLE.*Units*	15	1.07	42.4

Analysis of variance

Variate: ACC_W_LOSS

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

SAMPLE stratum 3 43.031 14.344 3.44

SAMPLE.*Units* stratum

STRUCTURE 2 3.271 1.635 0.39 0.682

VARIETY 1 237.510 237.510 56.97 <.001

STRUCTURE.VARIETY 2 5.896 2.948 0.71 0.509 Residual 15 62.531 4.169

Total 23 352.240

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 4.0 s.e. 1.6

SAMPLE R2G2 *units* 3 3.4 s.e. 1.6

Tables of means

Variate: ACC_W_LOSS

Grand mean 7.6

STRUCTURE	Cir	Local	Rec
	7.1	7.9	7.9

VARIETY	Denteh	Pona
	4.5	10.8

STRUCTUREVARIETY	Denteh	Pona
Cir	4.1	10.1
Local	4.1	11.8
Rec	5.2	10.5

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

s.e.d. 1.02 0.83 1.44

Least significant differences of means (5% level)

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

l.s.d. 2.18 1.78 3.08

Stratum standard errors and coefficients of variation

Variate: ACC_W_LOSS

Stratum	d.f.	s.e.	cv%
SAMPLE	3	1.55	20.2
SAMPLE.*Units*	15	2.04	26.7

Analysis of variance

Variate: %1st_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.1385	0.0462	0.31	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.2604	0.1302	0.89	0.433
VARIETY	1	1.1202	1.1202	7.62	0.015
STRUCTURE.VARIETY	2	0.6233	0.3116	2.12	0.154
Residual	15	2.2040	0.1469		
Total	23	4.3464			

Tables of means

Variate: %1st_MONTH

Grand mean 1.8

STRUCTURE	Circular	Local	Rectangular
	1.7	1.7	1.9

VARIETY	Denteh	Pona
	2.0	1.6

STRUCTUREVARIETY	Denteh	Pona
Circular	2.0	1.5
Local	1.7	1.7
Rectangular	2.3	1.6

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

s.e.d. 0.19 0.16 0.27

Least significant differences of means (5% level)

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

l.s.d. 0.41 0.33 0.58 Stratum standard errors and coefficients of variation

Variate: %1st_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.09	4.9
SAMPLE.*Units*	15	0.38	21.3

Analysis of variance

Variate: %2nd_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.3781	0.1260	0.95	
SAMPLE.*Units* stratum					

STRUCTURE	2	3.6899	1.8450	13.89	<.001
VARIETY	1	0.1141	0.1141	0.86	0.369
STRUCTURE.VARIETY	2	0.4748	0.2374	1.79	0.201
Residual	15	1.9919	0.1328		
Total	23	6.6489			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 2 -0.8 s.e. 0.3

Tables of means

Variate: %2nd_MONTH

Grand mean 2.5

STRUCTURE	Circular	Local	Rectangular
	2.6	3.0	2.0

VARIETY	Denteh	Pona
	2.6	2.5

STRUCTUREVARIETY	Denteh	Pona
Circular	2.8	2.4
Local	3.2	2.8
Rectangular	1.9	2.2

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

s.e.d. 0.18 0.15 0.26

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.39	0.32	0.55

Stratum standard errors and coefficients of variation

Variate: %2nd_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.14	5.7
SAMPLE.*Units*	15	0.36	14.3

Analysis of variance
Variate: %3rd_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.3921	0.1307	1.08	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.0209	0.0104	0.09	0.918
VARIETY	1	0.0027	0.0027	0.02	0.883
STRUCTURE.VARIETY	2	0.0182	0.0091	0.07	0.928
Residual	15	1.8197	0.1213		
Total	23	2.2536			

Message: the following units have large residuals.
SAMPLE R4G4 *units* 1 0.6 s.e. 0.3

Tables of means
Variate: %3rd_MONTH
Grand mean 2.0

STRUCTURE	Circular	Local	Rectangular
	2.0	2.0	2.0

VARIETY	Denteh	Pona
	2.0	2.0

STRUCTURE	VARIETY Denteh	Pona
Circular	2.0	2.1
Local	2.0	2.0
Rectangular	2.0	1.9

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.17	0.14	0.25

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4

d.f.	15	15	15
l.s.d.	0.37	0.30	0.52

Stratum standard errors and coefficients of variation
Variate: %3rd_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.15	7.4
SAMPLE.*Units*	15	0.35	17.4

Analysis of variance
Variate: %4th_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	1.0210	0.3403	1.50	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.2419	0.1209	0.53	0.598
VARIETY	1	3.0296	3.0296	13.34	0.002
STRUCTURE.VARIETY	2	0.2338	0.1169	0.51	0.608
Residual	15	3.4058	0.2271		
Total	23	7.9320			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 -1.1 s.e. 0.4
SAMPLE R2G2 *units* 3 -0.9 s.e. 0.4

Tables of means
Variate: %4th_MONTH
Grand mean 2.8

STRUCTURE	Circular	Local	Rectangular
	2.6	2.8	2.8

VARIETY	Denteh	Pona
	3.1	2.4

STRUCTUREVARIETY	Denteh	Pona
Circular	3.1	2.1
Local	3.2	2.5

Rectangular 3.1 2.6

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.24	0.19	0.34

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.51	0.41	0.72

Stratum standard errors and coefficients of variation

Variate: %4th_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.24	8.6
SAMPLE.*Units*	15	0.48	17.3

Analysis of variance

Variate: TOTAL_SPROUTS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.5967	0.1989	1.32	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.7158	0.3579	2.37	0.128
VARIETY	1	2.5476	2.5476	16.85	<.001
STRUCTURE.VARIETY	2	0.1587	0.0794	0.53	0.602
Residual	15	2.2677	0.1512		
Total	23	6.2864			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 -0.8s.e. 0.3

SAMPLE R1G1 *units* 3 0.7 s.e. 0.3

Tables of means

Variate: TOTAL_SPROUTS

Grand mean 4.7

STRUCTURE	Circular	Local	Rectangular
	4.6	4.9	4.5

VARIETY	Denteh	Pona
	5.0	4.4

STRUCTUREVARIETY Denteh Pona

Circular	5.0	4.2
Local	5.2	4.7
Rectangular	4.8	4.3

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE
VARIETY rep. 8 12 4 d.f. 15 15 15
s.e.d. 0.19 0.16 0.27

Least significant differences of means (5% level)

Table STRUCTURE VARIETY STRUCTURE
VARIETY rep. 8 12 4 d.f. 15 15 15
l.s.d. 0.41 0.34 0.59

Stratum standard errors and coefficients of variation

Variate: TOTAL_SPROUTS

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.18	3.9
SAMPLE.*Units*	15	0.39	8.3

Analysis of variance

Variate: %1st_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.12500	0.04167	1.00	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.08333	0.04167	1.00	0.391
VARIETY	1	0.04167	0.04167	1.00	0.333
STRUCTURE.VARIETY	2	0.08333	0.04167	1.00	0.391
Residual	15	0.62500	0.04167		
Total	23	0.95833			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 0.6 s.e. 0.2

Tables of means

Variate: %1st_MONTH

Grand mean 0.0

STRUCTURE	Circular	Local	Rectangular
	0.0	0.0	0.1

VARIETY	Denteh	Pona
	0.0	0.1

STRUCTUREVARIETY	Denteh	Pona
Circular	0.0	0.0
Local	0.0	0.0
Rectangular	0.0	0.2

Standard errors of differences of means

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

s.e.d. 0.10 0.08 0.14

Least significant differences of means (5% level)

Table STRUCTURE VARIETY STRUCTURE

VARIETY rep. 8 12 4 d.f. 15 15 15

l.s.d. 0.22 0.18 0.31 Stratum standard errors and coefficients of variation

Variate: %1st_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.08	200.0
SAMPLE.*Units*	15	0.20	489.9

Analysis of variance

Variate: %2nd_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.4322	0.1441	0.67	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.2749	0.1374	0.64	0.540
VARIETY	1	5.4045	5.4045	25.26	<.001
STRUCTURE.VARIETY	2	0.2749	0.1374	0.64	0.540
Residual	15	3.2091	0.2139		
Total	23	9.5955			

Message: the following units have large residuals.

SAMPLE R2G2 *units* 3	0.8	s.e.	0.4
SAMPLE R3G3 *units* 1	-0.8	s.e.	0.4

Tables of means

Variate: %2nd_MONTH

Grand mean 0.5

STRUCTURE	Circular	Local	Rectangular
	0.3	0.6	0.5

VARIETY	Denteh	Pona
	0.0	0.9

STRUCTURE	VARIETY	Denteh	Pona
Circular		0.0	0.7
Local		0.0	1.2
Rectangular		0.0	1.0

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.23	0.19	0.33

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.49	0.40	0.70

Stratum standard errors and coefficients of variation

Variate: %2nd_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.15	32.7
SAMPLE.*Units*	15	0.46	97.5

Analysis of variance

Variate: %3rd_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	0.2214	0.0738	0.40	
SAMPLE.*Units* stratum					
STRUCTURE	2	0.0842	0.0421	0.23	0.798
VARIETY	1	5.9747	5.9747	32.43	<.001
STRUCTURE.VARIETY	2	0.8258	0.4129	2.24	0.141
Residual	15	2.7633	0.1842		
Total	23	9.8695			

Message: the following units have large residuals.

SAMPLE R1G1 *units* 1 -0.9 s.e. 0.3

SAMPLE R1G1 *units* 2 1.0 s.e. 0.3

Tables of means

Variate: %3rd_MONTH

Grand mean 0.6

STRUCTURE	Circular	Local	Rectangular
	0.6	0.7	0.6

VARIETY	Denteh	Pona
	0.1	1.1

STRUCTURE VARIETY	Denteh	Pona
Circular	0.0	1.1
Local	0.0	1.4
Rectangular	0.4	0.9

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.21	0.18	0.30

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.46	0.37	0.65

Stratum standard errors and coefficients of variation

Variate: %3rd_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.11	18.0
SAMPLE.*Units*	15	0.43	69.6

Analysis of variance

Variate: %4th_MONTH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	2.3761	0.7920	4.98	
SAMPLE.*Units* stratum					
STRUCTURE	2	1.0179	0.5089	3.20	0.070
VARIETY	1	11.2181	11.2181	70.55	<.001
STRUCTURE.VARIETY	2	0.8722	0.4361	2.74	0.097
Residual	15	2.3851	0.1590		

Total	23	17.8694

Message: the following units have large residuals.

SAMPLE R2G2 *units* 6 0.6 s.e. 0.3

Tables of means

Variate: %4th_MONTH

Grand mean 1.0

STRUCTURE	Circular	Local	Rectangular
	1.0	1.3	0.8

VARIETY	Denteh	Pona
	0.3	1.7

STRUCTURE	VARIETY	Denteh	Pona
Circular		0.0	1.9
Local		0.7	1.8
Rectangular		0.2	1.3

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.20	0.16	0.28

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.42	0.35	0.60

Stratum standard errors and coefficients of variation

Variate: %4th_MONTH

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.36	36.2
SAMPLE.*Units*	15	0.40	39.8

Analysis of variance
Variate: TOTAL_ROT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SAMPLE stratum	3	3.3175	1.1058	5.95	
SAMPLE.*Units* stratum					
STRUCTURE	2	1.0280	0.5140	2.77	0.095
VARIETY	1	23.7838	23.7838	128.02	<.001
STRUCTURE.VARIETY	2	0.6742	0.3371	1.81	0.197
Residual	15	2.7868	0.1858		
Total	23	31.5903			

Message: the following units have large residuals.
SAMPLE R1G1 *units* 2 0.8 s.e. 0.3

Tables of means
Variate: TOTAL_ROT
Grand mean 1.4

STRUCTURE	Circular	Local	Rectangular
	1.2	1.7	1.2

VARIETY	Denteh	Pona
	0.4	2.4

STRUCTURE	VARIETY Denteh	Pona
Circular	0.0	2.4
Local	0.7	2.6
Rectangular	0.4	2.1

Standard errors of differences of means

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
s.e.d.	0.22	0.18	0.30

Least significant differences of means (5% level)

Table	STRUCTURE	VARIETY	STRUCTURE VARIETY
rep.	8	12	4
d.f.	15	15	15
l.s.d.	0.46	0.38	0.65

Stratum standard errors and coefficients of variation

Variate: TOTAL_ROT

Stratum	d.f.	s.e.	cv%
SAMPLE	3	0.43	31.2
SAMPLE.*Units*	15	0.43	31.3

Analysis of variance

Variate: WEEK1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
STRUCTURE	3	36.880	12.293		
Total	3	36.880			

Tables of means

Variate: WEEK1

Grand mean 81.50

STRUCTURE	CIR	LOC	OUTSIDE	REC
	79.30	80.50	86.70	79.50

Standard errors of differences of means

Table	STRUCTURE
rep.	1
d.f.	*
s.e.d.	*

Analysis of variance

Variate: WEEK2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
STRUCTURE	3	286.327	95.442		

Total		3	286.327			

Tables of means

Variate: WEEK2

Grand mean 78.97

STRUCTURE	CIR	LOC	OUTSIDE	REC
	73.40	74.90	93.60	74.00

Standard errors of differences of means

Table STRUCTURE rep. 1 d.f.

*

s.e.d. *

Analysis of variance

Variate: WEEK1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
STRUCTURE	3	256.188	85.396		
Total	3	256.188			

Tables of means

Variate: WEEK1

Grand mean 26.87

STRUCTURE	CIR	LOC	OUTSIDE	REC
	33.30	29.60	13.20	31.40

Standard errors of differences of means

Table	STRUCTURE
rep.	1
d.f.	*
s.e.d.	*

Analysis of variance

Variate: WEEK1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
STRUCTURE	3	87.961	29.320		
Total	3	87.961			

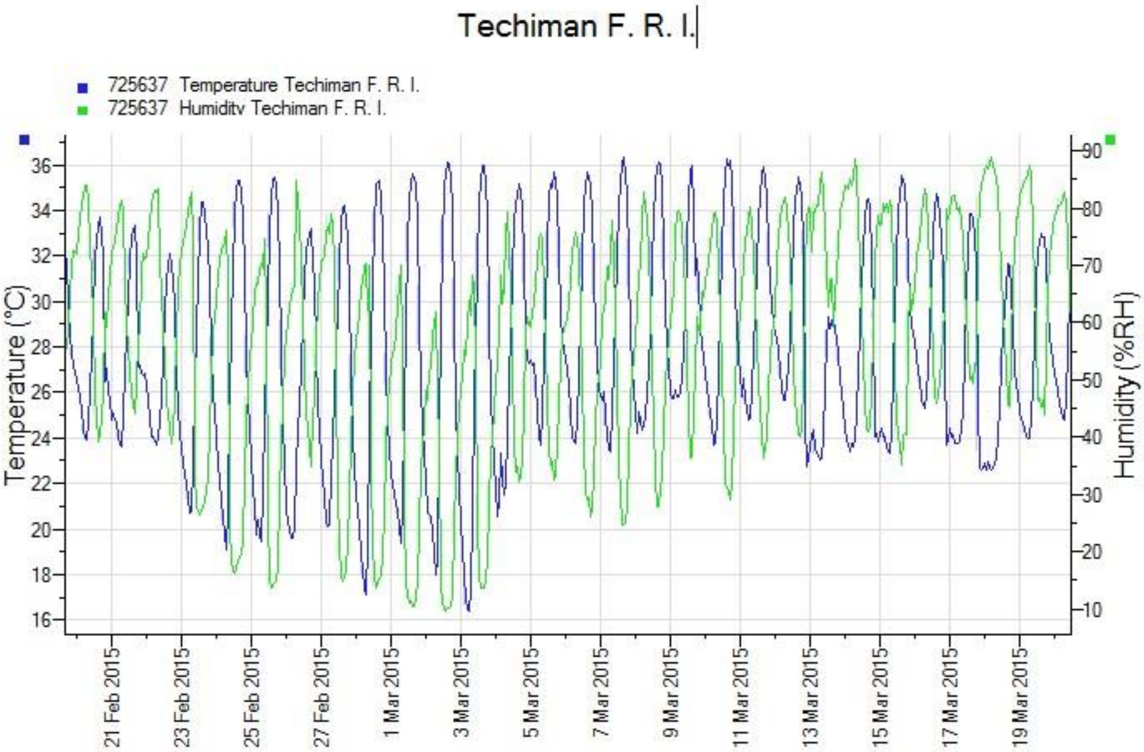
Tables of means
Variate: WEEK1
Grand mean 38.1

STRUCTURE	CIR	LOC	OUTSIDE	REC
	33.7	37.0	46.0	35.9

Standard errors of differences of means

Table	STRUCTURE
rep.	1
d.f.	*
s.e.d.	*

Appendix III: Sample of data from the Tinytag data logger



	Min	Max	Min	Max
19/02/2015	26.6 °C	31.9 °C	55.5 %RH	72.5 %RH
20/02/2015	23.9 °C	33.7 °C	39.1 %RH	83.9 %RH
21/02/2015	23.6 °C	33.3 °C	44.2 %RH	81.3 %RH
22/02/2015	23.5 °C	32.1 °C	38.9 %RH	83.3 %RH
23/02/2015	20.7 °C	34.4 °C	25.9 %RH	82.8 %RH
24/02/2015	19.1 °C	35.3 °C	16.1 %RH	76.2 %RH
25/02/2015	19.5 °C	35.4 °C	13.6 %RH	74.8 %RH
26/02/2015	19.5 °C	33.2 °C	34.8 %RH	84.8 %RH
27/02/2015	20.0 °C	34.2 °C	14.7 %RH	79.0 %RH
28/02/2015	17.1 °C	35.3 °C	13.8 %RH	70.3 %RH