UNIVERSITY OF CAPE COAST

DEVELOPING APPROPRIATE STORAGE TECHNOLOGY FOR SWEET POTATOES (*IPOMOEA BATATAS LAM*) IN THE COASTAL SAVANNAH ZONE OF GHANA

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CHAPTER ONE

INTRODUCTION

Background of research

Sweet potato (*Ipomoea batatas* (L.) Lam) is a native of tropical America and was domesticated at least 5000 years ago. The crop was brought to Spain by Columbus and subsequently introduced to Africa and Asia. Sweet potato is the only economic important plant of the family *Convolvulaceae* (Purseglove, 1968). The edible portion of the crop is known as tuberous root though young leaves and shoots are sometimes eaten as greens. The crop is a herbaceous perennial bearing alternate heart-shape or palmately lobed leaves and a medium sized sympetalous flowers. The edible tuberous root is long and tapered with smooth skin. The root colour ranges between red, purple, brown and white and the root flesh colour ranges from white through yellow, orange and purple (Purseglove, 1991; Woolfe, 1992).

Sweet potato is currently seen as a very important crop and according to Scott *et al.* (2000) sweet potato is likely to increase its importance over the next 20 years. Also, it is now cultivated throughout tropical, subtropical and warm temperate regions where there is sufficient water to support its growth. The crop does well in many farming conditions and have relatively few natural enemies. Sweet potato is grown on a wide variety of soils, but does well on a well drained light and medium textured soil with a pH range of 4.5-7.0 (Ahn, 1993). Mutandwa and Gadzirayi (2007) also observed that the crop does favourably well on a well drained ferratic, brown humic and calcimorphic soil. In tropical zones sweet potato can be grown at altitudes above 2500m. It is mostly cultivated by vine cuttings and it is relatively easy to propagate. The vines grow rapidly and easily shade out weeds, hence little or no weeding is required for excellent establishment (S. Aidoo, personal communication, May, 2008).

CGIAR (2005) stated that sweet potato is grown in more than 100 countries as a valuable source of food, feed and industrial raw material. According to FAO (2004) China is the leading world producer of sweet potato with a production of 10,500,000 tonnes from 49,000 km^2. Also in China sweet potato is ranked fourth as a food crop after rice, wheat and maize and about half of the crop is used to feed livestock (Li *et al.*, 1992).

In Africa sweet potato has recently gained importance because of the numerous potential of alleviating poverty, reducing night blindness, and improving the diet of the rural poor. It is the third most important staple food in Sierra Leone after rice and cassava. In terms of area under cultivation Nigeria is the leading producer in Africa followed by Uganda, (FAO, 2004) and majority comes from Southern and Eastern Africa (Roots, 1994). Improved Sweet potato yields recorded in Africa by IITA is between 21-41 tonnes per hectare in 140 days without fertilizer application while unimproved varieties average only 14 tons per hectare when harvested in 180-240 days after planting (IITA, 1985).

In Ghana sweet potato is grown by peasant and small-holder farmers scattered in Upper East and Central Regions. These two regions in Ghana produce about 93603 metric tonnes (SRID, 2007). Yields of sweet potato recorded in Ghana at the subsistence level are quite low compared with the

IITA varietal studies. Studies conducted to evaluate 19 sweet potato varieties for yield at Ohawu by Missah *et al.* (1991) revealed that an average yield of between 6-16 t/ha was recorded for improved varieties and 3.2-10.8 t/ha for unimproved or local varieties. However there has been an improvement in yield due to the release of improved varieties and good agronomic activities in Ghana.

In most tropical developing countries including Ghana, sweet potato roots have shelf-life of only 1-2 weeks (Rees *et al.,* 2003). Storage of these fresh roots presents the most serious constraint to the production of sweet potato. Fungal and viral diseases, insect pests, mites, nematodes and rodents combine in different ways under varying environmental conditions to cause high deterioration of the roots after harvest. Mariga (2000) indicated that post harvest losses due to pest and diseases account for as much as 60 % of the crop output. However, under controlled conditions the roots can be stored for extended periods where lower temperatures of 13-15 ^{o}C are maintained.

Optimum conditions required for storing sweet potato roots are temperature of 12-15 ^{o}C and relative humidity of 85-90 % (Picha, 1986; Woolfe, 1992) and under such conditions sweet potato roots can be stored for a year. Temperature and relative humidity management are the most important tools that can be used to extend the shelf life of the fresh roots; this is because relative humidity and temperature affect water loss, decay and disease development. However in the tropics, during harvesting bruising and cutting of the fresh roots occur which serve as entry points to diseases and micro organisms. So to minimize these effects, the roots must be cured in order to promote rapid healing of the wounds and increase the toughness of the skin (periderm). Curing is done at a temperature of 27-29.5 ^{o}C and at relative humidity of 85-95 % for 4-5 days before storage and care must be taken to prevent accumulation of carbon dioxide around the sweet potatoes (Onwueme, 1978). Curing improves storage life. Booth (1974) reported that for cured roots there was 17 % loss in weight after 113 days of storage while 42 % weight loss was recorded in the uncured samples.

Cold storage is the best for storing sweet potato roots since one can easily control and maintain the optimum storage conditions needed for prolonged storage of the roots. But this is only economically feasible in the developed countries where there is large scale production to offset the cost of operating refrigeration and there are reliable sources of electricity. However, in Ghana and other tropical developing countries cold storage is not justified because of major limitations beyond the reach of the sweet potato farmer. The famers produce on a smaller scale, and there is high cost of operating cold storage and they are also constrained by administrative and infrastructural problems.

To overcome this problem, farmers make use of storage methods derived from indigenous knowledge systems to improve the storage of the roots. The methods used to store sweet potato roots include delayed harvesting or in-situ storage, soil-based techniques, ash-based techniques, grass-based techniques, and above ground techniques though there are records of high losses associated with most of these techniques (Anonymous, 2006). Osei-Gyamera (2000) revealed that in the Central Region of Ghana 30 % of sweet potato farmers do not store their produce, 15 % store in sacks and boxes, 10 % store in the soil and 45 % store on platforms in rooms. Furthermore it was stated that on the average 50 % of the harvested roots stored well for less than 2 weeks; 25 % for 2-4 weeks; 15 % for 4-6 weeks and 10 % for 6 weeks. The shelf-life of sweet potato varies greatly depending on the variety, cultural practices, pre-storage treatment and the storage environment.

Various studies have been conducted to improve the post harvest handling and storage of sweet potato roots in Cape Coast metropolis. Duku (2005) studied the effect of defoliation and subsequent storage in barn and with this method the harvested roots stored for 5-10 weeks. However, weevil infestation and fungal decay were significant and also sprouting was observed in roots defoliated before harvesting. Golokumah (2007) also attempted to improve storage with pre-storage curing of the roots and also achieved a storage period of 4 weeks. These studies notwithstanding, there is still a high incidence of deterioration of sweet potato roots after harvest and this has constrained farmers from venturing into large scale production.

Problem statement

In tropical Africa sweet potato cultivation and harvesting is seasonal. However, the consumption of the crop is normally spread over the whole year. This necessitates the adoption of an appropriate storage technology to make it available for the whole year.

Storage of sweet potatoes however, is challenged by numerous problems and often beyond the average farmers' control. Despite the vast economic and nutritional prospects that could be obtained from the production and consumption of sweet potato, the edible tuberous roots are highly perishable, lasting only 1-2 weeks in tropical developing countries (Rees *et al.*,

2003) and not more than 5 weeks under ordinary storage conditions. Under controlled conditions however, the roots can be stored for extended periods of up to a year (Picha, 1986; Woolfe, 1992). The perishability of sweet potato is mainly because of its high moisture content which encourages excessive respiration. It also has thin delicate skin which easily gets damaged during harvesting and post-harvest handling predisposing the roots to microbial and insect invasion, especially weevils (*Cylas sp*). These insect pests are prominent in the tropics (Munthali, 1986). In the tropics the deteriorated roots show sprouting, shrinkage, decay, and weight loss. On the other hand, the edible tuberous root sustains chilling injury when stored at a temperature below 8 ^{o}C. Lack of appropriate storage technology for smallholder farmers continues to aggravate the problems of high post harvest losses to the farmers, especially during glut seasons when the roots are in abundant supply.

In the Cape Coast Metropolis, sweet potato production and marketing is a major income earner for small holder farmers in communities like Moree, Jukwa, Efutu, Ankaful and Koforidua communities. The farmers in these communities face the problem of high deterioration of the root and often have no control over when to sell, how much to sell and at what price to sell. The problem becomes more severe during glut seasons where farmers are forced by circumstances beyond their control to sell the roots at ‘give- away’ prices.

Research conducted by Birago (2005) and Golokumah (2007) revealed that sweet potato farmers in the Cape Coast Metropolis do not store their harvested sweet potato at all because of high deterioration in storage and inappropriate storage technology. Farmers therefore, practice *in-situ* storage or piece meal harvesting; that is they harvest in smaller bits and sell to consumers or retailers. This practice ties the land down to the crop, increases infestation of weevil (*Cylas sp.*) and roots become fibrous and are therefore offered at a give-away price. This situation drastically limits the potential income of the farmer and does not encourage large scale production.

Limited storage of sweet potato roots is practiced by retailers who sell by the road side; they store the roots in sacks under sheds or heap them on the floor in dark rooms. Under this condition the retailers store the roots not longer than 4 weeks with high losses. Duku (2005) indicated that farmers use traditional methods of storage in the metropolis, which involves heaping the roots on the floor in airy, dark rooms or under sheds, or in the corridors of homes and with these methods the roots store for 2-4 weeks with high losses.

According to Haines (2000) pest infestation in stored food in the tropics is inevitable and this is true for sweet potato storage. However farmers do not use any recommended repellent or natural insecticide to control the weevils in storage. The notable ones often are broad spectrum, poisonous and environmentally unfriendly. There is therefore the need to obtain insecticides of botanical origin to help control weevils in storage.

Inappropriate storage structures and botanical insecticides constitute the major problem associated with sweet potato production in Ghana. Often during the main harvesting season, between June and September, there are abundant supplies and little demand and the rest deteriorate drastically. On the other hand, in the lean season, there is scarcity of the roots and the price increases drastically or doubles because of high demand. Duku (2005) indicated that at 2003 prices of sweet potato roots fluctuated throughout the year from GH¢ 3.00 per 100 kg in the main harvesting season to GH¢ 5.00 per 100 kg during the off season. Unfortunately, the high incidence of deterioration does not enable farmers to take advantage of the off-season price increase. The small-holder farmers are therefore need solutions to the high post-harvest losses associated with sweet potato production.

Justification

In recent times, sweet potato (*Ipomoea batatas* (L.) Lam) has become an important root crop and its cultivation is likely to increase over the next two decades. The crop is cultivated in more than 100 countries and ranked seventh among the most important food crops worldwide (CGIAR, 2005). FAO (2004) stated that, the estimated world production is 127 million tonnes with the majority coming from China. Africa produces only about 12 million tons annually for human consumption. Southern and Eastern Africa are responsible for 76 % of the sweet potato production in Africa (Roots, 1994).

Though Ghana is not ranked among the top sweet potato producing nations in Africa, the crop is increasingly becoming an important staple food. The crop is the most efficient food crop in terms of calorific value per land area with many agronomic advantages even on marginal lands (Woolfe, 1992). Farmers in Ghana grow sweet potato mostly on marginal land and it does well where most crops fail. Often it has been used as a famine relief crop and to bridge hunger periods of food shortage before the next harvest.

Sweet potato is food and feed for human and livestock respectively. The roots are normally cooked by boiling or frying. The crop supplies rich nutrients such as carbohydrate, beta-carotene, dietary fibre, minerals (iron, calcium, potassium, manganese) and several vitamins such as vitamin C, niacin, riboflavin, and vitamin B6 (Woolfe, 1992). More so, the dark orange flesh variety is high in beta-carotene and increased cultivation of this variety is being encouraged. If sweet potato is available all year round and well integrated into the school feeding program it could help alleviate problems of malnutrition, beriberi and night blindness which is prominent in children in most rural communities.

There has been intensive pre-harvest research of sweet potato and has led to the release of many varieties. These varieties are high yielding, pest and disease resistant, good for food and provide industrial raw material and also have high nutritive value (high beta-carotene, protein and vitamin). These varieties without any doubt are contributing importantly to food security and poverty reduction in Ghana. However, unless suitable post-harvest technology is made available to the farming community, large scale production will remain less attractive, and the numerous varieties released following years of research, will not benefit the nation.

Reports that often accompany the release of new varieties always make provision for physico-chemical properties, nutritional composition, sensory properties, morphological and agronomic characteristics but no information on storability or storage performance is provided. The major task therefore is to find a suitable storage technology to keep the excess harvest and make the crop available all year round. It is also obvious that the cost of preventing food losses in general is less than producing an additional amount of food crop of the same value and quantity.

It is also generally believed that reducing post harvest losses would be the next most effective tool for preventing global food shortage. Furthermore, for the full benefits of an improved field production practices to be realised, it must partner synergistically with improved post-harvest practices. In this way, it would translate it fully into a number of desirable outcomes such as national food security, increased rural employment, reduced rural-urban migration and improved income of sweet potato farmers.

There is therefore the need to identify the most effective pre-storage treatments and storage structure that are suitable for increasing the shelf-life of sweet potato tuberous root.

Objectives

Main objective

To extend the shelf life of sweet potato tuberous roots

Specific Objectives

The specific objectives of the study were:

I. To determine some physical characteristics of the sweet potato varieties utilised in the study (natural angle of repose, porosity, 500 roots weight, co-efficient of friction, bulk density, surface area and volume).

II. To assess the impact of the storage environment created and various pre-storage treatments on:

a) Weevil damage
b) The rate of sprouting
c) The rate of decay (incidence and severity)
d) Shrinkage and weight loss
e) Wholesomeness

III. To determine the changes in energy content of sweet potatoes tuberous roots in storage.

Statement of Hypotheses

I. Pre-storage treatments have no influence on the storage performance of sweet potato tuberous roots.

II. Storage structures do not have any influence in prolonging the shelf-life of sweet potato tuberous roots.

CHAPTER TWO

LITERATURE REVIEW

Origin and diffusion of sweet potato

Sweet potato (*Ipomoea batatas* (L.) Lam) was first described in 1753 by Linnaeus as *Conolvulus batatas*. However in 1791 Lamarck classified this species within the genus Ipomoea based on the shape of the stigma and the surface of the pollen grains. The crop is a dicotyledonous plant, which belongs to the family *Convolvulaceae*. In this family there are about 50 genera and more than 100 species. But only *Ipomoea batatas* is of major economic importance. Sweet potato is believed to have originated from Central America and was domesticated 5000 years ago (CGIAR, 2005). From its origin the crop then spread to other parts of the world; Columbus brought it to Europe and further introduced it to Africa.

Sweet potato is now cultivated throughout the tropics and warm temperate regions. According to Scott (1992) it is cultivated in more than 100 countries worldwide and is ranked seventh among the most important crops. China is the leading producer of sweet potato where it produces about 80 % of global yield and the rest of Asia account for 6 %, Africa 5 %, Latin America 1.5 % and the U.S.A 0.45 % (FAO, 2004).

Sweet potato production and consumption

Sweet potato is the world's most important root and tuber crop (Lenne, 1991). Majority is grown in developing countries as a valuable source of food, feed, and industrial raw material.

In Africa sweet potato is mostly grown for human consumption. The roots are made into numerous food types; they are boiled, steamed, baked and fried. They are also made into flour and canned; the flour is further used in sweet dishes such as pies, puddings, biscuit and cakes (Woolfe, 1992). In some countries the roots are processed into starch, glucose, syrup and alcohol for industries.

Furthermore, non alcoholic beverages and vinegar can be derived from microbial fermentation of alcohol from starch in sweet potato (Woolfe, 1992). In the United States sweet potato are best known for their use in candied vegetable and Thanksgiving dinner.

Although sweet potato roots are of utmost economic importance, all other parts of the plant are also useful for food and feed. The young leaves and tips of vines are boiled and eaten as green vegetable. The leaves are also used to feed farm animals (Woolfe, 1992). In which one decade the use of sweet potato has been diversified beyond their classification as subsistence food security and famine relief crop.

Post Harvest Pests and Disease of Sweet Potato Roots

Post Harvest Pests

Post harvest and storage losses caused by pests includes fruit flies (*Drosophila sp*p), soldier flies (*Hermetia illucens*) and more importantly sweet potato weevil (*Cylas spp*) which is a serious storage pest in Tropical and subtropical regions (Talekar, 1982). The adult weevil feeds on leaves, vines as well as storage root but the most severe damage is caused by the larvae which tunnel the roots. In West Africa, the weevil can cause yield reduction of 40 –75 %. The damages are caused both on the field as well as during storage. The storage pest causes damage to the roots in two ways:

1. Boring holes in the roots, reducing the quantity and quality of the produce which in turn reduces the market value of the produce.
2. By damaging the epidermis providing entry for moulds/ fungi growth and bacteria to penetrate the roots and further reduce the storage life or shelf-life.

Particularly for weevils (*Cylas spp*), it is reported that infestation is usually more prevalent in roots harvested during the dry season. In the field the insect lays eggs on the stems and roots surfaces. The larvae would then bore a hole through the stem and the root causing considerable damage in storage.

Post harvest diseases

The most common organism causing storage rots are Java black rot, black rot, scurf, bacterial soft rot, surface rot, root rot, charcoal rot, and soft rot. Moyer (1982) indicated that time of infection varies with the organism, field, and harvest/storage conditions.

Black rot, fusarium root rot, scurf and bacterial soft rot can occur before harvest, during harvest and after harvest. On the other hand soft rot infection tend to occur at harvest and after harvest but charcoal rot, dry rot surface rot and root rot occur during harvest (Kays, 1991). All these harvest and post harvest pathogens require wounds to gain entry. It is therefore important to reduce injury during harvesting so as to enhance the shelf-life after harvest. Furthermore, roots should be cured immediately and stored at an optimum storage condition. Another disease in storage is internal cork which is a virus induced disorder where root tissue develops necrotic lesions during storage (Kushman & Pope, 1972). Control of post harvest disease is now centred on prevention, since little or nothing can be done after the root is infected.

Plate 1. Internal and external views of root infested with black rot

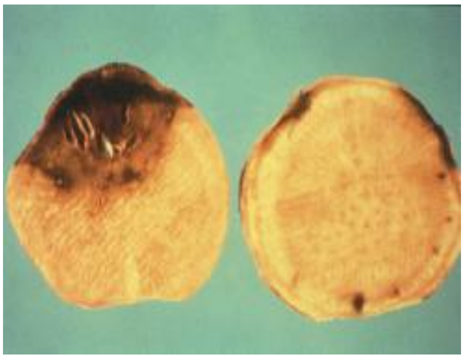


Plate 2. Cross-section of roots infested with fusarium soft rot

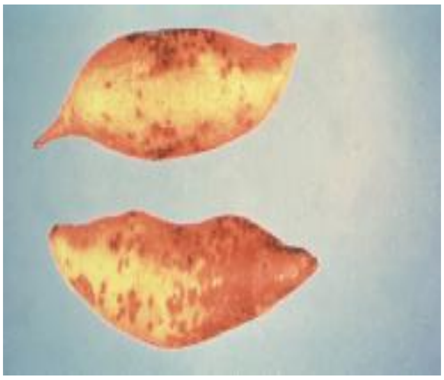


Plate 3. Root with scurf

Plate 4. Root with bacterial soft rot

Chemical composition of roots

The most important economic part of sweet potato is the tuberous root. The root is a complex organ possessing useful compounds. These compounds make-up the general organization of the roots and consequently contribute to the economic uses of the crop.

Dry matter

The dry matter content of sweet potato is low due to the high moisture content. On the average the dry matter content of sweet potato is 30% but varies widely depending on cultivar, location, climate, soil type, cultivation practice and the incidence of pest and disease (Bradbury *et al.,* 1988).

The dry matter content determined in the University of Cape Coast for five varieties ranged between 34.41 to 37.35 % (Aidoo & Tetteh, 2004). Also, 18 cultivars grown in Brazil revealed a dry matter content of 22.9 to 48.2 % (Cereda *et al.,* 1982). All these indicate that dry matter content of the roots in general is dependent on many factors.

Apart from the roots the green parts of sweet potato, mainly the petiole, stem and leaves have a dry matter content of 12 to 14 %. This is higher than some common useful vegetable for example cucumber, egg plant and carrot.

Total carbohydrates

Sweet potato contains considerable amount of carbohydrates, approximately 24-27 % of fresh weight is made up of carbohydrate (Woolfe, 1992). This consists of mainly starch, sugar, pectin, hemicelluloses and cellulose.

The composition of these compounds that make up the total carbohydrates varies greatly from cultivar to cultivar and time of harvest or maturity. The compounds determine the storage length of the root, the higher the total carbohydrates the better it stores, for carbohydrate content slightly deceases in storage because it is still a living material (Zhitian *et al.,* 2002).

Total carbohydrate levels have direct correlation with shelf-life due to the function pectin and hemicelluloses play in the cell wall strength of the roots. Woolfe (1992) indicated that storage and processing further influences texture and taste. Generally a longer storage period of the roots prior to processing reduces product firmness and flour pasting viscosity but glucose and sucrose increases (Zhitian *et al.,* 2002). Carbohydrate composition in sweet potato root also affects eating quality, storage life duration and processing trait (Picha, 1987; Walter & Palma 1996)

Starch

Starch is the major component of sweet potato root dry weight. It ranges from 55.9-73.9 % at harvest (Zhitian *et al.,* 2002). The starch shows wide variation in granule size (3-40 μm) and amylase content (15-30 %) and gelatinization temperature between 61 and 70 ^{o}C (Hae *et al.,* 2009). According to Jung (1991), sweet potato starch exhibits a higher viscosity profile and paste clarity compared to corn starch.

Sweet potato starch is used in the food industry as an ingredient in products such as noodles, soups, sauce, snacks and bread. The wide variation in the starch content depends mostly on cultivar. In 18 cultivars grown in Brazil, the starch content ranges between 42.6-70.0 % on dry weight basis (Cereda *et al.,* 1982). In storage the starch content decreases slightly because the root uses its own reserve to supply energy in the form of glucose. This is why glucose and sucrose concentrations changes in storage (Zhitian *et al.,* 2002).

Sugars

Sugar is an important part of sweet potato. It makes the tuberous root sweet but varies from location to location and cultivar to cultivar. The total level of sugar in sweet potato is made up of sucrose, glucose and fructose but varies among genotypes (Zhitian *et al.,* 2002)

In Southern Pacific total sugar of sweet potatoes ranges from 0.38-5.64% (Bradbury *et al.,* 1988). Again Picha (1985) stated that in American cultivars, sugar content range between 2.9-5.5 %, 6.3-23 % sugar content in cultivars from Puerto Rico, and about 38.9 % in Louisiana samples (Truong *et al.,* 1986).

Glucose is the main sugar in sweet potato. It account for 86% of total sugar and the rest accounting for 22-49 % depending on variety (Zhitian *et al.,* 2002). Furthermore, total sugar content is influenced by the time of harvest. Menezes *et al.* (1976) stated that roots harvested at 6 months after planting has the highest sugar concentration than those harvested in 4 and 8 months.

More so, storage increases the sugar content in sweet potato root. Zhitian *et al.* (2002) observed an increase in glucose and sucrose content in the earlier stages of storage and these were maintained relatively at constant levels with further storage period.

Non-starch carbohydrates

Non starch carbohydrates found in sweet potato are cellulose, pectic substances (propectin, pectic acid and pectin) and hemicelluloses. These constituents form the cell wall of the plant structure and are further known as dietary fibre. The dietary fibre of sweet potato roots ranges from 1.2-2.62 %

(Bradbury *et al.,* 1985b). The range depends primarily on varietal characteristics and location.

The dietary fibre plays an important role in the nutritional value of the sweet potato roots. It further influences the shelf life (storability) of the root because of the role hemicelluloses, cellulose and pectic substances play in the mechanical strength of the cell wall. It also prevents the entry of harmful micro-organisms and reduces water loss.

Total protein

The total protein is referred to as crude protein. 100g of the root of sweet potato is reported to contain 0.5-3.5 g of protein (Woolfe, 1992). Walker *et al.* (1984) stated that sweet potato yield contains 184 kg protein ha^{-1} on an average and this compares quite favourably with wheat and rice which are 200 kg ha^{-1}, 168 kg ha^{-1} respectively.

Woolfe (1992) revealed that total protein content is about 5 % on dry weight basis; it includes all nitrogenous compounds present in the analysate. At harvest sweet potato contains about 75 % true protein and 25 % non-protein nitrogen and the major protein is about 80 % of the total soluble protein in the root. Fresh sweet potato root possesses higher concentration of soluble protein but this reduces when it gets sprouted, also application of nitrogenous fertilizer increases total nitrogen in sweet potato roots.

The factors that affect total protein in sweet potato include soil fertility, climate, pest and diseases (Woolfe, 1992). Total protein in sweet potato is determined as Kjeldahl N x 6.25, the other methods such as dye-binding and spectroscopy are not suitable for mass field screening.

Available minerals and Vitamin

Sweet potato roots are an excellent source of vitamin and minerals. Per 100 g of root is noted to contain 21-36 mg of calcium, 38-56 mg of phosphorus, 0.7-2.0 mg of iron, 10-36 mg of sodium, 210-304 mg of potassium, 35-5280 mg of beta-carotene and 24 g of magnesium. Other minerals that are present in a trace are zinc, iodine, copper and manganese (Hug *et al.*, 1983). The vitamins present in the roots per 100 g of roots are thiamine 0.09-0.14 g, riboflavin 0.05-0.10 g, Vitamin C 16-22 mg, Niacin 0.6-0.7 mg, and Ascorbic Acid 21-37 mg. These values vary from variety to variety and from location to location.

Picha (1985) revealed that crude protein between cultivar ranges from 1.36-2.13 g 100 g^{-1}, Phosphorus from 38-64 mg 100 g^{-1}, Potassium from 245-403 mg 100 g^{-1}, Calcium 20-41 mg 100 g^{-1}, Magnesium 13-22 mg 100 g^{-1}, and Beta-carotene is between 5-11.5 mg 100 g^{-1}. Carotenoid also increased slightly after curing and at short storage temperature of 7 ^{o}C - 26.6 ^{o}C.

Energy content

The energy content of sweet potato roots varies between 32-152 kcal 100 g^{-1}, the variation depends on the dry matter content which also depends on the variety and location. According to Woolfe (1992) sweet potato supplies energy less than cassava, though it has an energy value similar to those of yam, taro and plantain. However, sweet potato flour has energy content similar to that of cassava flour or maize meal.

The energy content of sweet potato root can simply be determined by a method described by Bradbury (1986). In this method the percentage moisture content (M) is determined by an oven dry procedure and the outcome is incorporated into an equation,

$$E= -17.38\ M + 1699 \qquad (1)$$

Woolfe (1992) stated, that the equation over estimate the energy content but concluded that careful determination of moisture content by drying samples to constant weight in an oven at 100 ^{o}C should allow the calculation of the energy content with an accuracy of 5-10 %.

Nutritional and health benefits

Sweet potato is a low calorie and free fat vegetable with abundant useful minerals such as beta-carotene, vitamins (A, C, & E), magnesium, potassium and rich in antioxidants. These nutrients help to prevent heart attack, stroke, reduce blood pressure and maintain fluid and electrolyte balance in the body cells.

Sweet potato is ranked highest in nutritional value amongst other vegetables. The consumption of the roots relieves the symptoms of stomach ulcer, inflamed conditions of the colon, haemorrhoids and cancer prevention in glands and organs with epithelial tissue.

Move over, sweet potato roots and leaves are used in folk remedies to treat illnesses such as asthma, night blindness and diarrhoea. The roots are easily digestible and are good for eliminative system; it also detoxifies the system because it is believed to bind heavy metals.

The orange and yellow flesh varieties are rich in beta-carotene and can reduce night blindness in children. According to Tsou and Hong (1992) regular intake of 100 grams sweet potatoes with moderate amount of beta-carotene

(3 mg 100 g^{-1}) per day can supply the recommended levels of Vitamin A to children less than five years of age. Beta-carotene and vitamin C are very powerful antioxidants which help to eliminate free radical that damage the cells and cell membrane, thereby preventing the development of atherosclerosis, diabetes, heart disease, osteoarthritis and rheumatoid arthritis (Baybutt, 2000).

Structure of sweet potato

The structure of sweet potato roots is made up of the internal and the external parts of the root. The storage tuberous root is the proximal end that joins to the stem through the root stalk. This is where many adventitious buds are found and where sprouting originates.

The transverse section of sweet potatoes shows the protective periderm or skin, and cortex or cortical parenchyma. The cortical parenchyma varies from very thin to very thick depending on variety. The cambium ring is where the latex vessels and central parenchyma are found. The amount of latex formed depends on the maturity of the storage root, cultivar and the soil moisture.

Shapes of sweet potato

Shape is the geometric configuration of a product and very important aspect of product quality. It influences grade given to a produce for export and local market. For ease of trade sweet potato must have a recognised expected shape. Often misshapes are not acceptable and consumers offer lower price for them.

Sweet potato storage roots vary in shapes and size according to cultivar, type of soil and environmental conditions. The shapes are normally round, round-elliptic, elliptic, ovate, obovate, oblong, long oblong, long elliptic and long irregular or curved (Huaman, 1992).

Defects of sweet potato

Sweet potato tuberous root is normally smooth. However there are some noticeable defects such as alligator like skin, prominent veins and horizontal constrictions or longitudinal grooves. Lenticels are also located on the surface and in some cultivars they can be pro-rootant due to excess water in the soil. These noticeable defects often render the root susceptible to microbial infection and the root looks unacceptable to consumers.

Causes of post-harvest loss of sweet potato root

Post-harvest losses cannot be said to be caused by one known factor but it is a combination of factors right from the time of planting to the time of harvest. These are either internal or external factors that come together to cause the deterioration. These causes are:

Respiration

Sweet potato tuberous roots are living structures and that, they respire. The respiration process results in the oxidation of the starch (a polymer of glucose) contained in the cells of the root, which converts it into water, carbon dioxide and heat energy. This can be represented by the oxidation of glucose;

$$\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy} \quad \text{.......................} \quad (2)$$

During this transformation of the starch the dry matter of the root reduces, since the food reserve is not replenished. Therefore, high rate of respiration lowers the shelf-life of sweet potato roots. Hence if respiration rate is lowered it results in an increase in storage duration. In general respiration rate of roots are reduced as oxygen is lowered from 2-3 % oxygen concentration but below 3 % may result in an increase respiration due to fermentation metabolism.

A limited supply of oxygen and inadequate removal of carbon dioxide may lead to effective asphyxiation and the death of produce tissue. Normally, complete combustion of 1 g of glucose yields 1.47 g CO_2 + 16 kJ of energy. In practice about 5.1 kJ (32 %) of this energy is used as metabolic energy and 10.9 kJ (68 %) is released as heat. The rate of respiration is assessed either by measuring the uptake of oxygen or the quantity of carbon dioxide released and is expressed in milligrams of CO_2 per kilogram of root per hour.

Ethylene production and sensitivity

Sweet potato is one of the agricultural produce that produces very low amount of ethylene (0.1 µL kg^{-1}.hr). However, a much higher rate occurs after chilling, wounding and decay. When root of sweet potato is exposed to ethylene at 1-10 ppm it increases respiration rate, phenolic metabolism which adversely affect flavour, colour of cooked roots and shelf-life. When the ethylene concentration increases in the atmosphere around sweet potato roots it results in an unfavourable quality such as high deterioration and wastage.

Buescher *et al.* (1975b) revealed that roots exposed to 10 µL L^{-1} ethylene lowers beta-amylase activity. Furthermore, ethylene promotes synthesis of phenolic compounds and phenolic oxidizing enzymes which leads to discoloration. Therefore, proper ventilation in storage is necessary to reduce the level of ethylene concentration.

Physiological disorder

Physiological disorder is mostly the breakdown of tissue caused by the nutritional deficiency and adverse environmental condition. Notable physiological disorder associated with sweet potato root is chilling injury. Sweet potato roots are very sensitive to chilling injury at temperatures below 12 ^{0}C (Picha, 1987b). Roots show symptoms of internal pulp browning, root shrivelling, formation of surface pitting, abnormal wound periderm formation, fungal decay, internal tissue browning and hardcore formation (Buescher *et al.,* 1975a; Daines *et al.,* 1976). Walter and Purcell (1980) revealed that tissue browning comes as a result of synthesis of chlorogenic acid and other phenolic compounds.

Also roots suffering from chilling injury when cooked show “hardcore” defect and are darker in colour than non chilled roots, this defect is not apparent in fresh roots but appears after cooking/ processing. Hardcore is a physiological disorder in which various areas within the roots become hard apparently due to cold induced alteration in cellular membranes (Yamaki & Uritani, 1974). All cultivars are susceptible to hardcore but there are variations among cultivars and non cured roots are more susceptible than cured roots.

Pithiness is another disorder in which sound roots are characterized by reduced density and spongy feel when squeezed. Poor ventilation or anaerobic condition also exposes roots to emit a distinctive sour, fermented odour.

General senescence

Senescence is the progressive disorganization of the metabolic apparatus of the cell and it is caused by the concentration of ethylene around the roots. Senescence in sweet potato is promoted by ethylene which accelerates deterioration and consequently reduces post-harvest life of the crop because the ethylene increases respiratory activity, increases activity of enzyme such as peroxidase, lopoxidase, and alpha-amylase. Furthermore, it also increases cell permeability and loss of cell compartmentalization, which has direct influence on senescence and ageing.

Temperature

Temperature influences many factors that cause loss during storage. It is the single most important factor affecting the rate of respiration which consequently affects loss of food reserve. Furthermore, it influences the rate of sprouting, pest infestation and the development of rotting micro-organisms.

Temperature causes natural breakdown of (carbohydrate) food reserves and water content become depleted. The cooling of produce will extend its shelf-life by slowing the rate of carbohydrate breakdown.

Relative humidity

Relative humidity is the term for expressing the humidity of moist air and it is the ratio of water vapour pressure in the air to the saturation vapour pressure possible at the same temperature, expressed as a percentage. Saturated air therefore has a relative humidity of 100 percent. High humidity retards wilting and maintains the product in better condition. Most horticultural produce stores best in an atmosphere that has a relative humidity above 85 %.

Gas composition

Composition of gases in the storage structure plays an important role in prolonging the shelf-life of the roots. Sweet potato roots after harvesting under goes respiration and releases carbon dioxide. The build-up of the carbon dioxide in the storage structure further increases the respiration activity and encourages sprouting and cell break down. Respiration also utilizes the available substrate (e.g. glucose) and it is related to the rate of dry weight loss. External concentration of oxygen also influences respiration activity, CIGR (1999) stated that anaerobic metabolic processes start when oxygen concentration is 5 % and 7 % and encourages cell decomposition.

Physical damage

The outer covering or the skin of sweet potato root is normally an effective barrier against most potentially invading spoilage micro organism (bacteria and fungi) causing rotting. However, the skin has soft texture and any careless handling at harvest and transporting often ruptures the barrier causing injury to the skin, and providing an easy entry point for infections. It also stimulates physiological deterioration and dehydration. The wound influences respiration rate which further increases the required healing substances and the defence reaction by the cell (CIGR, 1999). There is therefore the need to gently handle the roots to minimize bruising and breaking of the skin.

Damaged roots if not properly cured should not be stored because of these reasons:

a. High risk of introducing disease causing organism into good ones.
b. Further high losses due to pathogens
c. Lower quality.

Hence careful harvesting and proper handling procedure is an important step towards successful storage.

Harvesting and quality indices

Harvesting

Quality of sweet potato roots cannot be improved after harvest, it can only be maintained therefore, it is important to harvest at a proper stage, size and at peak quality/maturity. Sweet potato tuberous roots are ready for harvesting 3-8 months after planting (Woolfe, 1992). It is important to harvest after sufficient roots have reached desirable market size. Immature or over mature roots do not store well. Different varieties mature at different times for example; early variety takes 3-4 months, medium variety takes 4-6 months and late variety more than 6 months.

Before harvesting, the field should irrigate to soften the soil; this helps to reduce surface wounds, injuries and cuts (Chew & Morgan, 1999). Harvest sweet potato early in the morning so that proper post harvest activities can proceed without delay and as well reduce field heat.

Harvesting can be done in three (3) ways namely; manual, semi-manual and mechanical.

a. Manual harvesting: is the simplest and normally used by small scale farmers. It involves using a hoe or digging stick to lever the roots out of the ground. This method is mostly practiced in tropical and sub-tropical regions

b. Semi-manual harvesting: of sweet potato involves the removal of the foliage with the help of a harrow which clears the foliage from the area to facilitate the final harvesting. The elimination of foliage must be carried out 24 hours before harvesting. After the foliage is removed a double mould board plough is passed down the centre of the hill leaving a ridge in between the original two and ensuring that the soil does not cover part of the adjacent ridges. The roots of the sweet potato exposed after the first pass are picked up by hand and removed prior to making a second pass. Roots are then again collected by hand.

c. Mechanical: It involves the use of a machine (sweet potato harvester) where mostly satisfactory results are achieved. With this method the roots can be collected in bulk in the field or on a trailer running along-side the harvester. Inadequate soil preparation makes this harvesting very difficult and less efficient.

Quality indices

Good quality sweet potato root should be smooth and firm with uniform shape and size, free from mechanical damage and have uniform peel colour and typical of that variety. Woolfe (1992) indicated that matured roots ranges in shape from almost spherical to spindle-shaped and measures from some few centimetres to more than 30 cm and weighs from 0.1 kg upwards.

According to Kays and Kays (1998) there are four grades used for sweet potato in the USA namely; U.S Extra number 1, U.S number 1, U.S commercial and U.S number 2. These grades are based on the degree of freedom from defect (dirt, cuts, bruises, growth cracks, decay, insect and diseases), size and weight. Desired sizes are 8.3-8.9 cm in diameter and 0.53-0.59 kg. Furthermore it was stated that roots are handled in 360 kg in bulk bins during storage. However in Africa and Ghana in particular there is no formal grading and the roots are sold in sacks with no recommended weight.

Pre-harvesting activities affecting post-harvest

Variety

Sweet potato has numerous varieties and the varietal effect on storage duration has been observed as very important factor. Rees *et al.* (2003) revealed that differences exist in the shelf-life of sweet potato varieties.

According to Data (1985) roots of different sweet potato varieties show different behaviour in storage; it was observed that after 10 days of storage some varieties sprouted, shrivelled or decayed whiles others did not, however after 90 days in storage sprouting and shrivelling became severe in all the varieties stored. Diamante and Data (1986) stated that, the effectiveness of storage method to some extent depends on variety stored, because different varieties differ in their respiration rate, susceptibility to pathogens and dormancy. Duku (2005) finally observed that varietal effect on moisture content, loss of energy, weight loss, weevil infestation and fungal decay was significant in storage.

It is now well known that different varieties will respond differently in storage. Therefore it is important to select for storability of sweet potato roots for all well known varieties. Rees *et al.* (2003) also revealed that for the cultivars studied there was a wide range in rates of weight loss, which was consistent between seasons and therefore suggested that breeding for extended shelf-life is feasible.

Fertilizer Application

Fertilizer application is very important in increasing the yield of sweet potato. A well balanced fertilizer provides not only large and better roots but also promotes shelf life or improves storage life. According to Ankumah *et al.* (2003) single application of N-fertilizer resulted in significantly higher yield in the storage roots than split application, more so, late maturing cultivars tended to have higher nitrogen recovery and physiologically efficient than early maturing cultivars. Sweet potatoes respond differently to fertilizer application. Hill (1984) reported that the ideal rates range from 0 to 46 kg N ha^{-1} and the response depends on variety (Haynes, 1970).

Defoliation

Defoliation before harvesting is an important practice. It involves the removing of the vines also referred to as vine killing. It can be done either by mechanical means, chemical or flaming or both. In the mechanical means precaution should be taken not to expose the roots to weevil invasion. The chemical means involve using herbicides, this can cause stem-end rot discoloration of roots and care should be taken. While, flaming method of defoliation involves burning of the vines. This controls vine borne diseases but burning regulations have discouraged this method (Delorit *et al.,* 1984).

Delorit *et al.* (1984) stated that defoliation hastens maturity of roots, ease harvesting and toughens the skin of the roots thereby reducing wounds created during harvesting and transportation. Furthermore vine killing according to Delorit *et al.* (1984) prevents dry rot caused by late blight spores which are distributed to the roots from vines during harvesting.

Sweet potato roots have high moisture content and relatively delicate skin and easily get damage during harvesting operation; hence vine killing is very helpful. According to Duku (2005) defoliation of sweet potato before harvesting reduces weevil infestation and fungal decay of roots and bruising of roots during harvesting and handling. It also improves storage of roots by reducing weevil infestation and fungal decay in storage. Duku (2005) however revealed that, defoliation before harvesting of roots increased sprouting of roots from 2.5 % to 14.2 %. But this disadvantage can be overcome by applying sprouting inhibitors.

Re-ridging

Re-ridging is an important pre-harvesting operation in sweet potato cultivation but it is often under estimated. It involves re-shaping the ridge to its original shape and form. Studies conducted by Appiah-Danquah (2005) revealed that during the later part of root formation ridges crack open due to the expansion of the roots. This make easy penetration of weevil and pathogens to the roots coupled with the fact that sweet potato roots have thin delicate skin. It was further revealed that re-ridging 3-5 weeks before harvesting reduced weevil infestation of roots and further improved storability.

Root shape and orientation in the soil differ from variety to variety therefore; re-ridging must be timed properly in order to shape the ridges before young roots show or emerge. Re-ridging 30 days after planting is effective for controlling *Cylas sp* (IITA, 1985).

Pesticide treatment

Pesticide applications have helped reduce the incidence and severity of *Cylas sp* infestation in sweet potato production, it is believed that if *Cylas spp* are checked very early in the growing stages, there will be no weevil damage on the roots even in storage. However continued dependence on organo-phosphorus and pyrethroid insecticides has disrupted biological control by natural enemies, led to outbreak of other insect species and development of resistance to pesticide (Salunke *et al.,* 2005). It has also had undesirable effect on non-target organisms and fostered environmental and human health concerns.

The problems have highlighted the need for the development of selective insecticide control measures of biological origin. Several plant extracts and essential oils have served as alternative sources of insect control agents because they are made up of bioactive chemicals. According to Moursy (1997) water, ethanol and acetone extract of *Calotropis procera* plant have insecticidal, larvicidal and antibacterial properties. Botanical treatments have recently been found to be very effective in the control of weevil infestation (*Cylas sp*) for both on field and in storage. When neem (*Azadirachta indica*) extract was incorporated into the ridge Appiah-Danquah (2005) stated that it was very significant in preventing weevil infestation on the field and in storage.

Irrigation

Irrigation is an important aspect of sweet potato production. It affects many aspect of the crop from field to storage. The crop needs uniform watering at least an inch of irrigation per week for normal growth. Watering or rainfall after a long dry period results in root cracking and high weevil infestation. Water is very vital during transplant establishment and root development hence watering is done frequently to enhance yield.

According to Onyekwere & Okafor (1992) sweet potato require an average water supply of 4500 m^3 ha^{-1}, and this amount of water distributed weekly will sustain yield of more than 20 t ha^{-1} of sweet potato in 4 months. Poor water supply leads to root cracks and abnormal root shape. It further predisposes the roots to weevil infestation and hence reduces the shelf life of the roots.

Post harvest treatment

Curing

Curing of sweet potato roots before storage is a standard procedure accepted by many (Hall, 1993, 1994; Kushman 1975; Walter & Schadel 1982). It involves exposing roots to high temperature of 29-32 ^oC and relative humidity of 90-96 % for about 4-8 days (CIGR, 1999). When curing, wounds created during harvesting and transportation become healed and coated with layers of lignified cells, suberin which protects the root against pathogenic invasion (Walter *et al.,* 1989). Furthermore curing prior to storage is known as a standard procedure to protect the roots against pathogens which cause soft rot of sweet potato roots in storage (Meijers, 1987; Snowdon, 1992; Afek & Warshavsky, 1998).

Generally sugar content of sweet potato roots increases during curing (Walter & Hoover, 1984; Picha, 1987). However, during storage after curing, sugar concentration vary with storage conditions, and length of storage furthermore, curing facilitates synthesis of enzymes operative in flavour development during cooking (Wang *et al.,* 1998).

Surface waxing

Waxing the surface of horticultural products is a treatment used on a number of commodities including citrus fruit, apples and recently cassava and sweet potato. Waxing retards the rate of moisture loss and maintains turgor and plumpness and modifies the internal atmosphere of the commodity. The wax imparts a gloss to the skin and gives the produce a more shiny appearance than the un-waxed commodity. Waxing of cassava for instance can extend the storage life from 2-3 days up to about 30 days by preventing discoloration in the vascular tissue. This potential can also be employed in sweet potato storage for better result since sweet potatoes have thin delicate skin compared to cassava.

Lantana camara

Distribution and taxonomy

Lantana camara Linn is a hairy shrub, native of America but now well distributed in all parts of Africa and Asia. It is mainly a weed though considered by some as an ornamental. Holm *et al.* (1977) estimated that there are about 4 million hectares of land infested with *Lantana camara* in Australia. In Africa and Ghana *Lantana camara* is mostly found on the coast (Ivens, 1974). Wide species of *Lantana camara* exist and is been cultivated for more than 300 years and the cultivars can be distinguished morphologically by their flower size, shape and colour, leaf size, hairiness and stem thorniness. Physiologically it also differs in growth rate, toxicity and chromosome number and DNA content Davis *et al.* (1992).

Plate 5. *Lantana camara* leaves and flowers

Chromosome composition

Chromosome studies revealed that *Lantana camara* showed somatic number as 33, 44, and 55 which is related to its polyploidy nature. Tetraploids form the majority of the wild population. Sinha *et al.* (1995) stated that DNA content showed differences per nucleus within the different ploidy levels.

Active Ingredients

Lantana camara is an excellent source of pentacylic trierpenoids some of which cause hepatotoxicity (Sharma & Sharma, 1989). The leaf is noted to contain 0.2-0.7 % lantithanine $C_{33}H_{52}O_5$ (lantadene A) and 0.2 % lantadene B ($C_{35}H_{52}O_5$), 0.05-0.2 % essential oil and other sesquiterpenses, caryophyllene 80 % and 10-12.5 % made up of phellandrene (tannis, resins dyestuffs, sugars).

Ross (1999) also stated that the leaves of *Lantana camara* contain verbascoside which has anti-microbial, immune suppressive and anti tumour properties. These play a very important role in using *lantana camara* as medicinal plant and recently have proved to be effective for the control of some vegetable pest. Also the flowers contain anthocyanin carotene and 0.07 % essential oil, the stem-bark contains resin and quinine substance with strong antipyretic and antispasmodic properties while the root contains resin. According to Pan *et al.* (1997) the roots contain six oligosaccharides namely; stachyose, verbascose, ajugose, verbascotetraose, and lantanose (A & B). Also six iridiod glucosides namely; theveside, epiloganin, shanzhiside methyl ester, theviridoside and geniposide .

Toxicity of Species

According to Ross (1999) most ruminant and non- ruminant will not feed on *Lantana camara* because of its pungent aroma and taste. Furthermore the leaves and berries are poisonous to most animals. However, Swarbrick and Thaman (1995) reported that it is being use as feed for cattle in Australia. The toxic compounds found in *Lantana camara* is pentacyclic triterpene acids, lantadene A & B and reduced lantandene A.

Signs of poisoning include anorexia, constipation, jaundice, photosensitization and rumenstasis, weakness, bloody diarrhoea and in acute cases death occur in 3 days (McSweeney, 1988). Chakravarty (1976) revealed that the lantandene in the leaves are used for fish poison and its cardioactive. Human poisoning is also reported in Florida by ingesting green fruits of *Lantana camara*

Bioactivity

The insecticidal property of *Lantana camara* is very enormous. Studies conducted by Sagoe (2003) revealed that leaf extract of *Lantana camara* was very effective against diamond black moth pest of cabbage. Moreover, studies on the active ingredient pentacycle triterpene was successful as ovicidal and oviposition deterrent (Sharma *et al.,* 1997), protect storage crop (Sinha *et al.,* 1995), biofungicidal (Srivastava, 1997), as a repellent and anti-feedants (Kulkarni *et al.*, 1997).

Medicinal uses

Lantana camara repels most organisms such as insect because of its pungent aroma and taste, the root decoction is used for the treatment of gonorrhoea (Morton, 1994). It is also use for the treatment of cancer and tumors.

Duke (1982) reported that *Lantana camara* is haemostat, nervine, pectoral stimulant, sudorific, sedative, antibiotic and pesticide. It is also a folk remedy for illness namely; fever, flu, measles, jaundice, chicken pox tetanus tumour, sore, snake bite, stomatitis, haemorrhage and neurodermatitis.

In many parts of the world *Lantana camara* is used to treat many illnesses; Mexicans for rheumatism, Chinese for leprosy and scabies, Bahamians apply the leaves in the treatment of diarrhoea, dysentery and gonorrhoea, and Costa Ricans for asthma and high blood pressure. Other minor uses according to Morton (1994) include seeds as lamb food and biogas production when straw is mixed with dung.

Lantana camara extract as pre-storage treatment

Lantana camara leaves are known to repel some insect pests, it possess both larvicidal and insecticidal activities. According to Raman *et al.* (1997) covering potato tubers with *Lantana camara* reduces potato tuber moth. *Lantana camara* extract prepared by using; ethanolic or chloroform or hexane or water releases the active ingredient flavonoids (Rajesh & Suman, 2006) and this is found to be effective against termites and potato tuber moths (Kroschel & Koch, 1996). Decoction of the leaves is also used as lotion for wound, anti-feedant, larval mortality, anti-bacterial and repellency (Rajesh & Suman, 2006).

Ash

Ash is an organic material derived from the burning of wood. This substance has alkaline property which is not favourable for the development of diseases, it also contains insecticidal property. The application of wood ash as a pre-storage treatment has received a great interest in the rural community; it is easy to come by, effective against most pests, available all year round and has relatively no side effect.

According to Mutandwa and Gadzirayi (2007) farmers get best result in using the combinations of wood ash and soil for the preservation of sweet potato roots. Mutandwa and Gadzirayi (2007) further reported that, ash acted as an absorbent to moisture and has a repelling effect on pests. The ash is applied by mixing the ash powder with the sweet potato roots.

Furthermore, ash has proved to be very effect against insect pest when used as pre-treatment but the only shortcoming is that the source of the wood used for the ash is not well known. Ash in the rural areas comprise of different kinds of wood because they are gotten from the burning of different species of trees and shrubs.

Brine

Brine is water saturated with salt, it is normally used to preserve vegetables and animal products in a process termed as brining. It is also used for pickling foodstuff as a means of preserving them. Brine possesses an alkaline property. This alkaline component is loathsome to most microbes and insects, therefore it can play important role in preserving sweet potato root from decay and weevil damage.

Sorting and grading

Sorting and grading are terms often used interchangeably in the processing industry, but they are different activities. Sorting is a separation based on a single measurable property of raw material units, while grading is the assessment of the overall quality of produce using a number of attribute; classification on the basis of quality (Fellows, 2000).

After harvesting of sweet potato, the roots are sorted by removing diseased and damaged roots from the healthy ones. The sorted ones are further graded using grade standards (Saravacos & Kostaropoulos, 2002). In this process they are grouped into various attribute such as shape, size, colour and weight, for further processing and storage.

Packaging

Packing is a vital product component. It is the science, art and technology of enclosing or protecting product for storage. It has a major influence on storage life and marketability of the roots when excellent environment is created. According to (CIGR, 1999) packaging fulfils several functions namely; containment, facilitating transportation, protection of produce from further damage, protection of the environment from contents of package and marketing.

In Ghana sweet potatoes are packaged in baskets, wooden crates and sacks. However, this type of packaging provides little or no protection to the roots, often times there are high losses and damages observed.

In packaging, enough ventilation must be provided to prevent condensation and excess dampness which may lead to sprouting and rotting. Ventilation is needed to remove heat and maintain oxygen levels as carbon dioxide is generated through respiration (CIGR, 1999). Therefore ventilation holes must be provided in the cartons or packages.

Storage and storage types for sweet potato tuberous roots

Storage of sweet potato is very necessary to increase availability all year round. Due to its seasonal nature and fluctuation of supply and demand many methods have been tried and used to store the roots but little impact is felt so far. The primary objective of storage is to maintain the best possible quality during storage.

Factors affecting storage life

Physiological Condition

Condition of produce at harvest determines how long the crop can be safely stored. For example, immature sweet potato roots will not store well but apples picked slightly immature can store safely for several months. Also, most crops can be made less prone to decay by management of crop nutrition such as calcium which has been more closely related to disease resistance than any other cat ion associated with the cell wall (Sams, 1994).

Increased calcium contents in potatoes and peaches have also been documented as reducing postharvest decay (Conway, 1989). In general, produce containing adequate levels of calcium do not develop physiological disorders and can be stored longer before they breakdown or decay.

Temperature

Temperature is a very important single factor to be considered in storage. It influences the following: the rate of biochemical reactions such that, lower storage temperatures slow degradation of food reserve. Typical temperature quotient (Q_{10}) values for spoilage reactions are approximately two, implying that spoilage rates would double for each 10 °C rise, or conversely that shelf-life would double for each 10 °C reduction. This is an over simplification as Q_{10} may change with temperature. Most insect activity is inhibited below 4 °C. The use of refrigerated storage is limited by the sensitivity of materials to low temperatures. Sweet potato roots display physiological problems that limit their storage temperatures, probably as a result of metabolic imbalance leading to a build-up of undesirable chemicals in the tissues. Less obvious biochemical problems may occur even where no visible damage occurs. For example, storage temperature affects the starch/sugar balance in potatoes; at temperature below 10 °C a build-up of sugar occurs, which is most undesirable for fried products. Refrigerated storage is expensive and not feasible especially in Africa.

Relative humidity

If the humidity of the storage environment exceeds the equilibrium relative humidity (ERH) of the food or produce, the food will gain moisture during storage, and *vice versa*. Uptake of water during storage is associated with susceptibility to growth of microorganisms, whilst water loss results in economic loss and more specific problems such as: cracking of seed coats of cereals, or skins of fruits and vegetables, shrinkage in roots.

Ideally, the humidity of the store would equal the ERH of the food so that moisture is neither gained nor lost, but in practice a compromise may be necessary. The water activity (aw) of most fresh produce is between 0.98-1.00, but they are frequently stored at a lower humidity. Some wilting may be acceptable in preference to mould growth and decay, while some surface drying of meat is preferable to bacterial slime. Packaging may be used to protect against water loss of raw materials during storage and transport.

Concentration of gases

Controlling the atmospheric composition during storage of many raw materials is beneficial. The use of packaging to allow the development or maintenance of particular atmospheric compositions during storage enhances shelf life. It is important to maintain required composition of gases in order to improve storage.

In living produce, atmosphere control allows the possibility of slowing down metabolic processes, hence retarding respiration, ripening, senescence and the development of disorder. According to Thompson (1998), the technique allows year-round distribution of most produce, where controlled atmospheres in combination with refrigeration can give shelf lives up to 10 months. Controlled atmospheres are also used during storage and transportation.

The gas concentration in a storage structure influences the gas exchange rate and on the metabolic activity of the tissue. For most stored root example sweet potato, when external oxygen concentration falls below 10 %, respiratory activity reduces drastically leading to anaerobic metabolic processes (Kays, 1991).

Furthermore respiration is directly related to gas composition in storage because during respiration there is a utilization of substrate (glucose) and a release of carbon dioxide. Therefore poor ventilation leads to the accumulation of gases which rein the product by causing off-flavours, internal break down and shrinkage and consequently reducing shelf life of the roots.

Mechanical damage

Damage caused during harvesting and subsequent handing and transportation increases the rate of deterioration of produce, it renders the sweet potato liable to attacks by destructive microorganism or decay organisms. Mechanical damage to sweet potato roots such as bruises, cuts, wounds and breakages causes heavy losses owing to bacterial decay. Moreover it makes it very easy for microbes to gain entry and this can be rectified by curing the roots before storage.

Pre-harvest infection

Sweet potato is known to be affected by *Cylas sp.* both in the field and during storage. Harvesting roots that have been affected by weevils should not be stored because weevils multiply and increase in number which consequently destroys wholesome roots within a short period of time. Decay of sweet potato is mostly caused by the infection of breaks and cuts created by mechanical injuries; the natural barriers are destroyed, hence making it easy for microbial penetration. More so, decay causing organisms penetrate through natural openings or even through the thin delicate skin. The infection either become established during the growth of sweet potato but remain quiescent until after harvest or often become visible only during storage or during handling and storage.

Physico-chemical changes in storage

Sweet potato roots continue to 'live' after harvesting and because they are detached from the supply of photosynthase from the leaves, it tends to rely on their own internal food reserves. This therefore leads to the changes in both physical and chemical composition of the harvested tuberous root. Depending on the cultivar and method of storage the roots show signs such as; weight loss, shrinkage, and decline in sugar and starch content. According to Zhitian *et al.* (2002) sweet potato roots stored 180 days after harvest showed a decrease in starch content, increase in alpha-amylase activity while, glucose and sucrose concentrations increased early in storage then reduced later on. Storage also influences both sensory and cooking properties; Zhitian *et al.* (2002) also observed that storage reduced flour pasting property. When roots are long in storage they become watery or soften when cooked and also lose their flavour.

Physical characteristics of sweet potato roots

Physical characteristics of raw, unprocessed food materials include, shape, porosity, bulk and particle density, moisture content, angle of repose and surface area. This describe the physical property of the produce; which is, a unique characteristic way a food material responds to physical treatments involving mechanical, thermal, electrical, optical, sonic and electromagnetic processes (Rao *et al.*, 1995).

According to Baryeh (2001); Pradhan *et al.* (2009); Yalcin and Karababa (2007) the physical property of fruits, grains, seeds is essential in designing, fabricating equipment and structures for handling, transporting, processing, storage and also for assessing quality. Furthermore, the physical property influences the cooling and heating load of the material (Sahay & Singh, 1996). Physical properties of other agricultural produce such as maize, cocoa, rice, potato (Irish) are known, but the physical properties of sweet potatoes are not known.

Bulk density

Bulk density is the mass of a group of individual particles divided by the volume of the space occupied by the entire mass, including the air space. It is expressed in metric units of gm cm^{-3} or kg m^{-3} (Stroshine & Hamann, 1995). Generally the density of food material is useful in mathematical conversion of mass to volume and calculation of storage capacity.

Porosity

When sweet potato roots are place in a container, there are airspaces between the roots. The porosity of the sweet potato roots is therefore defined as the percentage of the total volume occupied by air space. It also indicates the amount of pores in the bulk materials (Pradhan *et al.*, 2009). Porosity can be calculated from bulk and true density using the relationship given by Mohsenin (1970) as:

$P_{os} = (1-$ — ....(3)

where:

P_{os} = porosity (%),

Pb = bulk density (kg m^{-3})

P_t = true / particle density (kg m^{-3}).

Porosity of produce allows air, and liquid to flow through a mass of produce during processing. Low porosity implies low percentage air space and more resistance to fluid flow, thus difficult to cool or heat. While, in high porosity of produce air flows easily through the bed, and cooling or heating is faster and hence power required by pumps and fans is low (Rao *et al.*, 1995)

Angle of repose

The angle of repose is the maximum angle of a stable slope determined by friction, cohesion and the shapes of the particles. The angle of repose is the property of the bulk material which indicates the cohesion among the produce, and the higher the cohesion, the higher the angle of repose (Pradhan *et al.*, 2009).

Angle of repose is very useful; it indicates the ability to flow, design of equipment for processing, storage and to size conveyor belt for transporting the material. It can be determined by using the following relationship (Kaleemullah & Gunasekar, 2002; Sacilik *et al.*, 2003)

$$\Theta = \tan^{-1} \text{ —} \qquad \cdots\cdots\cdots\cdots\cdots (4)$$

where:

H = height of the cone (cm)

D = diameter of the cone (cm)

Co-efficient of static friction

Co-efficient of static friction is the ratio of the force required to slide the material over a surface divided by the normal force pressing the material against the surface (Bahnasawy *et al.*, 2004). The coefficient of friction according to other researchers (Bart-Plange *et al.*, 2005; Pradhan *et al.*, 2009) is calculated from the relationship:

$\mu = \tan \alpha$ ....(5)

where:

μ = the coefficient of friction

α = the angle of tilt in degrees.

Size and shape (Sphericity)

According to Mohsenin (1970), shape and size are inseparable in a physical object and are generally necessary if the object is to be satisfactorily described. Shape affects the grade of produce. To make the highest grade a tuber must have the common recognized expected shape of that particular produce. If misshaped, the produce will be down-graded and not sell or may sell at a lower price in high volume market.

Sweet potato tuberous roots vary in shape and size according to cultivar, type of soil and environmental conditions. The shapes are normally; round, round-elliptic, elliptic, ovate, obovate, oblong, long oblong, long elliptic and long irregular or curved. Various methods have been used to describe shape and size namely; sphericity, aspect ratio, roundness, and roundness ratio.

The sphericity can be described by defining three characteristics dimensions; the major, intermediate and minor (Mohsenin, 1986) and it is based on the assumption that the volume of a solid can be approximated by calculating the volume of a triaxial ellipsoid with diameters equal to the major (L), intermediate (W) and minor (T) diameters of the object (Stroshine & Hamann, 1995)

given as:

———— ....(6)

Volume

Volume of solids can be determined experimentally by liquid or gas displacement. In this procedure, a large beaker big enough to accommodate the solid is partially filled with water and the weight of the beaker and water determined (Wbw) on a platform scale. Then the solid is completely submerge in the water such that it does not touch the sides or the bottom of the beaker or container and the weight of beaker, water and object recorded (Wbws). The difference in the weights is equal to the buoyant force on the object and the volume determined by dividing the buoyant force by the density of water. Stroshine and Hamann (1995)

Vs = ―――――― ....(7)

According to Wilhelm *et al.* (2004), the volume of non-porous object such as vegetables and fruits can also be obtained by the use of platform scale or top loading balance. In this method the volume is computed from the relationship:

―――――――― ....(8)

500-roots weight

The weight of sweet potato roots vary widely from 90 g to 450 g but the variation depends widely on variety and location. Survey conducted at Jukwa market revealed that sweet potato (TIS 2 variety) sold in sacks is made up of 409 tuberous roots and weighs about 85 kg on average (S. Aidoo, personal communication, March, 2009). This information is very useful in determining the load imposed on the storage structure. It also gives an idea about the weight of bulk sweet potato roots and cost of conveying a particular tonnage.

Moisture content

The entire component of food material is made up of moisture content and dry matter content, the two sum up to unity or 100%. Moisture content of agricultural material is described as the percentage equivalent of the ratio of weight of water to the weight of dry matter or total weight. It can either be expressed on dry basis or wet basis using the formula;

—— , or —— ……………………………………………(9)

where:

Mw is moisture content on wet basis

Ww = wet weight

Wt = total weight.

Md = moisture content on dry basis

Wd =dry weight.

The storability of agricultural material is directly related to moisture content, along with temperature and availability of oxygen.

Processing and uses

Sweet potato processing methods vary from location to location. It either involves simply slicing and sun drying of the roots as practiced in most developing countries to large scale, multi-stage production such as frozen, canned or flaked products tailored to consumer expectations (Woolfe, 1992).

In Africa and Ghana in particular sweet potato is boiled and eaten. There is little processing, this involves slicing and sun drying, and finally grinding into flour. However, there is high potential of processing sweet potato roots into items such as starch, alcoholic beverages, sugar syrups, snacks, and flour for bread/pastries. It is very important to process and use sweet potato roots because it reduces losses, provides the product all year round and increases the economic value of the crop.

Sweet potato storage structures

There are various ways in which sweet potato is stored, though in Africa particularly West Africa where there is no definite structure, the harvested roots are either stored in sacks, heaped under trees, heaped on the farm and covered with palm fronts, clamps or pit storage where roots are buried in the soil. According to Mutandwa and Gadzirayi (2007), there is no universal method and small holder farmers use method passed on to them from generation to generation through indigenous knowledge systems. Woolfe (1992) reported that an ancient method practiced by New Zealand farmers for 100 years consist of underground storage houses, with timber roofs, dug into the side of a hill, the roots are placed on the floor covered with fern brush. However according to Keleny (1965) in this method there are heavy losses due to decay and rate damage.

Duku (2005) stated that in Kenya the roots are reported to be stored in purpose-built wooden stores roofed with metal sheets that offer convective ventilation and reduced losses about 50 % from 85 %.

Pit storage is also practiced in Zimbabwe and Malawi, where the roots are placed in pits and cover with thatch under a shed (Lancaster & Coursey, 1984). Generally, sweet potato can be stored in two main storage structures;

1. Storage without buildings: this involves the traditional way of storing; it is very simple and inexpensive. It includes delay harvesting or *in-situ* storage, clamp, covered clamp and pit storage.

   In-situ or delayed harvesting or in-ground storage involves leaving the sweet potato in the field until it is needed or in high demand (Opara, 1999). This method is not very encouraging because it leads to high weevil infestation and damage up to about 50%, it also prevents the use of the farm land for growing other crops.

   The clamp is very simple; the roots are placed on a bed of straw 1-3 m wide and ventilation duct placed along the bottom and the piled roots covered with straw casing.

   The pit method is generally considered better than *in-situ* storage for rural communities and it is mostly practiced in Zimbabwe, Malawi, Zambia and Kenya. In the pit method a pit is dug on an open ground, ash is sprinkled at the bottom and on the sides of the pit and covered with grass and soil under a shed or woven mat (Mbeza & Kwapata, 1995).

2. Storage in buildings- it involves refrigerated or controlled-atmosphere storage, multi-purpose building and ventilated stores.

   Refrigerated and controlled-atmosphere storage is mostly practiced in the developed countries where large scale commercial production is feasible. It involves complex operations which are very expensive but provides long term storage.

In ventilated stores the following essentials must be observed:

a. The building should be located at a site where low night temperature occur over the required storage period
b. It must be oriented to make maximum use of the prevailing wind ventilation.
c. The material covering the roof and wall should provide a better insulation from the heat of the sun; grass thatch on a bush-pole frame can be very effective, particularly if it is wetted to provide evaporative cooling
d. White paint applied to the surface of the material will help reflect heat from the sun
e. Provide ventilation spaces below floors and between walls and roof to give good air circulation.
f. If the store is subjected to cold night temperature, movable louvers are fitted and adjusted to limit the flow of warm air into the store during the day.
g. The structure should be built in the shade of trees if they do not interfere with the prevailing air flow, become of bush fire hazard or fall onto the structure during storms.

Type of structure and site selection

Storage structure is the first line that provides the defence between the produce and the environment; therefore care should be taken in the selection of the site and type of structure that provide the maximum defence.

The type of structure used is influenced by various factors such as: availability of local materials, climatic conditions, usage and skilled labour. The site should be easily prepared, and provide a shady and airy cool environment (Duku, 2005).

Material Selection

In building a storage structure there exist a wide range of materials available. The proper selection of the materials used in a particular storage structure would influence the cost, maintenance, ease of cleaning, durability and appearance.

In selecting the material for construction one has to consider the availability of the material, strength of the material and the cost and skill of labour. According to Duku (2005) in selecting materials, the following is essential:

a. Service requirement; the material should be strong, resistance to wear, resistance to weathering, thermal properties, ease of cleaning and workability of material.
b. Economic requirement; made up of the cost of acquiring and maintaining the materials.

Furthermore NRI (1995) indicated that the following factors need to be considered when choosing materials for construction:

a. Type and function of the building and the specific characteristics required of the materials used which includes strength, water resistance, and wear resistance, attractive, appearance etc.
b. Availability of the material in the area
c. Economic aspect of the building in terms of original investment and annual cost of maintenance.
d. Transportation cost.
e. Quality and durability of different types of materials
f. Availability of skilled labour required to install some type of materials
g. Cultural acceptability or personal preference.

Wood

All woods are classified as either hardwood or softwood. According to Lindley & Whitaker (1996), the classification is not an indication of the physical characteristics of the lumber, for example yellow pine which is a soft wood is harder than willow which is a hardwood. Hardwoods are obtained from angiosperm most of which are deciduous trees (those who lose their leaves in autumn) and include ash, oak, sapele, cottonwood, maple and balsa. Softwoods are obtained from gymnosperms which are primarily evergreens and coniferous or needle-bearing trees example cedars, pines, hemlocks, wawa, ebony, makore etc. (Lindley & Whitaker, 1996).

Chemically wood is made up of about 60 % cellulose, 28 % lignin and 12 % sugar and extractives, depending on the type. Also mechanical properties range from strong to weak, they are have a density of <400 to 801 kg m^{-3}, Modulus of elasticity is between 10.5 to 4 kN mm^{-2}, Bending stress 10-50 N mm^{-2}, and Compressive stress 2.5 to 29 N mm^{-2} (Duku, 2005).

Various species of wood have a number of physical characteristics which includes (Lindley & Whitaker, 1996): Strength; which is the ability to resist breaking when loaded. It is particularly important for application such as rafters, floor joists and beams

Stiffness; is the ability to resist deflection or bending when loaded. It is an important characteristic for members such as studs, joist and beam.

Toughness; this is the ability of wood to withstand shock loading.

Hardness; is the resistance to denting and wear, and is required for flooring

Paint holding ability; species that have a uniform grain and exhibit little swelling and shrinkage are likely to hold paint well.

Generally woods have both merits and demerits, the merits are: it is relatively cheap, light in weight and easy to work with simple tools. The demerits are; can easily catch fire, warps if not well seasoned, decay (dry rot / wet rot) affected by fungi and insect. However they are used for walls, openings, roof trusses, and stairs.

Bamboo

Bamboo is a perennial grass with over 550 species found in the tropics, subtropics and temperate zones. It reaches maturity in 5-6 years or even later depending on variety or species. Furthermore, bamboo can grow up to 35 meters in height and diameter of 10-300 mm and it should be harvested or cut before blooming since it loses its resistance and dies after blooming. After harvesting it should be seasoned and treated to prevent rot and insect attack.

Bamboo has a high percentage of fibre with a high tensile, bending and straining capacity (NRI, 1995).

However, the low durability of bamboo constitutes one of the main defects along with its flammability and the tendency to split easily which prevents the use of nails. The remedy is the use of nodes as places of support and joints, and the use of lashing materials in place of nails. Also dry bamboo is very susceptible to fire and this should be prevented by the use of fire retarding material.

The strength of bamboo varies widely with species, growing conditions, position within culm, seasoning and moisture content. It is believed that bamboo is as strong as timber in compression and very much stronger in tension. On the other hand it is weak in shear, only about 8 % of compression strength where timber is 20 to 30 % (NRI, 1995). Bamboo is used basically in building construction for wall poles, frame, roofing, and water pipes and after splitting it can be used to form flattened boards or woven wall and ceiling panels.

Thatch

Thatch is a material obtained from grass, reed or palm, or banana leaves. It is a very common roofing material used in developing countries most especially in the rural areas. However, it is susceptible to decay due to attack by fungi, insect and is easily destroyed by fire (NRI, 1995).

Thatch has a good thermal insulation capacity that keeps the inside of the structure cool and at uniform temperature while the outside temperature is hot or varying considerably. It is cheap, readily available and requires less skill to fix. Thatch can last up to 20-30 years if well treated with fire retardant and maintained properly.

Earth

Earth is among the oldest material used for building construction in the rural area. It is the subsoil excavated for use as a building material (Duku, 2005). The advantages of earth as a building material includes; it is a fire resistant, a good noise absorbent, has very high thermal capacity, cheap and readily available locally at most building site and also easy to work using simple tools and skill. On the other hand the material has the following limitation (NRI, 1995): low resistant to water penetration resulting in crumbling and structural failure, high shrinkage/swelling ratio resulting in crumbling and structural failure when exposed to changing weather conditions, and it has a low resistant to abrasion. Despite these weakness, earth as a building material can be made more suitable by mixing chopped grass or fibrous material with clay to improve the strength of the mud block and plastering the mud block with cow dung mixture (NRI, 1995). Alternatively, the earth can be mix with a stabilizer such as Portland cement, lime, bitumen and pozzolanas to reduce shrinkage and swelling and make the soil water proof.

Fastener

Fasteners in agricultural buildings are nails, bolts, screws, hinges, latches and twines. All these materials used bonds individual materials to each other and provide shear strength that enables the structure to withstand external forces. For example nail gives strength to a joint by the shear strength of its cross-section and the grip around its shank (Duku, 2005). It is therefore necessary to select the right type of nail in any particular situation. According to Duku (2005) the most common type of nail used to join wood is 101.6mm (2 inches) thick when it carries load while For Box nail used in boards it is 50.8mm or less and cannot be relied on to carry load.

Concrete

Concrete is composed of two components: past and aggregate. The paste is made by mixing Portland cement and entrained air with water. While the aggregates are generally fine aggregate which is sand and a coarse aggregate which is gavel, crushed rock and crush slag (Lindley & Whitaker 1996). Concrete has a lot of useful properties and it makes it eminently suited for wide range of agricultural uses. It is plastic and can be formed into any shape needed, and when cured it is even better, because in this condition it provides a hard, sanitary surface with an attractive appearance. Furthermore it is non-combustible, durable, nearly maintenance free, resistant to termites and rodents. However concrete is very heavy and adds significant high weight to buildings. Furthermore, altering concrete structure is not easy. Concrete has high thermal conductivity, losses strength at high temperature, low resistance to acids and sulphates. It is not commonly used in rural farm buildings because it is relatively expensive therefore, the cost of concrete can be reduce by using pozzolanas instead of cement.

Jute Sack

Jute sack is made from organic material. It is mostly use for packaging Agricultural materials such as cocoa and maize in Ghana. It is 117 cm long and 65 cm wide, when wet or socked in water, it takes a long time to dry. According to Faleh (2002) it has the highest cooling efficiency when it is used as a wet pad for constructing evaporative cooler.

Load on Building

Structural or design loads are forces acting on the structural members. These loads affect the total structure in so many ways. Hence structural component must be selected that are strong enough to withstand the forces or loads that will be imposed on the building. This must satisfy the equation stated by Lindley and Whitaker (1996): Load $\leq$ Resistance, meaning if the load effect exceeds the resistance, then the structure will fail. However, neither side of the equation can be determined with precision therefore, the designer must be able to assign a risk factor to the solution. Generally, forces or loads acting on structural members can be categorized into the following:

Dead load: Dead loads are the mass of all the elements of the building including foundation, footings, walls, suspended floors, frame, roof deck and any permanently installed item. Dead loads are an integral part of any Agricultural building; they are permanent and stationary hence, relatively easy to estimate.

Live load: Live loads according to Lindley and Whitaker (1996) include both static and dynamic loads resulting from the use or occupancy of the building. Static loads result from the weight or pressure from stationary equipment, and stored produce. Dynamic loads result from the dynamic effect of farm equipment and material handling equipment. Live loads are difficult to calculate because; the components vary from time to time.

Environmental load

Environmental loads are wind, snow and earthquakes or are forces of nature. These loads must be estimated on the basis of meteorological records for the area, it may vary from location to location. In the tropics wind load is one of the main environmental loads and where velocities are recorded wind loads can be calculated by the following equation (Duku, 2005).

$q = 0.0127\ V2k$ ....(10)

where:

q = basic velocity pressure (Pa),

V = wind velocity ($m\ s^{-1}$), $k = (h/6.1)^{2/7}$

h = design height of building (m)

6.1 = height at which wind velocities were recorded

Elements of Construction

The element of construction comprises the walls, roof, floor, footings and foundation.

Wall

Walls are essential component of farm building. It provides an enclosure, protection and security to properties. Walls may be divided into two groups namely; load bearing walls and non load bearing walls. Load bearing walls are walls which support loads from floors and roof in addition to their own weight. It resists side pressure from wind, and stored material from within the building. Non load bearing walls carry no load, only its own weight.

A good quality wall should provide strength, stability, weather resistance, fire resistance, thermal insulation and noise absorbent. There are various ways to construct wall and may be divided into four main groups namely; Masonry wall, Monolithic wall, Frame wall and Membrane wall. Duku (2005) reported that factors that determine the type of wall to use includes

a. Availability of material at a reasonable cost
b. Climate
c. Availability of skilled labour capable of using the materials
d. The purpose of the building- functional requirements.

Roof

The roof is an important part of any farm building in that it gives the necessary protection from rain, sun, wind, heat and cold. The strength of the roof is important for the structure of the building and the goods as well as the occupants. The roof structure must be designed to withstand the dead load imposed by the roofing and the framing materials. It should also withstand the forces of wind and in some areas impart of snow or drifting dust. A good roof must be leak proof, durable and satisfy other requirement such as fire resistant, good thermal insulator or high in thermal capacity (Duku, 2005).

The choice of roof shapes, frames and coverings vary widely, its variability is related to factors such as the size, use of the building, anticipated life, appearance and cost of the materials. According to Duku (2005) roofs may be classified in three ways: According to the plan of surface, according to the structural principles of the design and finally according to the span. The type or shape of roof includes hip roof, gable, shed, gambrel, and gothic. The slope and angle of roofing vary widely depending on the material use, for thatch roof covering it ranges from 34-45 ^{o} (Duku, 2005). The angle of roofing is very much important; it determines the rate of flow and leakage. A well selected roofing angle improves the structure as a whole.

Floor

The floor can be as simple as the compacted soil present on the site before the building was constructed or could be as complex as finished hardwood parquet. An excellent floor offers protection against rodents and vermin, easy to clean and dry, and durable. The floor should be able to sustain its own weight and other imposed load. There are different types of floors but the one commonly used is the solid or grade floors. In this type of floor the finished level should be at least 150 mm above outside ground level and it offers protection against flooding which is undesirable in farm building.

According to Lindley and Whitaker (1996) it is particularly important to have a dry floor in a storage structure, therefore a vapour seal of 4 to 6 mm polyethylene plastic with well lapped joints should be installed on top of the fill. A thin layer of stiff concrete or grout spread evenly under the plastic sheet will help avoid puncturing during placement of the concrete. Normally floors have slab thickness of 4 inches (100 mm) for ordinary usage and 6 inches (150 mm) when subjected to heavy loads such as tractor and trucks. Concrete used for floors should have small size coarse aggregate 25-40 mm and be mixed relatively stiff (5 to 6 gal/sack of cement) (Lindley & Whitaker 1996).

Footings and foundations

A footing is the enlarged base of a foundation while foundation is that part of the structure which is in direct contact with the ground to which the structure and other imposed loads on the structure are transmitted. An excellent design and constructed foundation is essential for the structural integrity of the building. The foundation must resist and distribute forces acting on it so that any movement will be small and uniform (Lindley & Whitaker 1996).

A good or properly constructed footings and foundations must keep buildings plumb, free of cracks and in the case of below grade basement, it must be free from leaks. According Lindley and Whitaker (1996) to important loads acting on foundations are

a. Dead load of the structure that is the contents of the structure, all acting in a vertical direction.
b. Wind loads that impose lateral or lifting forces on the foundation.
c. Horizontal forces from soil, water and stored commodities
d. Uneven soil forces caused by non uniform and variable moisture levels.

Foundations may be divided into several types and these types are suitable for specific situations example; continuous wall foundation is used for basement walls or as curtain walls, pier foundations are used to support the timber frames of light buildings, pad and pole used for light buildings with no floor loads. Foundation materials must be durable and balance, the common ones often used are; stones, earth, poured concrete, concrete blocks and bricks.

The total load and the soil bearing capacity determine the design of footing and foundation. An accurate footing area is needed and can be calculated by using the formula (Duku, 2005),

— ……………………………………………………………………………(11)

where:

A= footing area, (m^2),

P = load on column (N)

Sv = soil bearing capacity or allowable soil pressure (Pa)

Properties of structural sections

The properties used in designing structural sections in buildings include: centre of gravity, radius of gyration (r), slenderness ratio (λ), section modulus (Z) and moment of inertia (I).

Slenderness ratio (λ)

Slenderness ratio is the relationship between the length of the column with its lateral dimensions and the end fixity conditions. This affects the resistance of the column to buckling. Slenderness ratio can be expressed as.

— or – ……………………………………………………………(12)

where:

λ = slenderness ratio,

K = effective length factor

L = length of the column,

I = effective length of the column (K x L)

r = radius of gyration = √(I/A).

Section modulus

Section modulus describes the ratio of moment of inertia (I) about neutral axis of the section to the distance (C) from neutral axis to the edge of section. According to Lindley and Whitaker (1996) the ability of a beam to resist bending moment depends not only on its safe fibre stress, but also on its section modulus (S) which is based on shape, dimensions and position of installation. For rectangular cross section beam section modulus can be determined by:

— .... (13)

where:

b = breadth

d = depth as installed.

Radius of gyration

Radius of gyration of a cross-section is the measure of the distribution of the area of the cross section in relation to the axis. In design it is used in relation to the length of compression members, such as column and struts to estimate their slenderness ratio and hence their tendency for buckling (FAO/SIDA, 1988). Radius of gyration can also be describe as the distance at which the entire area could be concentrated and still give the same moment of inertia value (I) about a given axis (Craig, 1996). In slender compressing members clipping occurs about the axis for which the radius of gyration (r) is minimum. The general relationship is:

$I = Ar^2$ ....(14)

where:

A = Area,

r = radius of gyration

I = moment of inertia

Moment of inertia

Moment of inertia also called second moment of area. It is a property which measures the distribution of area around a particular axis of a cross section, and is an important factor in resistance to bending (FAO/SIDA, 1988).

The moment of inertia only measures how the geometric property or shape of a section affects its value as a beam or slender column. A very good shape for a section is the one in which the greater part of its area is far away from its centroidal and neutral axis.

Centre of gravity

Centre of gravity or centroid of a section is the point about which the area of the section is evenly distributed. Centre of gravity can sometimes be outside the actual cross section of the structural element. The reference axis is directly related to the centroid because it is usually considered as those passing through the centroid.

Air circulation and stocking bed depth in farm buildings

Air circulation is needed in a farm building; it regulates the temperature and controls the atmospheric composition in the building. For a better designed farm building the window and door should be oriented south to north or north to south, so that air can circulate freely. Sweet potato roots when stored are living and active like any other living material. It undergoes physiological activity such as respiration and this releases carbon dioxide and heat hence ventilation is needed, however resistance to airflow is a function of both product and air property (Jayas *et al.*, 1987) and the uniformity of air flow distribution in a bulk of sweet potatoes is also influenced by size and shape of the tubers (Irvine *et al.*, 1993). ASAE, (1995) stated that air flow resistance in a bed or a stockpile of Agricultural produce can be determined by the relationship:

$$ - \quad \overline{\qquad\qquad} \quad \text{..} (15) $$

where:

P = pressure drop (pa)

L = bed depth (m),

a = constant for particular product (obtained from table)

b = constant from a particular product (obtained from table)

Q = airflow ($m^3\, s^{-1} m^2$)

CHAPTER THREE

MATERIALS AND METHODS

Study area

The research was carried out at the Technology village of the School of Agriculture, University of Cape Coast from January 2008 to January, 2010. The experimental area falls within the Coastal Savannah zone of Ghana. It is between latitude 05^{o} 03'N and 05^{o} N and longitude 01^{o} 13'W and is characterized by annual rainfall of about 750 mm to 1200 mm (Boamah, 2008). There are two main seasons in the area; wet season and dry season. The wet season is divided into major and minor seasons. The major season starts from May to July and peaks in June while the minor season begins from September to November and peaks in October. The main dry season in the area is from December to February. Temperatures throughout the year are usually high, with maximum usually between 30–36 ^{o}C and minimum between 22–26 ^{o}C (Ayittah, 1996). The relative humidity in the area ranges from 70 % to 90 %, this reduces to 70% in the afternoon (Meteorological station Cape Coast, 2002).

The study involves three main experiments. Experiment one was the construction, and testing of two innovative storage structures. Experiment two was determination of some selected physical properties of two sweet potato varieties (TIS 2 and Ukerewe variety). The final experiment was to assess the shelf-life of two sweet potato varieties which were given four pre-treatments and stored in two different storage structures.

Experiment one

Two storage structures were constructed; these were Evaporative cooling barn (ECB) and Pit storage structure (PSS).

Site selection

A shady area was selected and levelled. Precaution was taken to avoid trees from interfering with the prevailing air flow, and also to prevent trees from falling on the structure during storms. The land also had a good drainage.

Material selection

For Evaporative cooling barn, the materials used for the construction of the storage structure included wood, bamboo, thatch (grass), jute sack, wire mesh, sack/net and cement blocks. The wood used was avodire (*Turraeanthus africanus*). This was selected because it was readily available, cheap and had good mechanical properties. Bamboo was used for the rafters and water trough because it was readily available, and relatively very cheap. It is also very strong and light weight, thus imparts little on dead load. Spear grass was used as thatch roofing because it was available or abundant at the site. Cement blocks were used for the wall because of their availability and strength.

For Pit storage structure, the materials used for construction are bricks, plywood, 3 inches PVC pipe, wood (Avodire), polythene sheets. Brick wall was selected because it was cheaper and readily available, while plywood was also selected because of its light weight and it was easy to work with into simple form.

Elements of construction

The Evaporative cooling barn had a wooden frame, roofed with spear grass thatch and had a two level cement block course at the base. Jute sack was used as the wall bamboo was used as a trough below and 3 inches PVC pipe as a trough above. The structure had four posts as a foundation post. The post and the floor had a concrete mix in the ratio of 1:3:5 with 31 kg of water per 50 kg of cement.

There was 50 cm thick concrete collar connected to the footings to make it strong. The floor was made with 4cm thick concrete and this was allowed to cure for 7 days. Two courses of cement blocks were raised above the floor to form a rectangular base of 3 m by 2.5 m as seen in Figure 1. The roof was double-pitched, covered with spear grass thatch with dropping eaves sloped at 45 ^{0} to reduce sun rays into the structure and facilitate easy run-off.

The structure had a non load bearing wall made of jute sack to serve as evaporator. This was fastened to the post and beam with thread and nails. In all 46 jute sacks were used and each had an area of (0.9 m^2). There were two windows oriented in south north direction (facing each other in the opposite direction) for better ventilation during the day and night (Plate 6).

For the Pit Storage Structure, a pit of 1.5 m wide, 3 m long and 1.2 m deep was dug out. Brick wall was laid in the pit and 3 inches PVC pipe was raise underground to the surface to provide underground ventilation, also a suck-way was created underground to improve temperature and relative humidity. Plywood was used to construct a 24 unit partitioned shelves and placed into the pit. The entire structure was constructed under a mono-pitch shade of 2 m high Figure 2 and Plate 7.

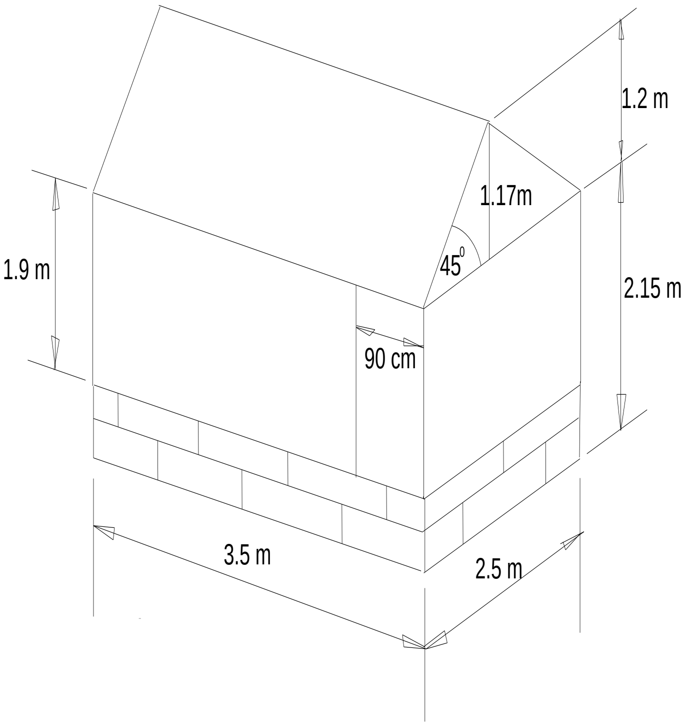


Figure 1. Sketch of Evaporative cooling barn

Plate 6. Evaporative cooling barn

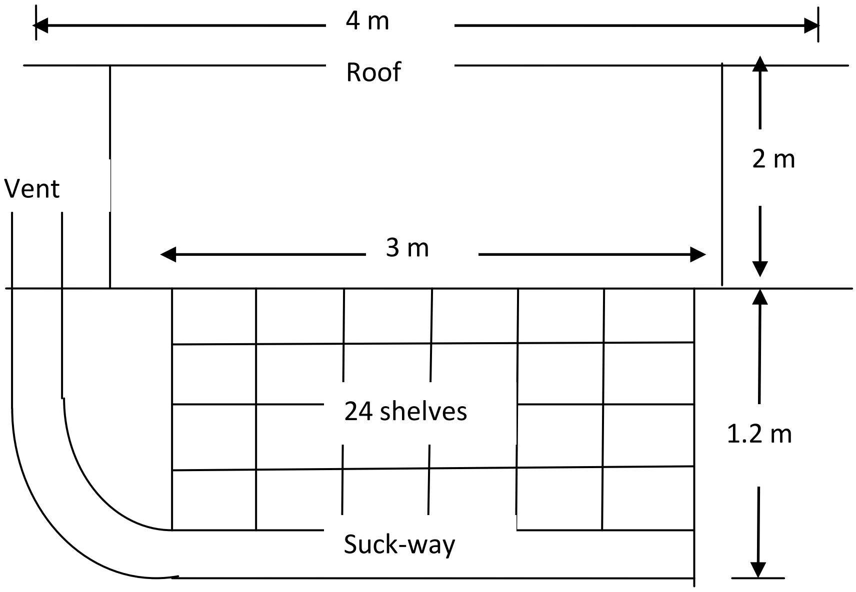


Figure 2. Sketch of Pit storage structure

Plate 7. Pit storage structure

Operation and environmental control in storage structures

Evaporative cooling barn

In the Evaporative cooling barn, 10 gallons (45 litres) of water was poured into the 3 inches PVC pipe at 9 am every day. The water flows by gravity, and wets the jute sacks while the excess water drips into the bamboo trough.

The wet surface cooled the dry hot air that passed through and it also increased the relative humidity and lowered the temperature.

Pit storage structure

Water was poured into the underground suck-way through the PVC pipe that was projected out on to the surface Plate 7. This cooled the hot air in the pit and raised the relative humidity.

Experiment two

Some selected physical characteristic of sweet potato tuberous roots such as: Bulk density, 500 root weight, porosity, angle of repose, coefficient of static friction, and volume & surface area were determined to provide an engineering data for sweet potato.

Bulk density

The bulk density of the two varieties was calculated by applying a test procedure used by Suthar and Das, (1996); Jain and Bal, (1997); Baryeh, (2001). A known volume of container was filled with the sweet potatoes and weighed on a sensitive balance. The bulk density was computed by dividing the average measured weight by the known volume of the container.

Porosity

Porosity was obtained by the method described by Stroshine and Hamann (1995). A container of known volume was filled with sweet potatoes to a known mark and distilled water was added or poured into the container with the sweet potatoes up to the known mark, the porosity was calculated as the ratio of the volume of water poured to the total volume of the container.

— ....(16)

where:

Va = volume of air space.

Vt = Total volume.

Angle of repose

The angle of repose was obtained by the procedure used by (Jain & Bal, 1997). The sweet potatoes were allowed to fall onto a mounted circular plate of known diameter from a falling height of 15cm to form a natural heap. The height of the heap was measured and the angle of repose (θ) calculated as follows:

–) ....(17)

where:

h = height of the heap (cm),

r = radius of the plate (cm)

Coefficient of static friction

Co-efficient of static friction was determined for sweet potatoes on Avodire wood surfaces because it was used to build the shelves. The materials were fastened to a tilting table. A frame made of square wooden bars was placed on the surface. The frame was filled with sweet potatoes and the table slowly tilted manually until there was movement of the whole mass. The coefficient of friction was determined as the tangent of slope angle (α) of the table measured with a protractor (Oje & Ugbor, 1991) and calculated from the relationship:

$$\mu = \tan \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

where:

μ = coefficient of friction,

α = angle of tilt in degrees.

Volume

The volume of the 100 randomly selected sweet potatoes was found individually. In this process a large beaker was partially filled with water and the weight of the beaker and water was determined (W_{bw}) on a platform scale. Then the sweet potato was completely submerged in the water such that it did not touch the sides or the bottom of the beaker. Then the weight of the beaker, water and sweet potato recorded (W_{bws}). The difference would be equal to buoyant force of the sweet potato. Finally the volume was determined by dividing the buoyant force by the density of water (P_w), Stroshine and Hamann (1995).

$$Vs = \frac{\quad}{\quad} \quad \text{or} \quad Vs = \frac{\quad}{\quad} \quad \ldots\ldots\ldots\ldots \quad (19)$$

where:

W_{bw} = weight of beaker and water,

P_w = density of water

W_{bs} = weight of beaker, water and submerged sweet potato

Surface area

Surface area was determined by measuring the length and girth (at root mid-point) for the 100 randomly selected sweet potatoes at the start of the trial. The root surface area was then estimated by the equation (Rees *et al.*, 2003), assuming the roots to be a perfect ellipsoid.

$A=2\pi r- + ((2\pi\, r_1 - r_2)/e) \times \text{Sin-1}\ (e)$ .... (20)

where:

Eccentricity (e) = $(r_1^2 - r_2^2)^{1/2}/r_1$,

A = Surface area (cm^2),

r_1 = 0.5 x length of root (cm) and

r_2= 0.5 x diameter of root = girth/2π.

500-roots weight

The 500 roots weight was obtained by randomly picking 500 sweet potatoes and weighing them on an electronic balance to 0.01 g accuracy. The procedure was repeated three times and the average 500 roots weight determined for each variety.

Preparation of pre-storage treatment

Ash pre-treatment

Ash from charcoal and fire wood was collected from a restaurant, wood used for the charcoal was suspected to be *Cassia siamea* (C. Essoun, personal communication, May, 2009). The ash was applied on the surface of the cured sweet potatoes and placed into a sack and kept in the shelves. For each sack there were 7 sweet potato tuberous roots and 200 g of ash was applied per sack.

Brine pre-treatment

Brine solution was prepared from common salt (NaCl). Correct concentration of brine solution was selected by using a simple molar concept approach. In this approach the concentration was found from the relationship:

______________ ……………………………………(21)

The concentration (C) of the brine solution used was 1.2 mol dm^{-3}. This was prepared by mixing 500 g of salt in 7 dm^3 of water. The cured sweet potatoes in the sacks were dipped into the brine solution and later packed on the shelves for storage.

***Lantana camara* extract pre-treatment**

Lantana camara leaves were harvested and soaked in water for 24 hours (2 kg was soaked in 10 litres of water). It was then pounded in a mortar, mixed with the water and sieved to obtain as aqueous extract of *Lantana camara*. The sweet potatoes were dipped into the aqueous extract and allowed to air dry before and then placed on the shelves for storage.

Plate 8a. Researcher appying pre-storage treatment

Plate 8b. Pre-treated sweet potatoes package for storage

Experiment three

The shelf-life of two sweet potato varieties, which were given four pre-treatments and stored in two different storage structures were evaluated.

Curing of sweet potato tuberous roots

Two varieties of sweet potato: TIS 2 and Ukerewe were selected because of their distinct morphological feature. TIS 2 has yellow skin colour while Ukerewe has red skin colour. After 4 months cultivation, they were harvested and cured at a temperature of 29-32 ^{o}C and relative humidity of 85-90 % for 5 days. Curing is a standard procedure which is also known as wound healing (Hall 1993, 1994). It protects the tuberous root against deterioration in storage.

Plate 9. Curing of sweet potato tuberous roots

Storage in structure

Twenty-four (24) unit shelves for each of the two storage structure were stocked with six (6) sacks per shelf with seven (7) cured sweet potatoes each. Each shelf was stocked with the same kind of treatment (Plate 6). In all there were 144 sacks per storage structure. A sack in each shelf was sampled every two weeks for 3 months. During each sampling, one sack was picked randomly for destructive analysis.

Experimental design and experimental procedure

The experimental design used was factorial combination of four pre-treatments (ash, brine, *lantana camara* extract and control), two varieties of sweet potato (TIS 2 and Ukerewe) and two storage structures in a completely randomized design (CRD) with 3 replications.

For the storage structures there were shelves partitioned into 24 units (Plate 8). Each unit contains 6 sacks of which there are 7 cured sweet potatoes. At every two weeks, random sampling technique was used to select a sack from each treatment replicate for assessment.

Plate 10. Shelves showing sweet potatoes in storage

Data collection

Storage data were collected every two weeks over the storage period of 12 weeks on:

1. Weight loss/ shrinkage in storage
2. Changes in energy content in storage
3. Extent of weevil damage
4. Decay (severity and incidence)

5. Sprouting index
6. Wholesomeness

Changes in moisture content / energy content

Firstly, the percentage moisture content of the roots were determined at every 2 weeks interval for all pre-treatment. A root was selected at random from each sack. It was chopped into slices and uniformly mixed. Ten grams was taken and dried in an oven at 105 ^{o}C until a constant weight was observed. The difference between the initial weight and final weight was determined as the moisture content (Coskun *et al.,* 2005). The energy content was then found by incorporating the moisture content figure into the formula (Bradbury, 1986; Woolfe, 1992).

$E = -17.38\ M + 1699$ .... (22)

where:

E = Energy in kJ per unit weight (kj 100 g^{-1})

M = Moisture content in percentage.

Determination of weight loss and shrinkage

Weight loss and shrinkage was determined at 2 weeks interval. Before the sweet potatoes were placed on the shelf each sack containing seven roots were weighed and taken as the initially weight. At every 2 weeks a sack was selected at random and reweighed. The difference in the initial weight and the final weight was determined as the weight loss per every pre-storage treatment.

Shrinkage of the roots was determined by measuring the diameter of the root in each sack with a calliper at the start of the study and also at every 2 weeks interval. The diameter measuring point at the start was marked with a permanent marker and this served as subsequent measuring point. The difference in the initial and final diameter was used to calculate for shrinkage.

Percentage weevil damage in storage

This was determined at 2 weeks interval. A sack containing 7 roots was selected at random from each treatment and the extent of weevil damage assessed. Sweet potatoes that showed the presence of *Cylas sp* or tunnels created by the weevils were recorded as damaged (Nicole, 1997).

Percentage decay in storage (incidence and severity)

For every fortnight, a sack containing 7 roots was removed from each pre-treatment and assessed for the presence and percentage of surface showing visible decay. Root showing extensive rotting (> 60% surface) was removed from the sack (Rees *et al.,* 2003). The incidence decay was found from the root showing the presence of decay whiles, percentage severity was also recorded using a scale of 1-5 depending on the percentage area of the root surface showing decay (scale of 1-5 where 1 = 0 %, 2 = 0-25 %, 3 =25-50 %, 4 = 50-75, 5 =75-100 %).

Sprouting index / Percentage sprouting

The sprouting index was calculated every 2 weeks interval. For each treatment a sack was selected at random and the number of roots examined for the occurrence of sprouting and sprouting index calculated by the formula (Obetta *et al.,* 2007).

Sprouting index = ―――――――――――― ....(23)

Wholesomeness

Percentage wholesomeness of the tuberous root was assessed at every 2 weeks interval. For each pre-treatment, a sack was selected at random and sweet potato roots that showed at least 25 % deterioration was considered unwholesome (Mutandwa & Gadzirayi, 2007) and the percentage wholesomeness calculated.

Data analysis

The results were subjected to analysis of variance using GenStat statistical software to determine whether there were significant differences in the parameters studied. Mean comparisons were done using Duncan's Multiple Range Test for separation of means (Russel, 1990).

Psychometric properties in storage structures

A digital psychrometer was used to measure the relative humidity and temperature in the storage structure and Ambient. Psychrometric software (CYTPsyChart) was used to generate the properties of air (specific volume, enthalpy, humidity ratio, and dew point temperature) in the storage structures.

Cooling efficiency (η)

The cooling efficiency for the storage structures were calculated from dry bulb temperature, ambient air dry bulb and wet bulb temperature using the formula described by (Getinet *et al.*, 2008).

$$\eta = \frac{}{} \quad \ldots \quad (24)$$

where:

Td = dry bulb temperature of ambient air

Tw = wet bulb temperatures of ambient air

Tc = dry bulb temperature of air in the cooling chamber.

Cost of construction

Cost of construction of the storage structures comprises materials and quantity of materials used for the structure. For the entire structure, each unit price was calculated and then summed up to make the cost of construction of the structure. Moreover, labour cost and ten percent of the total cost (for contingency) was added to obtain the overall cost of construction of the storage structure (Tables 1 and 2).

Tables 1 and 2 show the materials and quantities used as well as the total price of the materials. Table 1 shows total cost for constructing Evaporative cooling barn while, Table 2 also shows the total cost for the Pit storage structure.

Table 1. Materials and actual cost for Evaporative cooling barn

Items	Materials	Quantity	Unit price (Gh¢)	Total cost
1	Hard wood 2”x3”x14’	38	4.00	152.00
	Hard wood 4”x4”x4”	4	12.00	48.00
2	Nails 4”	½ box	9.00	9.00
	Nails 3”	½ box	9.00	9.00
	Nails 2”	¼ box	5.00	9.00
	Nails 1½	¼ box	5.00	5.00
3	Cement	3	9.50	28.50
4	Jute Sack	60	1.50	90.00
5	Welder mash	1	18.00	18.00
6	Thatch (grass)	35	1.50	52.50
7	3” PVC pipe	4	9.00	36.00
8	5” cement block	50	1.00	50.00
9	90^o PVC elbow	4	4.00	16.00
10	PVC pipe reducer	1	7.00	7.00
11	3” Bamboo	15	1.00	15.00
12	Wood 1’’x12’’x7’’	14	9.00	126.00
13	Machine Plaining	14	5.00	70.00
14	Nylon rope	1	3.00	3.00
15	Sack	1	2.00	2.00
16	10 % contingency			74.6
17	Labour cost	3	40.00	120.00
18	Transportation		15.00	15.00
	Total cost			955.6

Table 2. Materials and actual cost for Pit storage structure

Items	Materials	Quantity	Unit price (Gh¢)	Total cost
1	Hard wood 2"x3"x14'	38	4.00	152.00
	Hard wood 4"x4"x4"	4	12.00	48.00
	Plywood ½''	4	9.00	36.00
2	Nails 3"	½ box	9.00	9.00
	Nails 2"	¼ box	5.00	9.00
	Nails 1½	¼ box	5.00	5.00
3	Cement	3	9.50	28.50
4	Brick wall	600	4000	240.00
5	Welder mash	1	18.00	18.00
6	Polythene sheet	2	1.50	52.50
7	3" PVC pipe	2	9.00	36.00
9	90^{o} PVC elbow	2	4.00	16.00
10	PVC pipe reducer	1	7.00	7.00
11	3" Bamboo	4	1.00	15.00
15	Sack	2	2.00	4.00
16	10 % contingency			67.6
17	Labour cost	3	40.00	160.00
18	Transportation		15.00	15.00
	Total cost			918.6

CHAPTER FOUR

RESULTS

Volume and load on the storage structures

Table 3 shows the volume and load of the storage structures assuming 2/3rd full.

Table 3. Volume and load on the storage structures

Structures	Volume (m^3)	Load (kN)	$- \times V \times \beta \times g$
		TIS 2	Ukerewe
ECB	18.8	74	72
PSS	7.2	28	27

ECB = Evaporative cooling barn
PSS = Pit storage structure

Water evaporation from the storage structures and ambient condition

Figure 3 shows cumulative evaporation per unit surface area from the storage structures (no-load) and ambient condition over a two-month period. The evaporation rate at ambient condition was higher at 0.3592 g cm^{-2} daily followed by the pit storage structure and the evaporative cooling barn at 0.0522 g cm^{-2} and 0.0327 g cm^{-2} daily respectively.

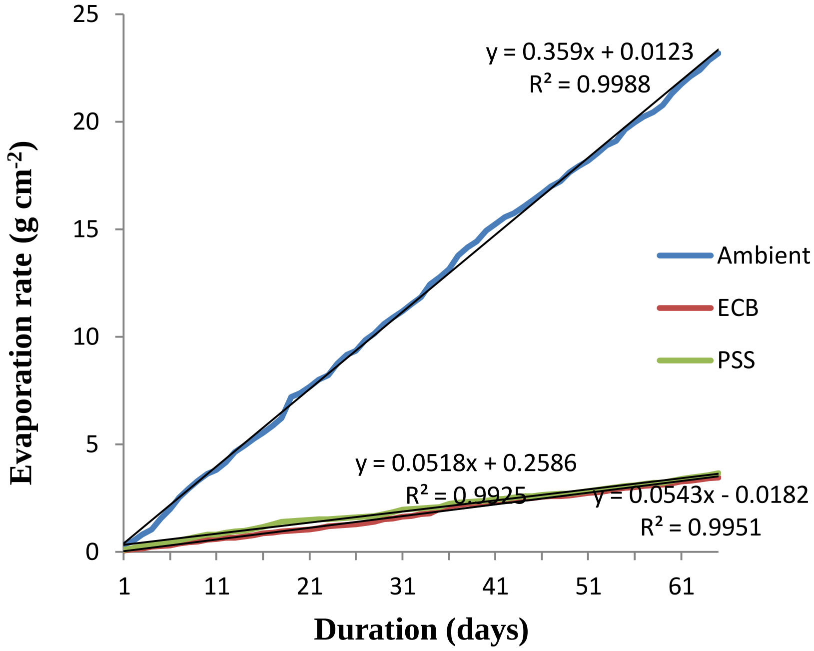


Figure 3. Cumulative evaporation in storage structures and ambient

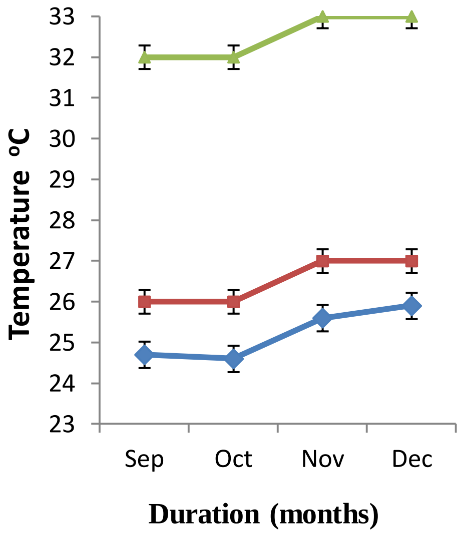
Psychrometric properties in storage structures and ambient

The psychrometric properties that were determined included: moisture content of air, enthalpy, specific volume, temperature, and relative humidity.

Temperature variation in ECB, PSS and ambient

Figures 4a and 4b show the mean monthly maximum and minimum temperatures in the two storage structures and the ambient. Maximum temperatures were recorded during the day (9:00 am and 3:00 pm) and minimum temperatures recorded in the night (9:30 pm). The temperature increased steadily from September to December, with ambient recording the highest maximum temperature of (31.0-34 ^{o}C) followed by the PSS (26.0-27.0 ^{o}C) and the ECB (24.6-25.9 ^{o}C) respectively.

From Figure 4b the mean monthly minimum temperature was lowest for the ambient, followed by the Evaporative cooling barn and the Pit storage structure respectively.



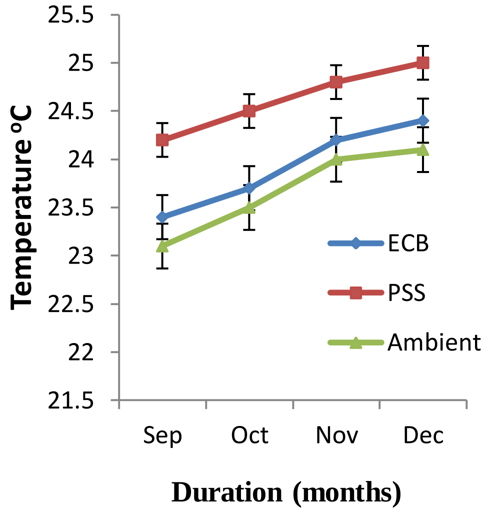


Figure 4a. Maximum temperature in storage structures

Figure 4b. Minimum temperature in storage structures

Relative humidity variation in ECB, PSS and ambient

Table 4 shows the relative humidity variation of the ambient air and inside the two storage structures. The ECB recorded the highest relative humidities (89-91 %) followed by the PSS (85-88 %) and the ambient (67-68 %).

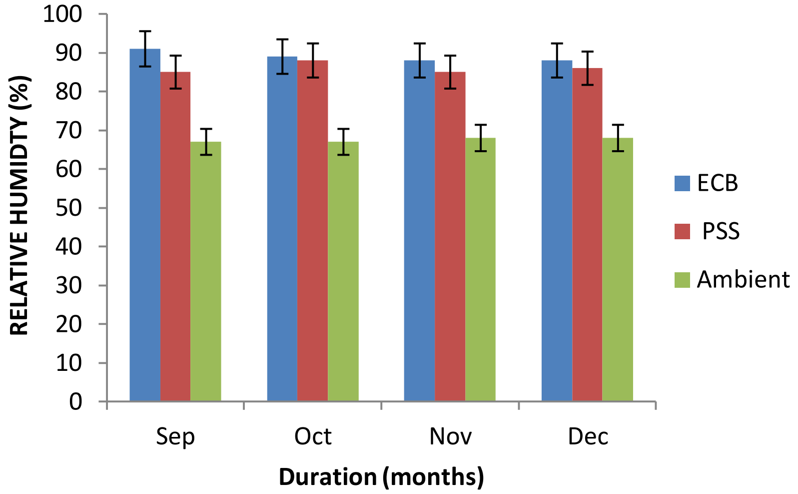


Figure 5. Relative humidity in storage structures and ambient

Enthalpy and specific volume of air in the storage structures

From Figure 5a, the enthalpy of the air was lowest in the Evaporative cooling barn (69.16-72.36 kJ kg^{-1} dry air), followed by the Pit storage structure (76.29-76.89 kJ kg^{-1} dry air) and the ambient (80.13-84.90 kJ / kg dry air) respectively. Also from Figure 5b the specific volume was lowest in ECB (0.8678 -0.8714 m^3 kg^{-1} dry air) while PSS was (0.8718 - 0.8766 m^3 kg^{-1} dry air) and Ambient recording the highest (0.8878-0.8930 m^3 kg^{-1} dry air).

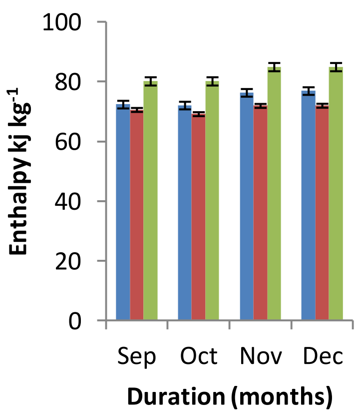


Figure 6a. Enthalpy in storage structures

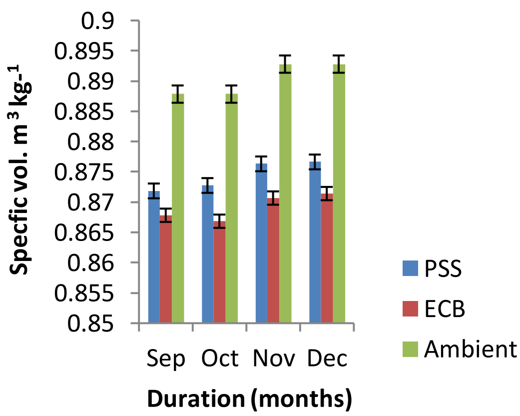


Figure 6b. Specific volume in storage structures

Physical properties of sweet potato tuberous roots

Table 4 shows some selected physical properties of the two sweet potato varieties stored in the structures. It was observed that, the physical properties of TIS 2 variety were higher than Ukerewe variety.

Table 4. Physical properties of two varieties of sweet potato tuberous roots

Variety	Bulk density kg m^{-3}	Porosity %	500 root weight kg	Volume cm^3	Angle of repose (^{o})	Surface area cm^2	Coefficient of friction (Avodire wood)
TIS 2							
Mean	594.00	61.74	111.00	214.38	37.5	159.89	0.577
Sd	9.02	18.01	1.58	129.51	0.50	59.41	0.018
s.e	4.03	1.80	0.71	12.95	0.22	5.94	0.008
Ukerewe							
Mean	578.00	47.43	73.00	109.69	36.6	103.20	0.500
Sd	29.13	3.02	3.91	72.90	0.54	42.32	0.007
s.e	13.02	0.30	1.74	7.29	0.24	4.23	0.016

Pre-treatments and storage performance in storage structures

The results determined includes: percentage wholesomeness, percentage weight loss, percentage sprouting, percentage weevil damage, percentage decay (severity and incidence), percentage shrinkage and energy content (total sugar) are shown below.

Wholesomeness in Evaporative cooling barn & Pit storage structure

Figures 7a & b to 8a & b indicate the wholesomeness of the pre-treated sweet potato varieties in storage. In all cases there were reductions of wholesomeness over time. However, for overall performance, *Lantana camara* treatment gave more wholesome sweet potatoes than the other treatment in all the storage structures. Furthermore, in the two storage structures TIS 2 variety maintained higher percentage wholesomeness than Ukerewe (Uke) variety.

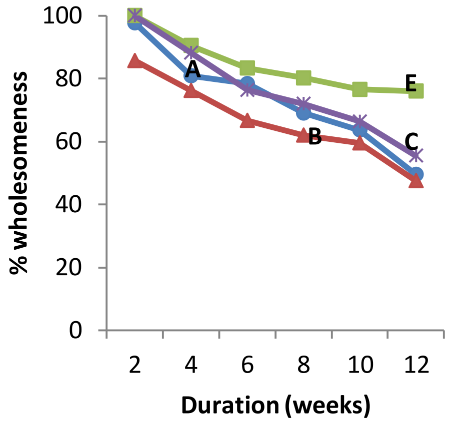


Figure 7a. Percentage wholesomeness for the treatments in Evaporative cooling barn

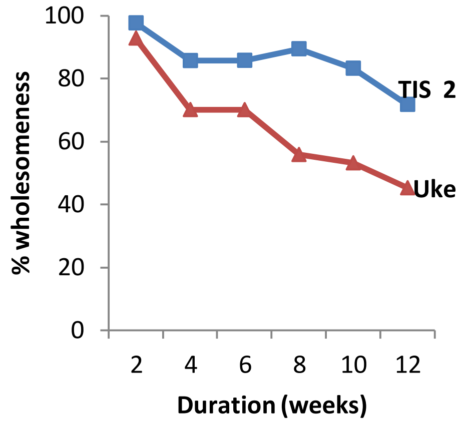


Figure 7b. Percentage wholesomeness the varieties in Evaporative cooling barn

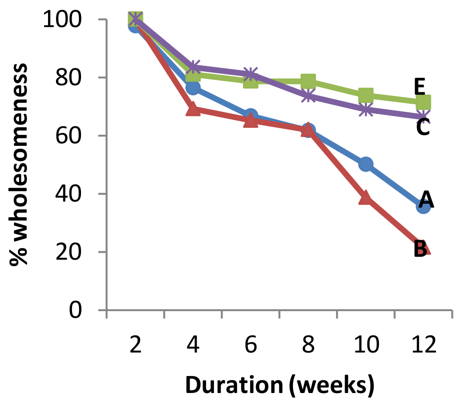


Figure 8a. Percentage wholesomeness for the treatments in Pit storage structure.

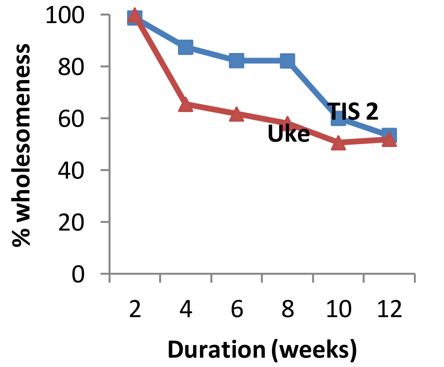


Figure 8b. Percentage wholesomeness varieties in Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Weevil damage in Evaporative cooling barn & Pit storage structure

Figure 9a & b to 10a & b shows the percentage weevil damage for pre-treated sweet potato varieties in storage. Weevil damage was not observed until after 4 weeks when it was seen in samples in the Pit storage structure and after 5 weeks in the Evaporative cooling barn. Generally brine and *Lantana camara* treatments reduced weevil damage in storage. Also TIS 2 had lower weevil damage in all the storage structures.

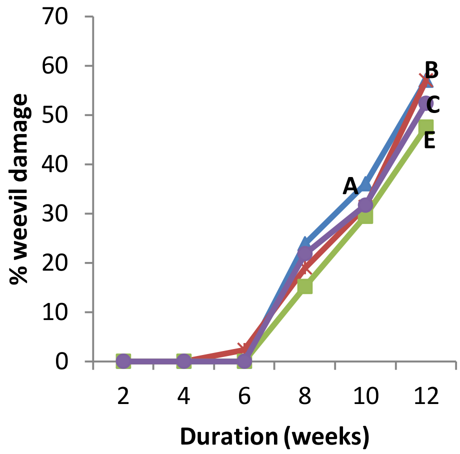


Figure 9a. Percentage weevil damage for all treatments in Evaporative cooling structure

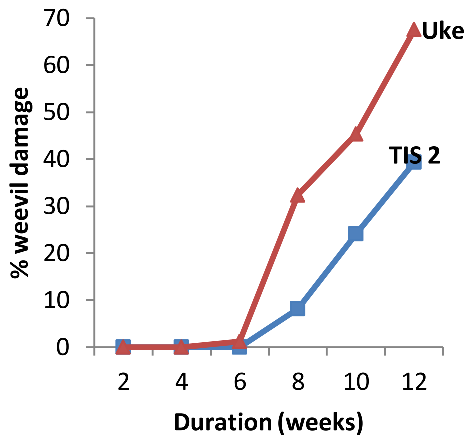


Figure 9b. Percentage weevil damage for varieties in Evaporative cooling structure

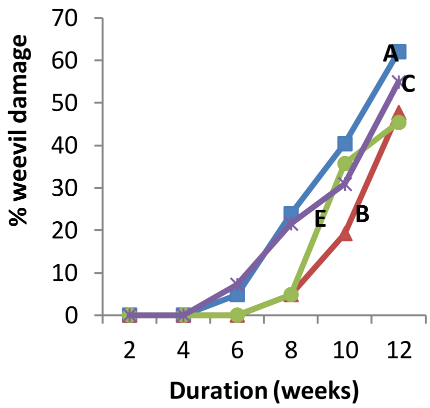


Figure 10a. Percentage weevil damage for all treatments in Pit storage structure

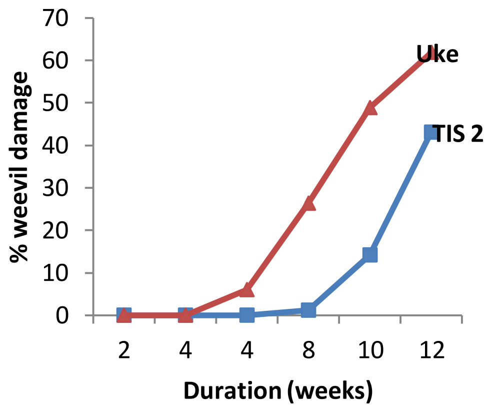


Figure 10b. Percentage weevil damage for varieties in Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Sprouting in Evaporative cooling barn & Pit storage structure

Figure 11a & b to 12a & b measure the sprouting index of the pre-treated sweet potato varieties in the two storage structures. Sprouting became pronounced after 4 weeks. However, Ash treatment showed the lowest sprouting and it started at 8 weeks in ECB and 6 weeks in PSS. TIS 2 started sprouting at 7-8 weeks in ECB while in PSS both varieties sprouted at 4 weeks

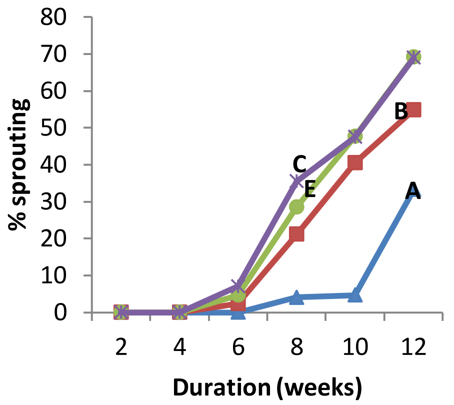


Figure 11a. Percentage sprouting for treatments in Evaporative cooling barn

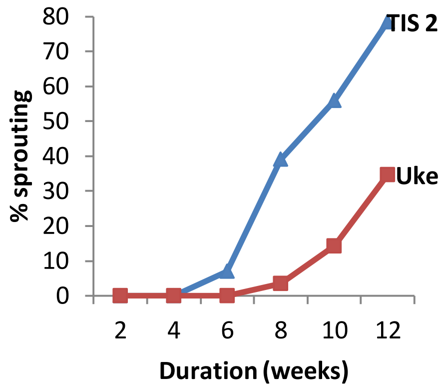


Figure 11b. Percentage sprouting index for varieties in Evaporative cooling barn

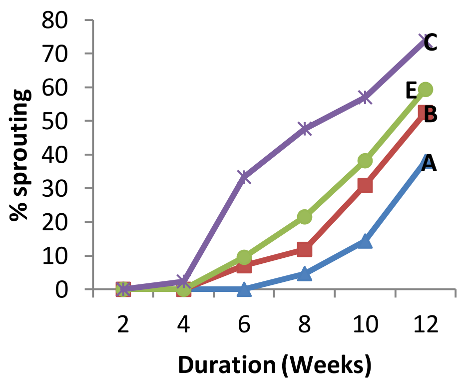


Figure 12a. Sprouting index for treatments in Pit storage structure

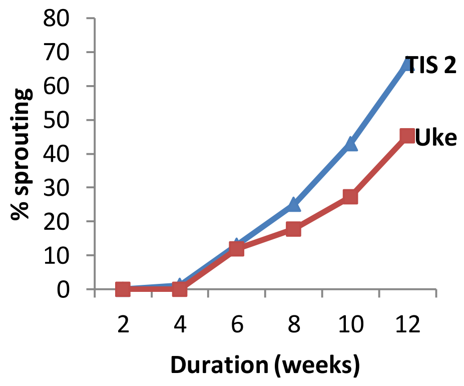


Figure 12b. Sprouting index for varieties in Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Weight loss in Evaporative cooling barn & Pit storage structure

Figure 13a & b to 14a & b are the weight loss of pre-treated sweet potato varieties in storage. In ECB *Lantana camara* extract had the lowest weight loss though it was slightly different from control. On the contrary, Control had the lowest weight loss in PSS. Overall weight loss in storage was lower in TIS 2 variety than Ukerewe.

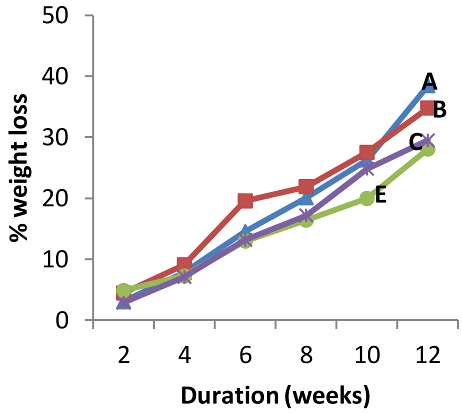


Figure 13a. Percentage weight loss for all treatments in Evaporative cooling barn

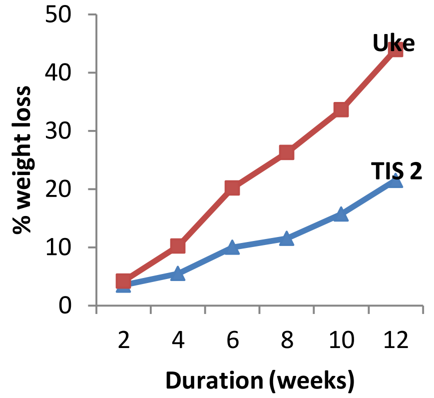


Figure 13b. Percentage weight loss for varieties in Evaporative cooling barn

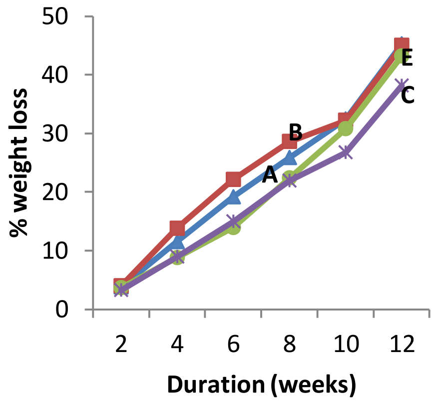


Figure 14a. Percentage weight loss for all treatments in Pit storage structure

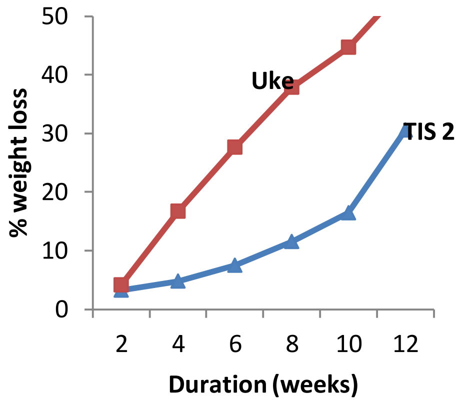


Figure 14b. Percentage weight loss for varieties in Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Shrinkage in Evaporative cooling barn & Pit storage structure

Figure 15a & b to 16a & b show the effect of pre-treatments on shrinkage of sweet potato varieties. Generally shrinkage started at 2 weeks and was lowest for sweet potatoes treated with *Lantana camara* extract. More so, shrinkage was more in Ukerewe than TIS 2.

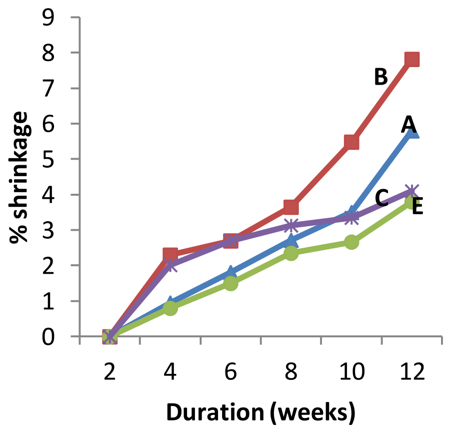


Figure 15a. Percentage shrinkage for all treatments in Evaporative cooling barn

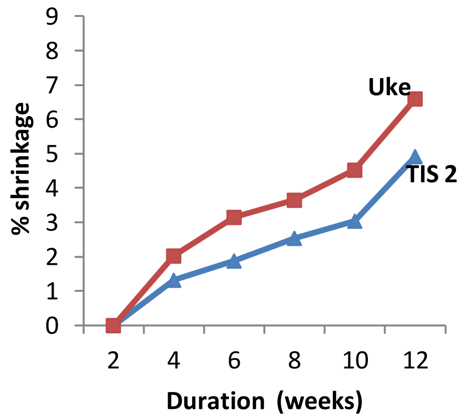


Figure 15b. Percentage shrinkage for varieties in Evaporative cooling barn

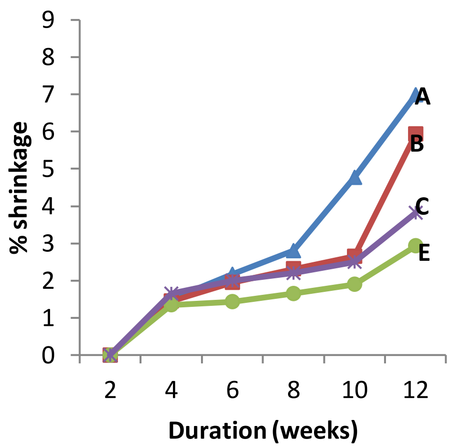


Figure 16a. Percentage shrinkage for all treatments in Pit storage structure

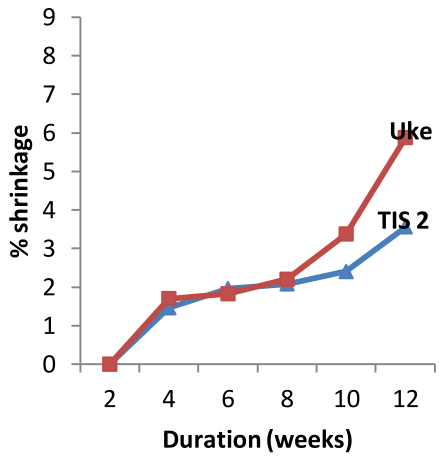


Figure 16b. Percentage shrinkage for varieties in Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Incidence decay in Evaporative cooling barn & Pit storage structure

Figure 17a & b to 18a & b indicate percentage incidence decay of the pre-treated sweet potato varieties in storage. In ECB and PSS *Lantana camara* extract had the lowest incidence decay. Also TIS 2 variety had the lowest incidence decay in storage.

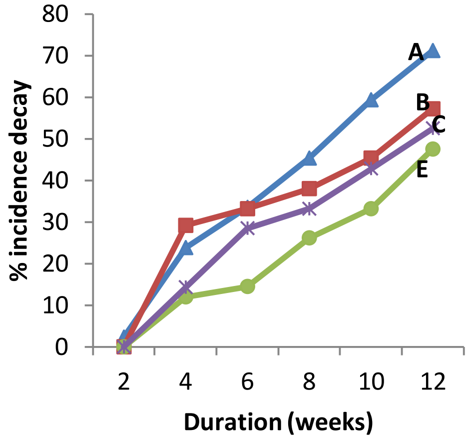


Figure 17a. Percentage incidence decay for all treatments in Evaporative cooling barn

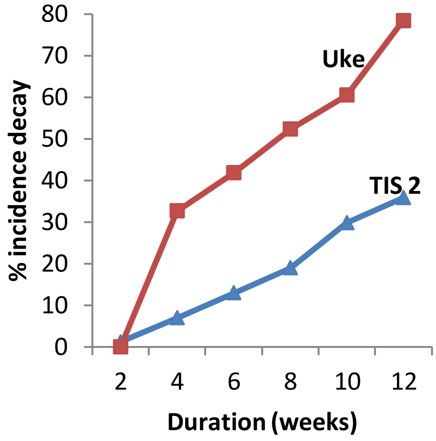


Figure 17b. Percentage incidence decay for varieties in Evaporative cooling barn

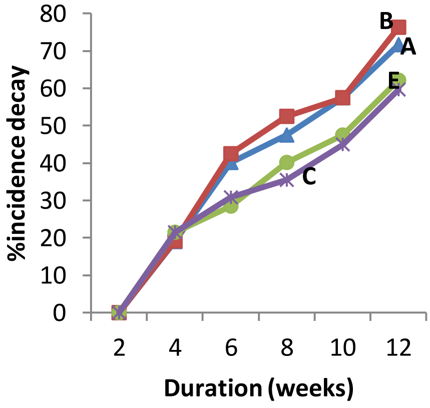


Figure 18a. Percentage incidence decay for all treatments in Pit storage structure

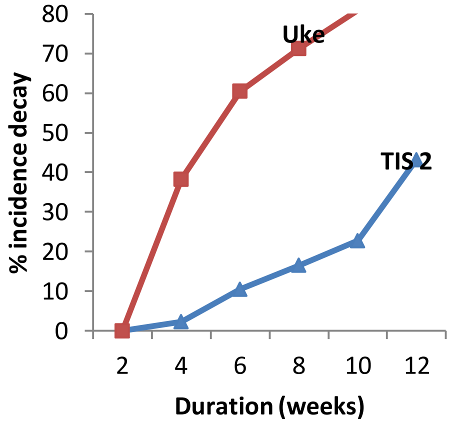


Figure 18b. Percentage incidence decay for varieties Pit storage structure

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Severity decay in Evaporative cooling barn & Pit storage structure

Figure 19a & b to 20a & b show the severity decay of the pre-treated sweet potato varieties. Generally, *Lantana camara* extract performed better than all the others. However, Control was not so much different from the extract. Also TIS 2 maintained a lower severity decay than Ukerewe variety.

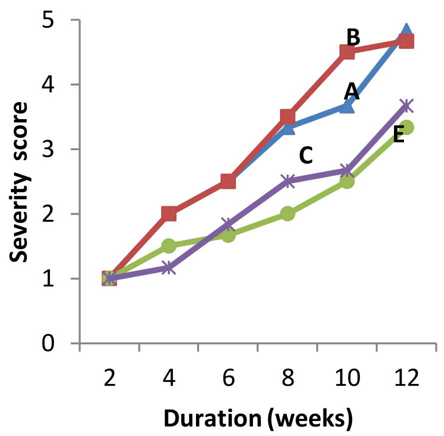


Figure 19a. Severity decay for all treatments in Evaporative cooling barn

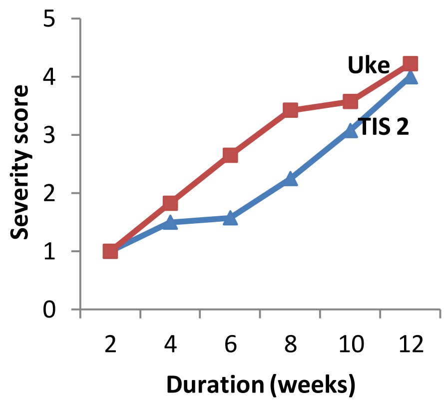


Figure 19b. Severity decay for varieties in Evaporative cooling barn

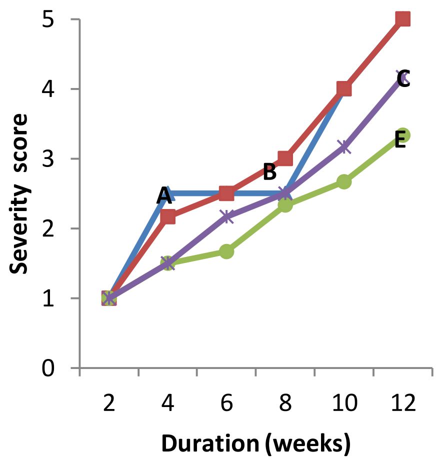


Figure 20a. Severity decay for all treatments in Pit storage structure

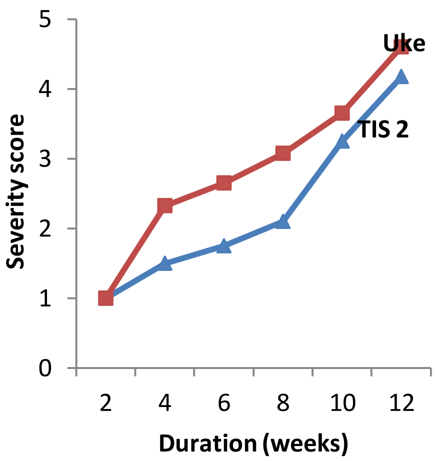


Figure 20b. Severity decay for varieties in Pit storage structure

(Severity score 1 =0%, 2 =0-25%, 3 =25-50%, 4 =50-75, 5 =75-100%)

A=Ash, B=Brine, C=Control and E=*Lantana camara* extract

Energy content of sweet potato tuberous roots in storage structures

Figure 21 measure the changes in energy content (total sugar) of sweet potatoes in storage. In all there was an increase in energy content (total sugar). However, sweet potatoes in PSS had higher energy content after 8 weeks compare to those in ECB.

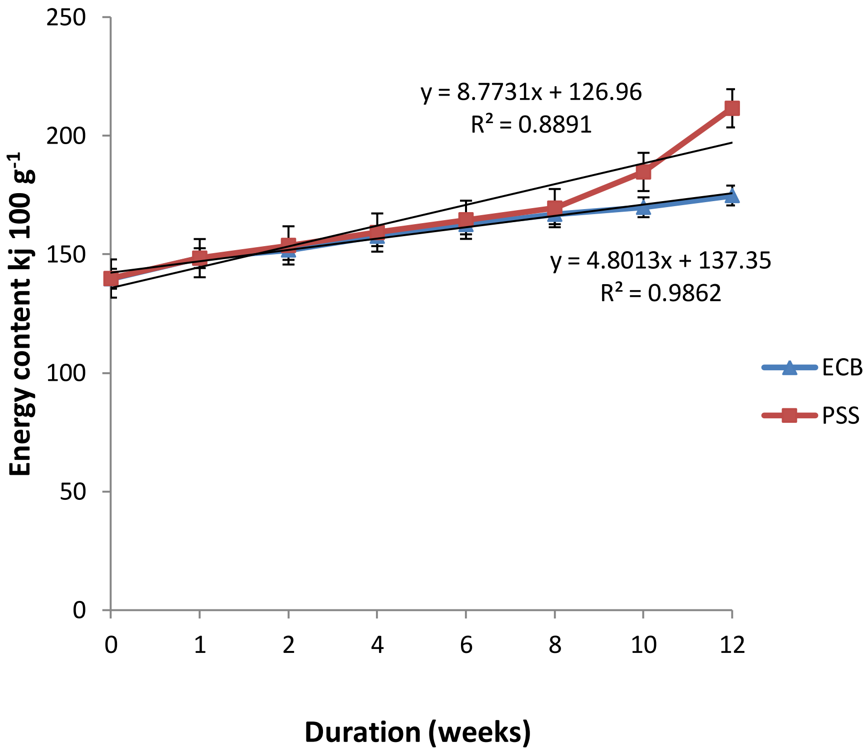


Figure 21. Changes in energy content (total sugar) in storage structures

CHAPTER FIVE

DISCUSSION

Evaporative cooling barn

The Evaporative cooling barn was constructed with the following materials namely: wood, jute sack, cement blocks, PVC pipe and spear grass thatch. A shady airy area was selected and the structure constructed, during the construction the direction of the sun and wind were observed. It was roofed with spear grass because it is a good insulator and abundant. The spear grass roofing material helped in keeping the inside of the structure cool. The cladding wall was made of jute sack, which acted as a wet pad. Jute sack was selected because it has the highest cooling efficiency and the least salt deposition among all other local fibres available (Faleh, 2002). Also the smaller holes in the jute sack improved ventilation. Cement block was used to raise two courses, this provided structural stability and prevented rain water or run-off from entering the storage structure when it rained. Furthermore, it prevented the jute sack from touching the ground and thus prevented termite damage. The floor of the storage structure was cemented; this provided further strength to the structure and also prevented moisture up take and fungi growth. After a successful construction the storage structure was tested and the mean temperature and relative humidity was 24.7 ^{o}C and 90 % respectively.

Pit storage structure

The Pit storage structure was also constructed under shady airy place; this was to provide cool fresh air. To improve ventilation in the pit, two 3 inches PVC pipes were projected upward to the surface. One PVC pipes were directed against the direction of air flow while the other one was directed along flow for better air circulation. Finally, rubber shed was erected 2 meters above the pit storage structure to prevent rain drops from entering the pit. The structure collectively provided relatively cool temperature and high relative humidity of 26 ^{o}C and 88 % respectively. With this atmosphere the shelf life of sweet potato could be enhanced.

Psychrometric properties in structures and ambient

Temperature and relative humidity

The ambient temperature was relatively higher than the temperature in the two storage structures; this was because in the two storage structures, water was used for evaporative cooling where it reduced the heat energy coming into the structure. For Evaporative cooling barn (ECB), the jute sack wall was occasionally moistened to reduce temperature. The wet jute sack acted as a cladding wall to reduce hot air entering the storage structure, also a bowl of water was placed inside the storage structure to check high temperature build-up and improve relative humidity. More so, in the Pit storage structure (PSS), the suck-away beneath the shelves was moistened daily to improve relative humidity and temperature. Comparatively, two storage structures; Evaporative cooling barn had a better relative humidity and temperature than the Pit storage structure. However, the two storage structures had a better temperature and relative humidity than ambient condition, therefore to a large extent the structures improved environmental conditions and maintained a fairly good relative humidity and temperature.

Enthalpy and specific volume of air

The enthalpy for ambient and the storage structures were different. This is because the cooling in the storage structures were adiabatic processes. The high ambient sensible heat blown through the wet pad was converted to latent heat by vaporization of moisture and a depression in the internal enthalpy of air in the storage structures. Furthermore, heat generated by respiration of the sweet potatoes was too small to raise the enthalpy to be equal to the ambient enthalpy.

The specific volume for ambient air was higher than the specific volume in the two storage structures, while that of Pit storage structure was also higher than Evaporative cooling barn. These differences were due to their enthalpy, dry bulb and wet bulb temperatures. The highest specific volume was recorded in December this was because temperature increased while relative humidity dropped.

Evaporation in structures and ambient

Evaporation of water per area was recorded for both ambient and in the two storage structures. It was detected that the mean evaporation recorded for ambient condition was 0.3592 g cm^{-2} which was far higher than the mean recorded in the two storage structures. Furthermore, for the two storage structures, evaporation in Evaporative cooling barn was 0.0327 g cm^{-2} day^{-1}

while that Pit storage structure was 0.0521 g cm^{-2} day^{-1}. These revealed that there were slight differences in temperature and relative humidity in the two storage structures. Therefore, if sweet potatoes were stored outside they would have lost more weight by evaporation of moisture and deteriorated in the ambient than inside the two storage structures.

Physical properties of sweet potatoes

Bulk density

The bulk density of TIS 2 and Ukerewe was 594.00 kg m^{-3} and 578.00 kg/m^3 at moisture content of 68 % and 60 % respectively. The two varieties were all denser than water, however TIS 2 variety had moisture content higher than Ukerewe and this corresponded to a higher bulk density. This is because bulk density is dependent on weight and to some extent moisture increases weight. More so, the differences in bulk density could be due to the genetic make-up of the two varieties. It has been recorded that bulk density of some crops increased as moisture content increased, for Karinga seeds (Suthar & Das, 1996), Coffee (Chandrasekar & Viswanathan, 1999) and Bambara groundnut (Baryeh, 2001). Therefore the differences in bulk density of the two sweet potato varieties revealed that they would exert different loads on the storage structures.

Angle of repose (^{o})

The angle of repose recorded for TIS 2 and Ukerewe was 37.5 ^{o} and 36.6 ^{o} respectively. The angle of repose depends on the size and shape of the sweet potatoes, the value recorded falls within the range stated by Burton

(1989). The different values recorded for angle of repose reveals that the surface roughness of the two varieties differs.

Volume (cm^3)

The volume of TIS 2 was found to be 214.38 cm^3 while that of Ukerewe was 109.69 cm^3. This reveals that TIS 2 variety has bigger dimension and occupy bigger volume than Ukerewe, therefore for the same volume there would be more Ukerewe variety than TIS 2 in store. This information could be useful for packaging and storage design.

500-root weight

The 500-root weight for the two sweet potato varieties revealed that for the same number of sweet potatoes, TIS 2 was found to be heavier than Ukerewe. Therefore for the same number of tuberous root TIS 2 exerted more pressure on the storage structures than Ukerewe.

Porosity

The porosity recorded was 61.74 for TIS 2 and 47 for Ukerewe. It means that in a given shelf or container there would be more air space around TIS 2 than Ukerewe, hence better ventilation and cooling for TIS 2 than Ukerewe. Therefore their storage behaviour would differ.

Surface area (cm^2)

The average surface area for TIS 2 and Ukerewe varieties were found and according to Burton (1989) surface area for individual potatoes depends on size and it varies from 65 cm^2 to 290 cm^2 for 50 g and 500 g tuber respectively and the two varieties falls within that range. However, for the two varieties, TIS 2 had a bigger surface area than Ukerewe. This means that TIS 2 tuberous roots were bigger in size than Ukerewe and would require more surface coating than Ukerewe.

Co-efficient of friction

Avodire wood was used for the construction of the shelves and the co-efficient of friction for the two varieties were found to be 0.58 and 0.50 for TIS 2 and Ukerewe respectively. Based on the result, TIS 2 variety would not slip easily and had firmer hold on the shelf than Ukerewe.

Pre-treatments and storage performance in storage structures

Percentage wholesomeness

For percentage wholesomeness in storage, significant differences were observed among the pre-storage treatment applied. In all the two storage structures *Lantana camara* extract and control pre-storage treatments performed better than the others. This could be due to the effect of ash and brine on the thin delicate skin. It was found that the thin delicate skin of the sweet potatoes was damaged and this exposed the sweet potatoes to further microbial infection which rendered the roots unwholesome. However, *Lantana camara* extract and control had more wholesome sweet potatoes than the other pre-treatments. It could be due to the combine effect of the storage structure and the efficacy of the extract. Also, *Lantana camara* extract did better in wholesomeness than control because of the insecticidal and biofungicidal property *Lantana camara* extract (Raman *et al.*, 1997). Furthermore, for the two varieties stored (in both storage structures), TIS 2 had more wholesomeness tuberous roots at the end of storage than Ukerewe. This could be attributed to their differences in physical and physiological properties.

Weevil damage

The level of protection offered by the pre-storage treatment differed from one another; ash and control offered poor protection from weevils, this could be due to the low resistance offered. On the other hand, *Lantana camara* extract and brine pre-storage treatment gave some level of protection, though it did not totally eradicate weevils in storage. *Lantana camara* extract offered more resistance to weevil damage than brine during storage, a similar trend was observed by Rajesh and Suman (2006). This could be due to the insecticidal properties of *Lantana camara* extract or the repellent property found in *Lantana camara* extract. Also, for the two varieties, TIS 2 offered was more resistant to weevil damage than Ukerewe. This could be due to better natural defence barrier for TIS 2.

Sprouting

Sprouting is a major problem in the tropics. Normally sprouting starts from 1-3 weeks after harvest depending on the variety and the environmental conditions. In this research it was observed that during the first 4 weeks of storage there was no sprouting recorded. This could be due to factors such as; favourable temperature, low light intensity in the structure and good oxygen and carbon dioxide balance. However, during the subsequent weeks it was seen that (in both storage structures) ash pre-storage treatment had a lower percentage sprouting than all the others, and this was followed by brine, extract and control. This was because ash and brine pre-treated sweet potatoes were deteriorated. More so, TIS 2 sprouted more in storage than Ukerewe, this could be due to the difference in the genetic make-up of the two varieties.

Weight loss

In tropical environment weight loss in storage is inevitable and is primarily noted to be caused by water loss (Rees *et al.,* 2003) however it can be reduced to the lowest means possible. In the ECB, it was observed that *Lantana camara* extract comparatively minimized weight loss better in storage. This could be attributed to physical protection offered by the extract against weevil damage and microbial infections which further contribute to weight loss in storage, because pathogens reduce the ability of the tissue to resist infections. Also, for PSS control did better in minimizing weight loss, followed by *Lantana camara* extract. This reveals that in PSS, the stored produce required no disturbance or pre-treatment. Moreover, for the two varieties used, Ukerewe lost more weight in storage than TIS 2. This could be due to the differences in their genetic make-up. Also, environmental conditions created in the storage structure could have favoured TIS 2 for extended shelf-life.

Shrinkage

Shrinkage in storage is as a result of weight loss which is related to water loss. For all the pre-storage treatments applied shrinkage was not observed in the first two weeks in both structures. This could be due to the negligible reduction of water loss in the tissue of the roots. Interestingly, shrinkage was observed for all the treatments and the storage structures during the subsequent weeks. Sweet potato pre-treated with *Lantana camara* extract had the lowest shrinkage followed by control in the two storage structures, however among the two storage structures shrinkage in ECB was below 4% and below 3% in PSS. This reveals that *Lantana camara* extract reduces infestation which further reduces stress on the roots. Also, the level of the control could be due to the protection offered by the storage structure. On the other hand, for the two varieties used, Ukerewe shrank more in storage than TIS 2, suggesting that breeding for prolonged storage life was feasible (Rees *et al.*, 2003).

Incidence of decay

Decay is a major form of deterioration in storage. In this research it was observed that the presence of decay was different for all the treatments and the storage structures. In ECB *Lantana camara* extract had lower levels of incidence decay; this was because of the biofungicidal property of *Lantana camara* which offered resistance to decay. Also, in PSS, control and *Lantana camara* extract did well in reducing the incidence decay, this showed that the storage structure offered protection whiles the extract also contributed synergistically in reducing deterioration. Furthermore, for the two varieties used TIS 2 was more resistant to incidence decay than Ukerewe, it further support the idea that there is the need to select for storability.

Severity of decay

For the two storage structures, *Lantana camara* extract had the lowest severity decay. This means that the extract improved the resistance to severity decay because it is known to have a biofungicidal property (Raman *et al.,* 1997). Furthermore, for the two storage structures TIS 2 had lower severity decay than Ukerewe. This reveals that the two varieties have different mechanisms for resisting decay and hence varietal selection is practicable.

Energy content (Total sugar)

Changes in starch and energy content of stored produce is inevitable, however the rate of change can be minimized to prolong the storage life of the stored produce. For the two storage structures it was observed that there was a similar build-up of total sugar in storage. According to Takahata *et al.* (1995) starch content in sweet potato decreases in storage while sucrose content increases due to the role of α-amylase in starch degradation and sucrose synthase. However, after 8 weeks in storage, total sugar concentrations in PSS were higher than ECB. The trend could be due to a more stable environmental condition in ECB.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The two varieties used in this research had different physical properties and hence behaved differently in storage. The knowledge of physical properties of the sweet potatoes tuberous root made an important and essential engineering data in the design of the storage structures e.g. the bulk density was used to estimate the structural loads on the storage structure.

Generally, TIS 2 variety stored better than Ukerewe. Comparatively TIS 2 was resistant to: weevil damage, sprouting, incidence decay, severity decay, shrinkage and weight loss than Ukerewe variety.

Significant differences existed among the pre-storage treatments in all the parameters namely: weevil damage, sprouting, decay, shrinkage, weight loss and wholesomeness. *Lantana camara* extract pre-treated samples exhibited lower weevil damage, decay, weight loss and more wholesomeness tuberous roots than all the other pre-storage treatments used. Ash pre-storage treated sweet potatoes had lower sprouting than all the other pre-storage treatments because most of the tuberous root decayed.

For the two storage structures, significant differences existed in some of the parameters while the others showed no significant differences. There were significant differences in weevil damage at 8 weeks of storage but not at 12 weeks in storage. Also, there were no significant differences in the storage structures for shrinkage, sprouting, wholesomeness and severity decay. There were significant differences for weight loss and incidence decay among the two storage structures. Generally, Evaporative cooling barn (ECB) was better than Pit storage structure (PSS) because, it was lower in weight loss, shrinkage, and more wholesomeness tuberous root. Moreover, the two storage structures were far better in all the parameters studied than local storage method which stored sweet potatoes for 1-2 weeks (Rees *et al.*, 2003).

Sweet potatoes stored in the two storage structures exhibited similar changes in energy content (total sugar). However, after 8 weeks energy was higher in PSS than ECB. Also, the loss of water (evaporation) was lower in the two structures than ambient however water lost (evaporation) was more in PSS than ECB.

Temperature and relative humidity were slightly different, but it was better in ECB than PSS though there was fairly stable temperatures and relative humidity for the two structures. Monthly maximum temperatures were drastically higher in ambient than in the structures because, the evaporative cooling reduced temperature. Furthermore, there was a better evaporative cooling in ECB than PSS. On the other hand, monthly minimum temperature was lower in ambient (outside) than in the storage structures. This reveals that heat of respiration increased the temperature at night in the structures even though the minimum temperature was low outside,

Enthalpy and specific volume of air were lower in ECB than PSS because, the temperature and relative humidity in ECB was slightly lower than in PSS. Also, there was a better reduction of temperature and improvement of relative humidity in Evaporative cooling barn (ECB) than Pit storage structure

(PSS). In the two storage structures, the processes of cooling was evaporative cooling (adiabatic process) and therefore a rise in ambient temperature resulted in a slight rise in temperature in the storage structures.

Conclusions

The physical properties of the two varieties differed from each other, TIS 2 variety had better physical properties for extending shelf-life than Ukerewe; e.g. TIS 2 variety had a higher porosity which enhanced ventilation and cooling.

TIS 2 variety was more resistant to weevil damage, decay, shrinkage, weight loss and had more wholesome tuberous root in storage than Ukerewe.

Lantana camara extract pre-storage treatment was better than the other pre-storage treatments in reducing weevil damage, weight loss, decay, shrinkage and had higher percentage wholesomeness. Ash pre-storage treatment also reduced sprouting better than the other pre-storage treatments.

The two storage structures improved sweet potato storage by reducing general deterioration. However, Evaporative cooling barn (ECB) was slightly better in reducing weight loss, weevil damage, shrinkage, decay and more wholesomeness tuberous roots than Pit storage structure (PSS). On the contrary, PSS also had slightly lower sprouting index compare to ECB.

The changes in energy content of sweet potatoes in the two storage structures were the same until after 8 weeks where ECB did better in reducing changes in energy content (total sugar) than PSS.

Recommendations

Evaporative cooling barn (ECB) could be used for sweet potatoes storage because it reduces general deterioration.

Lantana camara extract should be used as a pre-storage treatment on sweet potatoes before storage. However, further work should be carried out to verify the efficacy *Lantana camara* extract against weevil in storage.

Farmers in Cape Coast could grow and store TIS 2 variety. While screening for storability of sweet potatoes should be carried out in Ghana.

Finally, the combined effects of ash and *Lantana camara* extract should be studied against sprouting.

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APPENDICES

A1: Wood used and their mechanical properties:

Avodire (*Turraeanthus africanus*)	Bamboo (*Phyllostachys pubescens*)	Dahoma (*Piptadeniastrum africanum*)
Density = 0.58 gcm^{-3} Modulus of elasticity = 12590 Mpa Crushing strength = 52 Mpa Static bending strength =94 Mpa Coefficient of volumetric shrinkage = 0.36 % Total tangential shrinkage = 6.6 % Total radial shrinkage = 3.8 % Fibre saturation point = 39 %	Density = 0.71-0.75 gcm^{-3} Modulus of elasticity = 74100-102290k gcm^{-2} Crushing/compression strength = 503.17-564.79 $kgcm^{-2}$ Modulus of rupture = 393.7-969.4 $kgcm^{-2}$ Linear expansion = 0.7-0.17 % Thickness swelling = 2.47-4.08 % Bending strength 40.77-55.82 $kgcm^{-2}$	Density = 0.70 gcm^{-3} Modulus of elasticity = 15190 Mpa Crushing strength = 57 Mpa Static bending strength 98 Mpa Coefficient of volumetric shrinkage = 0.55 % Total tangential shrinkage = 8.5 % Total radial shrinkage = 3.8 % Fibre saturation point = 27 %

(TROPIX 6.0, 2009)

A2: Air temperature in structures and ambient

Month	Ambient Temp. ^oC		Temp. ^oC in ECB		Temp. ^oC in PSS	
	Min.	Max.	Min	Max	Min	Max
September	23.1	32.0	23.4	24.7	24.2	26.0
October	23.5	32.0	23.7	24.6	24.5	26.0
November	24.0	33.0	24.2	25.6	24.8	27.0
December	24.1	33.0	24.4	25.9	25.0	27.0

Evaporative cooling barn (ECB), Pit storage structure (PSS)

ANOVA TABLES

A3: Analysis of variance measured at 10 weeks in storage

Source of Var	Df	% wholesomeness	% weight loss	% weevil damage	% sprouting	Severity of weevil damage	Incidence of weevil damage
Struct. (S)	1	682.0 *	170.7 **	40.8 **ns**	35.8 **ns**	0.19 **ns**	243.9 **
Treatment (T)	3	529.8 *	45.0 **ns**	450.1 **	2531.8 **	7.24 **	333.5 **
Variety (V)	1	2030.8 **	2841.3 **	4949.1 **	4713.0 **	2.52 **	9073.0 **
S x T	3	415.2 **ns**	9.9 **ns**	281.9 **	191.8 **ns**	0.58 **ns**	67.8 **
S x V	1	607.6 **ns**	100.1 *	183.8 *	653.9 **	0.02 **ns**	935.9 **
T x V	3	229.8 **ns**	93.7 **	264.9 **	163.4 **ns**	0.69 **ns**	67.2 **
T x V x S	3	488.2 *	65.2 **ns**	421.9 **	774.1 **	1.08 *	41.4 *

A4: Analysis of variance measured at 12 weeks of storage

Source of var.	Df	% wholesomeness	% weight loss	% weevil damage	% sprouting	Severity decay	Incidence decay
Struct. (S)	1	82.2 **ns**	520.9**	24.4**	145.2 **ns**	0.75 **ns**	1153.6 *
Treat. (T)	3	1386.9 **	75.3 **ns**	221.0 **ns**	1506.1 **	6.94 **	411.1 **ns**
Variety (V)	1	1141.6 **	2649.4 **	3016.3 **	6363.6 **	1.33 **ns**	12288.9 **
S x T	3	285.2 *	12.8 **ns**	75.5 **ns**	101.2 **ns**	0.14 **ns**	152.1 **ns**
S x V	1	566.5 *	0.17 **ns**	148.6 **ns**	1169.5 **	0.08 **ns**	165.1 **ns**
T x V	3	191.9 **ns**	186.3 *	135.0 **ns**	87.8 **ns**	1.17 **ns**	212.3 **ns**
T x V x S	3	864.9 **	162.1 *	541.7 *	1008.9 **	0.25 **ns**	54.7 **ns**

** = **significant at 1%**
* = **significant at 5%**
ns = not significant

A5: Least significant difference test for wholesomeness in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	47.6a	36.2a	TIS 2	52.8a	49.2a
Brine	33.8a	34.2a			
Extract	61.1b	64.1b	Ukerewe	46.9a	46.3a
Control	56.7b	56.6b			
$Lsd_{0.05}$	18.71	13.71	$Lsd_{0.05}$	13.23	9.70

A6: Least significant difference test for wholesomeness in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	53.3a	45.0a	TIS 2	67.1a	58.7a
Brine	58.1a	46.8a			
Extract	61.5a	61.5b	Ukerewe	47.0b	42.1b
Control	55.2a	48.3a			
$Lsd_{0.05}$	9.72	8.21	$Lsd_{0.05}$	6.87	6.95

A7: Least significant difference test for weevil damage in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	36.7a	49.1a	TIS 2	25.84a	36.1a
Brine	33.9a	49.1a			
Extract	42.2a	40.9a	Ukerewe	42.23b	55.5b
Control	23.1a	44.1a			
$Lsd_{0.05}$	3.58	11.73	$Lsd_{0.05}$	2.53	8.33

A8: Least significant difference test for weevil damage in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	38.7a	55.0a	TIS 2	20.1a	41.1a
Brine	21.4b	43.6a			
Extract	35.9a	42.2a	Ukerewe	44.3b	53.4b
Control	32.8a	48.2a			
$Lsd_{0.05}$	7.81	10.83	$Lsd_{0.05}$	5.53	7.66

A9: Least significant difference test for weight loss in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	30.6a	38.0a	TIS 2	22.8a	26.7a
Brine	31.2a	35.6a			
Extract	25.7b	31.1b	Ukerewe	35.3b	41.4b
Control	28.5a	31.5b			
$Lsd_{0.05}$	6.18	9.84	$Lsd_{0.05}$	4.37	6.96

A10: Least significant difference test for weight loss in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	34.4a	42.2a	TIS 2	23.6b	33.2b
Brine	33.9a	41.8a			
Extract	32.0a	40.3a	Ukerewe	41.93a	48.1a
Control	30.7b	38.1a			
$Lsd_{0.05}$	3.02	6.08	$Lsd_{0.05}$	2.13	4.30

A11: Least significant difference test for sprouting in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	7.3b	34.8c	TIS 2	46.3a	68.6a
Brine	39.0a	48.2b			
Extract	41.3a	61.8a	Ukerewe	19.1a	35.7b
Control	43.2a	63.7a			
$Lsd_{0.05}$	11.54	11.67	$Lsd_{0.05}$	8.16	8.25

A12: Least significant difference test for sprouting in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	18.2c	37.3c	TIS 2	40.7a	55.2a
Brine	32.8b	46.8bc			
Extract	37.8b	50.3b	Ukerewe	28.2b	42.0b
Control	49.1a	59.9a			
$Lsd_{0.05}$	8.41	8.96	$Lsd_{0.05}$	5.94	6.34

A13: Least significant difference test for shrinkage in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	12.1a	7.3c	TIS 2	9.2a	8.4b
Brine	11.4a	15.5a			
Extract	8.4a	10.8b	Ukerewe	11.5a	13.9a
Control	9.2a	11.2b			
$Lsd_{0.05}$	5.94	2.01	$Lsd_{0.05}$	4.2	1.42

A14: Least significant difference test for shrinkage in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	12.4a	14.1a	TIS 2	8.5a	10.1a
Brine	9.0b	14.0a			
Extract	7.7c	8.2c	Ukerewe	10.0b	13.5b
Control	7.9c	11.0b			
$Lsd_{0.05}$	1.34	2.43	$Lsd_{0.05}$	1.34	1.72

A15: Least significant difference test for incidence decay in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	50.4a	60.0a	TIS 2	32.4b	36.3b
Brine	42.2b	51.8a			
Extract	34.1c	43.2a	Ukerewe	51.1a	64.6a
Control	40.4b	46.8a			
$Lsd_{0.05}$	5.32	12.74	$Lsd_{0.05}$	3.76	9.01

A16: Least significant difference test for incidence decay in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	50.3a	61.3a	TIS 2	28.1b	42.4a
Brine	50.3a	68.6a			
Extract	43.2b	57.6a	Ukerewe	64.4a	78.1b
Control	41.4b	53.6a			
$Lsd_{0.05}$	3.74	19.77	$Lsd_{0.05}$	2.65	13.98

A17: Least significant difference test for severity decay in Evaporative cooling barn

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	3.6b	4.8a	TIS 2	3.1b	4.0a
Brine	4.5a	4.7a			
Extract	2.5c	3.3b	Ukerewe	3.6a	4.3a
Control	2.6c	3.7b			
$Lsd_{0.05}$	0.35	0.93	$Lsd_{0.05}$	0.24	0.66

A18: Least significant difference test n for severity decay in Pit storage structure

Treatments	10 weeks	12 weeks	Variety	10 weeks	12 weeks
Ash	4.0	5.0a	TIS 2	3.2a	4.1a
Brine	4.0a	5.0a			
Extract	2.6b	3.3c	Ukerewe	3.7a	4.6b
Control	3.1b	4.1b			
$Lsd_{0.05}$	0.79	0.61	$Lsd_{0.05}$	0.55	0.43

UNIVERSITY OF CAPE COAST

DEVELOPING APPROPRIATE STORAGE TECHNOLOGY FOR SWEET POTATOES (*IPOMOEA BATATAS LAM*) IN THE COASTAL SAVANNAH ZONE OF GHANA

BY

ERNEST TEYE

THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING OF THE SCHOOL OF AGRICULTURE, UNIVERSITY OF CAPE COAST IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN POST HARVEST TECHNOLOGY

MAY 2010

DECLARATION

CANDIDATE'S DECLARATION

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's signature.. Date…………............

Name: Mr. Ernest Teye

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature……………………........ Date………………….....

Name: Professor Jonathan Padi Tetteh

Co-Supervisor's Signature... Date………………..........

Name: Mr. Robert Sarpong Amoah

ABSTRACT

The storage of sweet potato tuberous root in Ghana is a major challenge to farmers and retailers. In this research, a factorial combination of four pre-storage treatments (Ash, Brine, *Lantana camara* extract and Control), two sweet potato varieties (TIS 2 and Ukerewe) and two storage structures (Evaporative cooling barn and Pit storage structure) in a completely randomized design (CRD) with three replications were used and evaluated over a three-month period.

All the parameters studied (weevil damage, weight loss, shrinkage, decay, sprouting and wholesomeness) showed that significant differences existed among the pre-storage treatments used. Sweet potato tuberous roots pre-treated with *Lantana camara* extract exhibited the least weevil damage, the lowest weight loss and decay, and had more wholesome sweet potato tuberous roots.

For the two varieties, TIS 2 generally stored better than Ukerewe. It was also more resistant to: weevil damage, decay, weight loss and shrinkage. Again the tuberous roots were more wholesome at the end of three months of storage.

The two storage structures improved the shelf-life of sweet potatoes over eight weeks. However, after ten to twelve weeks, the Evaporative cooling barn was significantly better than the Pit storage structure.

TIS 2 sweet potato variety pre-treated with *Lantana camara* extract was recommended for storage in Cape Coast while the Evaporative cooling barn was the preferred storage structure for sweet potato tuberous roots.

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DEDICATION

To my mother, Mrs. Elizabeth Ashong Teye.

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LIST OF ACRONYMS

ANOVA	Analyses of variance
ASAE	American Society of Agricultural Engineers
CGIAR	Consultative Group on International Agricultural Research
CIGR	International Commission of Agricultural Engineering
CO_2	Carbon dioxide
CRD	Complete block design
DNA	Deoxyribonucleic acid
ERH	Equilibrium relative humidity
ECB	Evaporative cooling barn
FAO	Food and Agriculture Organisation
H_2O	Hydrogen oxide
IITA	International Institute of Tropical Agriculture
LSD	Least significant difference
MoFA	Ministry of Food and Agriculture
NaCl	Sodium chloride
NRI	Natural Resources Institute
PSS	Pit storage structure
PVC	Poly-vinyl chloride
Q_{10}	Temperature quotient
RTIMP	Root & Tuber Improvement and Marketing Programme
SIDA	Swedish International Development Agency
SRID	Statistics, Research and Information Directorate